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A Review of Hot Executive Functions in Preschoolers

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Abstract

Executive functions (EF), a term used to refer to a large number of abilities involved in self-regulation, has become an important focus of research in early development. A distinction between cool and hot EF is often made based on whether a problem involves abstract versus motivational aspects. While research on cool EF in preschoolers is abundant, relatively little work has been done on hot EF abilities. The current paper focuses primarily on research utilizing two hot EF tasks: the delay of gratification task (Mischel et al. 1989) and preschool variants of the Iowa Gambling task (Bechara et al. 1994). The pattern of findings clearly indicate age improvements in hot EF during the preschool period. Finally, processes involved in hot EF tasks are placed into the broader context of early EF and self-regulation and areas warranting future research are discussed.

Keywords

hot executive functions; cool executive functions; delay of gratification; Iowa Gambling task; preschool

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A Review of Hot Executive Function in Preschoolers

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1 Introduction

Defined as a set of abilities involved in the regulation of thoughts, emotions, and behaviors (Diamond 2013), the construct of executive functions (EF) has gained increasing prominence in the last two decades, due in part to its association with important outcome measures such as early school success (Blair/Dennis 2010; Morrison et al. 2010) and social success with peers (Eisenberg et al. 2003, 2004; Eisenberg et al. 2009). Researchers distinguish hot and cool EF abilities; hot EFs are primarily associated with affective challenges, and cool EF with abstract problem solving (Zelazo/Mueller 2002, 2011). In addition, the two have been linked to different neurological substrates, both prefrontal areas: hot EF with ventromedial prefrontal (VMPFC) areas, and cool EF with lateral prefrontal (DLPFC) areas (i.b.). Although a significant amount of work has been done on cool EF in childhood (Best/Miller 2010; Garon et al. 2008 for reviews), research on hot EF in children has been comparatively scant.

The primary goal of the current paper is to review the literature on early hot EF, focusing mainly on two popular hot EF tasks, both designed to assess individual choices in order to maximize personal benefit: (a) the Iowa Gambling Task (IGT), and (b) the Delay of Gratification Task (DoGT). Each of these tasks exists in different versions, leading to diverging sets of results. Before analyzing potential reasons for this phenomenon in more detail, research exploring the general distinction between hot and cool EF abilities will be presented. A third section explores how measures of hot EF fit within the wider context of EF and self-regulation. Finally, issues for future research are discussed.

1.1 Regulation and Executive Functions

Given how closely the constructs of self-regulation and EF overlap, there has been confusion in the literature about how these differ. Self-regulation tends to be defined as a broader concept that encompasses EF (Blair 2016; Blair/Dennis 2010), and usually refers to any type of regulation that is adaptive for the individual, including bottom-up mechanisms such activation and arousal (Tucker et al. 1995). Most theories of EF have considered primarily the top-down aspects of self-regulation. For instance, Miyake and Friedman (2012) have argued that EF is composed of partially dissociable components that share an underlying process. They focused on three core cool EF components that involve primarily top-down regulation: working memory, response inhibition, and shifting.

In contrast, EF models that have incorporated hot EF processes, such as the Iterative Reprocessing (IR) theory (Zelazo/Cummings 2007), highlight the importance of bottom-

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up regulation. The IR theory emphasizes reflective thought as central to EF, but also includes the idea of iterative reprocessing, whereby lower level representations are reprocessed into more abtract representations. This suggests that higher levels of processing are dependent on the lower level, bottom-up processes. Proponents of cybernetic theories of self-regulation have also considered bottom-up processes and their relation with EF (Blair 2016; Lewis/Todd 2007; Tucker et al. 2015). For instance, Blair (2016) distinguished between bottom-up regulatory processes and top-down effortful regulatory processes, arguing for the importance of these bottom-up processes in regulating top-down processes. In addition, Blair (2016) argued that self-regulation includes both types of processes whereas EF includes only top-down regulatory processes. In this paper, self-regulation is considered to be a process involving bottom-up and top-down regulation while EF is considered to involve primarily top-down regulation, most consistent with Blair's conceptualization.

1.2 Distinguishing between Hot and Cool EF

Whereas there is general agreement in the literature about the distinction between self-regulation and EF, there is relatively less clarity in distinguishing between the constructs of hot versus cool EF (Peterson/Welsh 2014, for a review). Zelazo and Mueller (2002) distinguished between hot and cool EF in terms of the type of problem solving, with hot EF involved in motivational contexts, and cool EF involved in abstract, decontextualized contexts. Allan and Lonigan (2014) directly tested this idea by manipulating response inhibition tasks either to be hot -- by increasing the motivational context (providing rewards and losses for performance), or cool -- by administering the task in the standard manner. They used a confirmatory factor analysis (CFA), testing a model whereby all tasks loaded on one factor and another model where the tasks loaded on two factors. While the two-factor model provided a good fit, the one-factor model also provided a good fit, leading the researchers to accept the more parsimonious, one-factor model. The findings suggest that just increasing motivational aspects of a task does not necessarily engage different processes.

Studies that have succeeded in finding a distinction between hot and cool EF measures have used variations of the Delay of Gratification task (see Table 1). These tasks have long been accepted as hot EF tasks. One variation of DoGT involves delaying or choosing to delay a gratifying response with a goal of getting a larger reward. A second variation of DoGT also involves delaying gratification, but upon the request of an adult; therefore the goal involves social reward rather than a larger reward. Note that both types of task, however, involve conflicting motivations. In contrast, giving or taking away rewards following correct response inhibition does not involve such motivational conflict. Although failing DoGT will provide some gratification (i.e. get a reward immediately), failure to inhibit a prepotent response (e.g. saying "day" when you see a moon in the cool EF Day-Night task, Gerstadt et al. 1994) is not gratifying. As can be seen in Table 1, most studies have used temptation tasks to assess hot EF in preschoolers. While some findings have been inconsistent, the majority of studies have found evidence of a distinction between hot and cool EF measures (see Table 1), indicating that hot and cool EF tasks assess different abilities, as early as the preschool period.

Table 1: Studies Exploring Distinction of Hot and Cool EF Tasks

		Hot EF Tasks				Cool EF Tasks			CFA/	Hot	Hot and Cool EF Associations
	Age		DoG						EFA	Cool	
Study	years	delay	choice	tempt	CGT	WM	INB	SHIFT		Distinct	
Brock et al. (2009)	5 y			√			√		CFA	√	Cool EF predicted behaviour in class & math outcomes in kindergarten
Allan & Lonigan (2011)	3-6		√	√			√		CFA	X	Single EF predicted academic outcomes & behavioural problems
Sulik et al. (2010)	4			√			√		CFA	X	N/A
Willoughby et al. (2011)	3-5			√			√		CFA	√	Hot EF predicted behavioural problems; Cool EF predicted academic outcomes
Bassett et al. (2012)	3-5			√			√		CFA	√	Hot EF predicted classroom adjustment, sensitivity and co-operation, and aggressive behaviour; Cool EF predicted academic outcomes
Denham, Warren-Knot et al. (2012)	3-4			√			√		CFA	√	Higher-order EF factor (with hot and cool factors) predicted teacher rated behavior and learning
Masten et al. (2012)	4-6			√			√	√	CFA	X	Single EF predicted academic outcomes, prosocial behaviour, peer acceptance, attention and conduct problems
Caughy et al. (2013)	2			√		√	√	√	CFA	√	N/A
Kim et al. (2013)	3-4			√			√		CFA	√	Hot EF predicted later behavioural problems Cool EF predicted later academic problems
Allan & Lonigan (2014)	3-6						√		CFA	X	3 Cool EF tasks were modified to be "hot" by giving rewards for correct response; Single EF predicted academic outcomes and behavioral problems
Denham, Bassett, Zinsser & Wyatt. et al. (2014)	3-4			√			√		CFA	√	Hot & Cool predict social cognition Hot EF predicted behavior problems; Cool EF predicted classroom readiness and adjustment
Mulder et al. (2014)	2			√		√	√		CFA	√	Cool EF predicted academic outcomes and behavioral problems 1 year later; Hot EF predicted behavioral problems 1 year later
Pauli-Pott et al. (2014)	3-6			√			√		EFA	√	Cool EF predicted by conduct problems and ADHD symptoms; Hot EF predicted by ADHD symptoms

EF = Executive Function, WM = Working Memory, INB = Response Inhibition, SHIFT = Shifting/Flexibility, CFA=Confirmatory Factor Analysis, CGT = Child's Gambling task, EFA=Exploratory Factor Analysis; SPS = Social Problem Solving

Source: Own representation.

2 Hot Executive Function Tasks

2.1 Delay of Gratification

DoGT in adults. In the adult literature, the standard DoGT, called temporal discounting, involves having participants make a choice between a small, immediate reward and a delayed, larger reward. Adults associate a smaller *subjective* value to a reward when it is delayed (Green/Myerson 2004). Furthermore, a variety of factors affect the subjective value of the delayed reward, with the most important being the objective value and the delay involved (Kable 2015). For instance, the subjective value of a delayed reward increases as its objective value increases and the time delayed is reduced.

CAPs Model. To explain the findings from the DoGT literature, Mischel and his colleagues (Metcalfe/Mischel 1999; Mischel/Ayduk 2011) proposed the Cognitive-Affective Processing system (CAPs), which argues that choice is the result of an interactive process between a hot, motivational system and a cool, effortful, abstract representation system. Poor choice can result from an overactivation of the hot system or an underactivation of the cool system. As a result of the faster development of the hot system in comparison to the cool system, the CAPs model suggests that preschoolers make poor choices because of an overactive hot system that is not modulated by an immature cool system (Mischel/Ayduk 2011).

In agreement with the CAPs model, most researchers have acknowledged that choice is the result of at least two interactive processes involving motivation and cognition. What has been disputed is the role of hot versus cool EF processes (Kable 2015). For instance, some neuroimaging research supports an antagonist interaction between the brain network underlying hot EF and the brain network underlying cool EF, with choices to delay involving activation of the cool EF network and choices for immediate gratification involving higher activation of the hot EF network (McClure et al. 2004). These findings have been taken to indicate that choices to delay involve the cool EF network downregulating the hot EF network (i.b.). However, other neuroimaging research support a more co-operative interaction between the two brain networks. For instance, Hare, Hakimi and Rangel (2014) found that increased activity of both hot and cool EF networks was associated with increased choices to delay. Hare et al. (2014) have argued that both networks play a role in delayed choice, with the hot EF network being critical for representing the subjective value of both choices and the cool EF network providing updated, relevant information on goals. Furthermore, an important consideration in evaluating the preschool literature is the findings that the hot EF brain network plays a direct role in regulating bottom up hot motivational processes through its ability to integrate motivation with more abstract concepts and representations (Kable 2015).

DoGT in preschoolers. The preschool literature contains three main variations of DoGT. The tasks most similar to the adult temporal discounting task involve having preschooler make simple repeated choices between a small immediate and a larger delayed reward, with the number of 'choices to delay' used as the dependent measure. In the remaining two tasks, children do not choose whether they want to delay. Rather they are placed in a waiting situation and the delay they are able to endure serves as the dependent measure. In one of these tasks, children are placed in front of a reward and told that if they wait until the examiner returns, they will receive a larger reward. In the other task, children are asked to delay or suppress a response to a tempting stimulus. For clarity in the discussion to follow, the first type will be called 'DoGTchoice'; the second, 'DoGTwait', and the third, 'DoGTtemptation'.

DoGTchoice. The standard DoGTchoice used involves having children choose between an immediate reward now and a larger delayed reward after a specified period of time (Mischel/Metzner 1962). Rewards typically include treats, money, and small toys; time can vary from a few minutes to weeks. More recently, the task has been adapted further, particularly for preschoolers. For instance, Thompson, Barresi and Moore (1997) used stickers as rewards and the end of the game as the delay period. In this variant, children were asked to make several choices between 1 sticker now or 2 stickers at the end of the game.

Age improvements during preschool have been found on the DoGTchoice task (Lemmon/Moore 2001, 2007; Moore et al. 1998; Prencipe/Zelazo 2005; Rozek et al. 1977; Thompson et al. 1997), but are inconsistent (e.g. Garon et al. 2012; Moore/Macgillivray 2004). For instance, Garon et al. (2012) found U-shaped performance on the choice DoGTtask in children aged 2 to 4 years when children made choices between 1 sticker now and 1, 2 and 4 stickers later. Whereas 4-year-olds showed a trend to choose more 'delay' as quantity increased, 3-year-olds did not show evidence of choices being moderated by the quantity of the delayed choice. Surprisingly, the youngest group seemingly performed best, showing a linear increase in choices as the delayed reward increased. To explain the findings, Garon et al. noted that lacking a representation of their future selves, 2-year-olds chose based on quantity alone. In contrast, 3-year-olds may have chosen more immediate options because their choices incorporated time as well as quantity. However, because they were unable to resolve the conflict between the future and current self's desires, they chose in accordance with the desire of the immediate self. Psychological distance from the current self's desire may play a critical role in 3-year-olds' difficulty with resolving the conflict (Prencipe/Zelazo 2005). By 4 years of age, children can resolve this conflict, perhaps in part due to the ability to shift between attention sets (a cool EF ability), which develops during this period (Zelazo et al. 2002).

Findings from preschoolers are consistent with an interaction of hot and cool EF processes in optimal DoGTchoice. First, research indicates that factors such as length of delay and objective size of the reward influence choice. Whereas some research suggests that sensitivity to length of delay is not present until middle childhood (Mischel/Metzner 1962; Reynolds/Schiffbauer 2005), simpler tasks reveal sensitivity to both delay and reward magnitude in preschoolers. Studies using such tasks have found that even preschoolers show some sensitivity to length of delay (Garon et al. 2011; Schwarz et al. 1983). For instance, Schwarz et al. (1983) gave children aged 3 to 5 years delays of 7 hours versus 1 day and found that preschoolers were more likely to delay when told that they would receive their delayed reward in the afternoon rather than the next day. Similarly, sensitivity to the magnitude of the delayed reward (Garon et al. 2012; Inouye et al. 1979; Ito et al. 2009; Lemmon/Moore 2007) has also been found in preschoolers. Lemmon and Moore (2007) for instance, gave 3- to 4-year-olds a choice between 1 sticker now and a larger number of stickers later (varying from 2 to 5). They found that only 4-year-olds chose to delay more in accordance to the size of the delayed reward, supporting the idea that these older children considered the desires of their future selves in making their choices.

The preceding findings fit with the idea that choice is a result of the competition between the subjective value of the present reward and the future reward. Choice, therefore, can be biased toward the future by reducing the subjective value of the immediate reward, as suggested by the CAPs model, or by increasing the subjective value of the future reward. The findings support the idea that increasing the subjective value of the delayed reward will increase choice for the delayed reward, particularly in older preschoolers. Another way to increase the subjective value of the delayed choice is by having children engage in prospection, which involves simulating the self in the future. Having adults imagine their future self has been found to increase choice of the delayed reward in adults (Daniel et al. 2013). Furthermore, there is evidence that engaging in prospection may increase delayed choice in part through its activation of the hot EF network (Sellitto et al. 2011). A recent study found a significant increase of delayed choices in preschoolers when they engaged in prospection as opposed to a control condition (Garon et al. 2014). Furthermore, children who did well on another hot EF task, the Preschool Gambling task (PGT), showed higher self-control for trials in which the immediate and delayed rewards were closer in value, in comparison to children who did poorly on the PGT (Garon et al. 2014). This suggests that hot EF may be particularly important for adjusting the subjective value of delayed rewards.

Other evidence points to a role of cool EF ability in the DoGTchoice. Imuta et al. (2014) created versions that encouraged use of a cool EF strategy by highlighting the numerical difference between the immediate and delayed choice. This led to significant improvements in the younger preschoolers' choice of delayed reward. The association of performance on DoGTchoice and response inhibition tasks in preschoolers (Moore et al. 1998; Yu et al. 2016), also supports the importance of cool EF in the early development of DoG ability.

DoGTwait. The 'marshmallow task' (Mischel 2014, for review) is the classic DoGTwait. In this task, children are seated in front of a marshmallow and a bell. They are told that if they wait until the experimenter returns, they can have 2 marshmallows; however, if they no longer want to wait, they can ring the bell and consume the marshmallow. This paradigm, therefore, more specifically assesses the ability to tolerate frustration since the presence of the reward throughout the delay increases temptation. Although an association is generally found between measures of DoGTchoice and DoGTwait, it is weak to moderate (Duckworth/Kern 2011), suggesting that the processes involved overlap, but also differ.

Age-related improvements in the ability to wait have been consistently found using this task (Atance/Jackson 2009; Mischel 2014; Steelandt et al. 2012; Yates et al. 1981). In contrast to the DoGTchoice, age effects have been found from 2 to 4 years, with 2-year-olds delaying for significantly shorter periods than 3-year-olds (Steelandt et al. 2012). Moreover, whereas 3- and 4-year-olds were able to delay for longer periods when the delayed reward was increased in size, 2-year-olds did not demonstrate this effect. This is interesting given 3-year-olds' failure to take delayed reward size into consideration in the DoGTchoice (Lemmon/Moore 2007), and suggests that 3-year-olds can increase waiting time, but making the choice to wait is difficult for this age group.

As with the DoGTchoice, findings from the DoGTwait indicate roles of both hot and cool EF processes. In particular, the role of attention has been consistently implicated in the 'wait' variation. The ability to direct attention away from the hot, affective properties of the reward seems to be the variable most strongly associated with children's success (Mischel 2014). Moreover, the control of attention as early as the first two years predicts preschoolers' performance on the DoGTwait (Sethi et al. 2000). While the importance of attention is indisputable, the mechanism by which it improves wait time is not as clear. The bulk of the evidence indicates that control of attention seems to improve performance through its reduction in the salience of the immediate reward (Mischel et al. 1989). Findings have consistently supported this idea, with children waiting longer in conditions that reduce the salience of the immediate reward through self-verbalization (Steelandt et al. 2011; Toner/Smith 1977), imagery (Mischel/Baker 1975), or pictures (Mischel/Moore 1973). Other findings suggest that distraction is also helpful in improving waiting times (Mischel/Ebbesen 1970; Mischel et al. 1972; Yates et al. 1981). Finally, Mischel et al. (1989) argued that another important mechanism underlying the ability to wait is knowledge about which strategies are effective. Interestingly, while preschoolers are able to benefit from, and may even spontaneously use, attentional strategies (e.g. Steelandt et al. 2014), explicit knowledge about strategies does not develop until children are in elementary school (Mischel/Mischel 1983).

DoGTtemptation. All of the several variations of the DoGTtemptation include two components: an attractive toy or activity and prohibition to use or engage in the activity. For instance, Kochanska et al. (1996) gave children aged 25 to 45 months a snack delay task, in which they put a treat under a clear plastic cup and asked children to wait until the experimenter rang a bell to get the snack. Another example, gift bow, involves requiring the child to wait before touching a bag containing a gift while the researcher retrieves a bow. Notably, a critical distinction between this task and the DoGTwait is that children do not receive a larger reward for waiting. Rather than a conflict between a smaller immediate reward and delayed, larger reward, the conflict in the

DoGTtemptation is between an immediate reward accompanied by social sanctions and a delayed reward with social approval. As a result, the ability to integrate rewards and losses in making a choice may be an important factor. In fact, there is evidence that avoiding negative outcome plays a role in preschoolers' ability to resist (Jensen/Buhanan 1974).

In other respects, however, findings from the DoGTtemptation parallel those of DoGTwait. For instance, a gradually increasing ability to resist temptation is seen from the second year of life onward throughout the preschool period (Hartig/Kanfer 1973; Kochanska et al. 1996; Pecora et al. 2014). Also, reduction in the salience of the immediate reward through self-verbalization (Abe 1980; Hartig/Kanfer 1973; Manfra et al. 2014), distraction strategies (Ebbesen et al. 1975; Mitsutomi 1991), and even encouraging negative evaluations of the toy (Mitsutomi 1991) will increase children's ability to wait.

Summary of DoGT in preschoolers. Research on the three variations of DoGT indicates age differences during the preschool period and beyond. However, this developmental pattern is less consistent for the DoGTchoice. In part, this may reflect how 2-year-olds, as opposed to older children, approach the task. Rather than representing the two choices in a temporal fashion (self now versus self later), 2-year-olds may consider only quantity (Garon et al. 2012), making it appear as though they are choosing advantageously. A similar paradoxical pattern has been found in animal research (e.g. Paglieri et al. 2013). At least a minimal ability to imagine future states, which is beginning to emerge at 3-year-olds (Atance 2008), may be required to perform this task.

The findings suggest involvement of hot and cool regulatory process in all of the DoGT. In particular, reducing the salience of the immediate reward through strategies such as self-verbalization and distraction appears to be helpful for DoGTwait and DoGTtemptation. For the DoGTchoice, increasing the subjective value of the delayed reward by increasing its objective value (i.e. increasing quantity) or reducing time improves performance, particularly in older preschoolers. As well, having older preschoolers imagine their future selves with the reward improves performance.

Iowa Gambling Task

The Iowa Gambling task (IGT; Bechara et al. 1994), was originally designed to provide a more sensitive assessment of adults with lesions to the VMPFC, the critical brain area of the hot EF network. The task involves choosing among four decks of cards, two of which are advantageous (lead to more wins over 10 cards) and two of which are disadvantageous (yield net losses). In the original version given by Bechara et al. (1994), the participants were not told anything about the deck contingencies, but instead were instructed to accumulate as much money as possible by choosing from the decks. Two of the decks (A and B) were actually disadvantageous in the long run – although they led to a win of $100 on every card turn, they also led to large unpredictable losses, totaling $1250 over ten card turns. In effect, choosing from these two decks led to a net loss $250 over ten card choices. The remaining two decks (C and D) were advantageous, leading to a win of $50 on every card turn and smaller losses of $250 over ten card choices that resulted in a net win of $250 over ten chard choices. Another important distinction among the decks, which will be addressed later, was frequency of loss. Two of the decks had losses occurring over 50% of the trials (A and C) while two of the decks had losses occurring over 10% of the trials (B and D). As hypothesized, patients with

VMPFC did not learn to avoid the two disadvantageous decks over 100 card choices, whereas control participants learned to choose advantageously.

Somatic marker hypothesis. In contrast to the CAPs model, the somatic marker hypothesis (Damasio et al. 1991; Damasio 1994), created to explain the difficulties encountered by the VMPFC patients, involves more in depth consideration of bottom-up processes in making good decisions. Damasio hypothesized that the VMPFC functioned as a convergence zone in the brain where cognition and emotion information were integrated. These somatic markers were described as a summary of affective response associated with a category of stimuli and assimilated over multiple repeated experiences. As such, somatic markers enabled quick decision making, guiding the decision maker to important aspects of the situation and reducing the amount of information to consider. This hypothesis emphasizes the importance of bottom-up motivational processes (e.g. calculating rewards and losses over time) in the success of top-down regulation (e.g. making an adaptive decision). In fact, there is evidence that an inability to engage in this bottom-up regulatory processes as occur with damage to limbic areas such as the amygdala, also leads to top-down regulatory failure (Bechara et al. 1999). Finally, while proponents of the somatic marker hypothesis, acknowledge that cool EF processes such as working memory are involved in decision making, they argue that cool EF processes are dependent on the hot EF brain network (Reimann/Bechara 2010). In fact, there is evidence that individuals who have explicit knowledge without having implicit value representations perform poorly on the IGT (Bechara et al. 1997; Cui et al. 2015).

In sum, the nature of the interaction between the hot and cool EF network may be a critical distinction between the IGT and DoGT. While all DoGT variants involve explicit instructions and provide information on the value of each choice and the delay involved, the IGT does not provide information on losses and wins for each choice. Rather, the participant is required to learn the value of each choice through feedback (win and loss) from each trial. As a result, during the learning phase, bottom-up and top-down processes have to interact to a larger extent (Damasio 1994). In addition, participants have to then use this newly constructed value representation (somatic markers) to make choices in the second stage of the game. Finally, another distinction is in translating this value representation into explicit knowledge (Wood/Bechara 2014), a process thought to involve the body's introceptive system (Craig 2009). As shall be discussed, this ability to become aware of the IGT task appears to be particularly helpful for augmenting the number of advantageous choices in preschoolers.

IGT variants in children. To assess affective decision making in preschoolers, Kerr and Zelazo (2004) developed the Child's Gambling task (CGT). Previous research had indicated rapid improvement on another hot EF task, object reversal, between the ages of 13 months and 54 months (Overman et al. 1996). The object reversal involves a switch in contingencies once children consistently choose one of two rewarded stimuli. The CGT was designed to be a child-friendly version of the IGT, with the number of decks reduced from four to two and children receiving candy rather than money as rewards. Wins were indicated by happy faces and losses by sad faces, and the number of choices was reduced from 100 to 50 cards. In support of expectations, four-year-olds chose significantly more from the advantageous deck, whereas three-year-olds showed a tendency to choose more from the disadvantageous deck. Furthermore, there was a marginal male advantage among three-year-olds, consistent with previous findings of male advantage on the reversal learning task in younger preschoolers (Overman et al. 1996).

Other studies using the CGT have provided support for this age effect in decision making during the preschool period (Bunch et al. 2007; Gao et al. 2009; Heilman et al. 2009; Mata et al. 2013; Mata et al. 2013). However, the male advantage has only been found a few times (Heilman et al. 2009; Gao et al. 2009), with most studies finding no gender difference and some even finding a female advantage (Bunch et al. 2007). Hence, the role of gender is still unclear.

Another preschool IGT variant, the Preschool Gambling Task (PGT; Garon/Moore 2004), modelled closely on the CGT, has found similar results to the CGT (Garon/Longard 2015; Garon et al. 2015; Garon/Moore 2007a, 2007b), with 4-year-olds passing the 2-deck, but not the 4-deck variant (Garon/Moore 2004). Studies done on PGT variants, however, have indicated that even older preschoolers' ability to choose advantageously is highly dependent on task structure. In support of this view, the task structure for variants given to older children and adolescents is considerably different from those given to preschoolers, leading to different developmental findings. While most preschool studies suggest that by four, children have developed affective decision making, results of IGT and IGT variants given to children and adolescents suggest that the ability to make advantageous decisions does not develop until adolescence (Overman 2004; Crone/van der Molen 2004).

Task structure*.* Table 2 provides a summary of the structure of the standard IGT and a reversed version (frequency of losses and gains are reversed; Bechara/Damasio 2002). The structure of the child-friendly Hungry Donkey task (Crone et al. 2003) is shown for comparison. In this task, participants are presented with 4 doors (representing the 4 decks) and a hungry donkey on a computer screen. Participants are told that the goal is to get as many apples as possible to feed the donkey. As seen in Table 2, the contingencies of the standard Hungry Donkey task closely parallel the contingencies of the original IGT, with 4 options/decks: two advantageous and two disadvantageous options. Similar to the IGT, doors A and B are disadvantageous; each choice leads to a win of 4 apples with large losses resulting in a net loss of 10 apples after 10 choices. Doors C and D are advantageous; each choice leads to a win of 2 apples and smaller losses resulting in a net win of 10 apples over 10 choices. In comparison, the vast majority of preschool variants, with the exception of that of Garon and Moore (2004), have used only two decks. Furthermore, using a 4-deck variant, Garon and Moore failed to find advantageous decision making in preschoolers, suggesting that number of options/decks may contribute to differences in task complexity that affect age-related performance.

Game variables. Table 2 displays two main ways that IGT task structures vary: between games (game-varying) and between decks within a game (deck-varying). Figure 1 illustrates these differences. For instance, Game A differs from Game B in terms of frequency across trials. In Game A, the two options have 5 losses occurring over 10 trials, whereas Game B has two options with 1 loss occurring over 10 trials. Game C has options that vary in terms of frequency of loss. The literature reviewed in the next section indicates that frequency of loss/win serves two functions. First, higher frequency of loss leads to more feedback (as in Game A) and more opportunity to form a representation (regardless of whether it is conscious) of the decks. Second, frequency of loss when it varies between the two options (as in Game C) also increases avoidance of a particular deck.

Table 2: Summary of Preschool IGT Variants

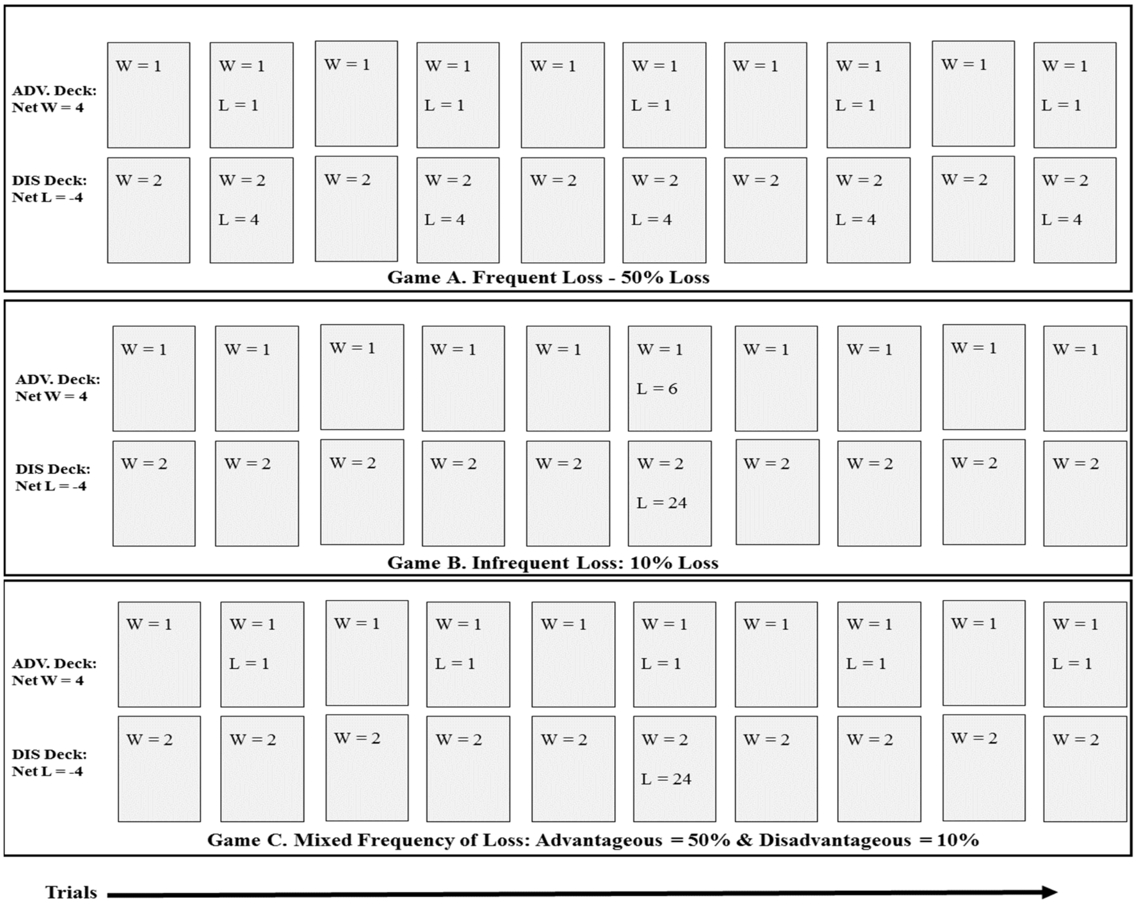
	Game-Varying		Deck-Varying (Differences between advantageous versus disadvantageous decks) v=varies between decks							
	Frequency		Magnitude		Frequency		# decks		Net Win	Age of Adv Ch.
Studies	Loss	Win	Win	Loss	Win	Loss	2	4		
Standard IGT										
Bechara et al. (1994)	10% & 50%	100%	v	v	X	v	X	v	v	Controls (Adults)
Reversed IGT										
Bechara & Damasio (2002)	100%	10% & 50%	v	v	v	X	X	v	v	Controls (Adults)
Standard Hungry Donkey Game										
Crone & van der Molen (2004)	10% & 50%	100%	v	v	X	v	X	v	v	> 12 years
Modified Hungry Donkey Game										
Crone et al. (2005)										
• 4-deck frequent	50%	100%	v	v	X	v	X	v	v	7 years to adult
• 2-deck frequent	50%	100%	v	v	X	v	v	X	v	7 years to adult
• 2-deck infrequent	10%	100%	v	v	X	v	v	X	v	> 12 years
Child's Gambling Task (CGT)										
Kerr & Zelazo (2004)	50%	100%	v	v	X	X	v	X	v	4 years
All studies using standard CGT except Hongwanishkul et al.	50%	100%	v	v	X	X	v	X	v	4 years
Modified CGT										
Gao et al. (2009) E2	50% & 70%	100%	v	v	X	v	v	X	v	4 years
Bunch et al. (2007)										
• Binary loss version	50%	100%	X	v	X	X	v	X	v	3 years
• Binary gain version	50%	100%	v	X	X	X	v	X	v	3 years
Preschool Gambling Task (PGT)										
Garon & Moore (2004)	20% & 50%	100%	v	v	X	v	X	v	v	6 years
Garon & Moore (2007a)	20%	100%	v	v	X	X	v	X	v	4 years
Garon & Moore (2007b)	30%	100%	v	v	X	X	v	X	v	4.5 years
Garon et al. (2013)										
• Infrequent loss version	10%	100%	v	v	X	X	v	X	v	None
• Frequent loss version	50%	100%	v	v	X	X	v	X	v	4 years
Garon & Longard (2015)	50%	100%	v	v	X	v	v	X	v	4 years for low conflict

Note: IGT = Iowa Gambling task; Adv Ch= Advantageous Choice

Source: Own representation.

With the exception of the Reversed IGT shown in Table 2, wins within decks do not vary across trials in all IGT and IGT-variants. That is, the same magnitude of win occurs for every trial within a deck/option. Given this non-varying aspect across all trials, participants can quickly learn that the disadvantageous decks always give a larger win on individual trials (Dunn et al. 2006). However, a more difficult aspect of the task to learn is the frequency of loss, as this does vary from trial to trial, with only some trials leading to losses. In the standard IGT and Hungry Donkey task, two decks (1 advantageous and 1 disadvantageous) have losses on 50% of trials and the other two decks have losses on 10% of trials. The decks with 50% losses provide an obvious learning advantage over the decks with 10% losses. Furthermore, in most preschool variants, a loss frequency of 50% is used, pointing to this aspect as a possible reason for different patterns of findings for the preschool versus child/adolescent IGT variants. In fact, research comparing games with 10% versus 50% losses suggest that both preschoolers (Garon et al. 2015) and older children (Crone et al. 2005) make significantly more adaptive choices on games with 50% as opposed to 10% losses.

Figure 1: Examples of IGT-variant games varying according to frequency of loss between and within games



Note: In Game A and B, frequency of loss is the same for the advantageous and disadvantageous deck, allowing children to focus on difference in magnitude of loss. Children would be expected to make more adaptive choices on Game A in comparison to Game B. In Game C, decks differ in frequency of loss. Children would be expected to choose according to frequency of loss and choose the deck with less frequent loss, even though in this case it leads to disadvantageous choices. DIS = Disadvantageous; ADV = Advantageous

Source: Own representation.

Deck variables. As seen in Table 2, advantageous and disadvantageous decks within a game can vary in several ways. First, the net win (overall payoff) determines whether a deck is classified as advantageous or disadvantageous, and is therefore consistent across all variants of the IGT, i.e. net wins are larger for advantageous decks. Second, decks can differ in frequency of wins/ losses and magnitude of wins/losses. Note that in this section, frequency of loss is discussed in reference to differences between decks *within* a game (see Game C, Figure 1). Furthermore, the 4 decks/options in the standard IGT differ in terms of frequency of loss, but not in frequency of wins (i.e. wins occur in 100% of trials). When facing options varying in frequency of loss, even adult participants tend to prefer decks with a lower frequency of loss (e.g. Lin et al. 2009). In fact, frequency of loss seems to be a particularly salient characteristic, more important than magnitude of loss (Huizenga et al. 2007). In a sample aged 6 to 25, Huizenga et al. (2007) found a developmental shift in strategy from an early guessing strategy in the youngest particpants, to a unidimensional strategy whereby participants focus on frequency of loss (tending to choose from decks with lower frequency of loss), and finally, to the oldest participants using a strategy that considers both frequency and amount of loss.

This conclusion is consistent with findings in the preschool literature. Although the IGT and standard Hungry Donkey task present participants with options varying in frequency and magnitude of loss, the vast majority of preschool variants use decks that do not vary in frequency of loss. Rather, the options vary in magnitude of loss, with the disadvantageous decks having higher magnitude losses. This suggests that, with advantageous and disadvantageous decks not differing in frequency of loss, young children can focus on magnitude of loss and make advantageous decisions. Their problem may occur when both frequency and magnitude of losses vary across decks within a game, and both must be considered when making a choice. Supporting this idea, a recent study found that older preschoolers' performance deteriorated significantly when they had to consider both magnitude and frequency of loss to make an adaptive choices (Garon/Longard 2015). As in Piaget's conservation tasks, preschoolers have difficulty considering more than one dimension at a time (e.g. Houdé 1997).

Number of differences between decks. Another potentially important variable that affects preschoolers' performance on IGT variants is the total number of features that differ between the advantageous and disadvantageous decks. Bunch et al. (2007) created two new versions of the CGT to explore this. They reasoned that the two decks in the CGT differ in terms of the magnitude of immediate gains, the magnitude of losses, and net payoff. According to Bunch et al., three features, may be too complex for the younger preschoolers; varying only two features might help 3-year-olds to choose advantageously. In the binary-relational gain version, the advantageous and disadvantageous decks differed on win magnitude (10 versus 20 candies) and net payoff (see Table 2). In the binary-relational loss version, the two decks differed on loss magnitude (5 versus 25 candies) and net payoff. Bunch et al. found that even 3-year-olds could chose advantageously in these simplified versions of the task.

Awareness in decision making. As has been found in the adult literature (e.g. Brand et al. 2006), there is evidence that awareness of the game plays a role in preschoolers' decisions. Garon and Moore (2007a) found that the majority of 4-year-olds had some knowledge of the game at the first awareness test (after 40 choices), that this awareness improved by the end of the game, and that awareness was associated with performance. Garon and Moore suggested that asking children awareness question may even help them consolidate their implicit and explicit knowledge and lead to improved choices. In a second experiment, children who were asked the awareness questions showed a significant improvement in performance. These findings indicate that not only is higher awareness associated with better performance, but just having children reflect on the game may provide "scaffolding", leading them to integrate and use knowledge of the game more systematically. This corresponds well with research indicating that metacognitive processes are still immature at this age (Sodian et al. 2012). Encouraging preschoolers' awareness of their knowledge may thus be especially helpful.

Two recent studies conducted in the preschool population further suggest that simplifying task structure will improve children's awareness and performance. Garon et al. (2015) found that children in the frequent loss (50%) condition had significantly higher awareness levels compared to children in the infrequent loss (10%) condition. They further found that the effect of loss frequency on card choice was partially mediated by awareness performance, suggesting again that explicit knowledge improves performance. Finally, Andrews and Moussaumai (2015) assigned preschool children to three conditions. In the first condition, children played the standard CGT. In the binary experience condition, they played a simpler binary versions of the CGT (see Table 1) and then completed the CGT. Finally, in the binary experience + awareness condition, children played the simpler versions followed by awareness questions about these versions. Results indicated that for younger preschoolers, playing a simpler game first improved awareness of the standard game and this was associated with increased choices from the advantageous deck. These findings show a pattern of increasing integration of implicit learning and explicit knowledge influencing choices from early to later preschool.

Summary of IGT variants in preschoolers. In sum, the findings from IGT variants during preschool indicate that, in parallel to adult findings, the IGT entails two main stages. Furthermore, each stage appears to show distinct patterns of age differences. The first stage of integrating conflicting rewards and losses over multiple trials appears to be the most challenging for both preschoolers and older children. Reducing feedback (i.e. frequency of loss) and varying both frequency and magnitude of loss appears to be too taxing even for older preschoolers. This stage may be particularly difficult due to its reliance on bottom-up (forming a value-based representation) and top-down (quickly updating and activating these representation) regulatory processes. The findings also suggest that preschoolers have difficulty transitioning to an explicit stage of decision making, particularly when the task structure is more complicated. For instance, older preschoolers can use explicit knowledge of a game to improve decisions, but may need adults to help them to integrate this knowledge (Garon/Moore 2007a). Perhaps integration of hot and cool EF abilities is just beginning to develop.

3 Hot and Cool EF Interaction

At present, few theories consider both hot and cool EF processes and their associations. Most theories consider primarily cool EF processes (e.g. Miyake/Friedman 2012) or hot EF processes (e.g. Wood/Bechara 2015). Notably, hot EF theories put a stronger emphasis on bottom-up regulatory processes (e.g. Metcalfe/Mischel 1999). Some recent theories including the Iterative Reprocessing theory (Zelazo/Cummings 2007) and cybernetic theories of self-regulation (Blair 2016; Lewis/Todd 2007; Tucker et al. 2015) have argued for the importance of bottom-up regulatory influences in regulating top-down EF processes. As previously discussed, this may be an important distinction between hot and cool EF processes.

Figure 2 illustrates some similarities and distinctions of hot and cool regulatory processes. Hot and cool EF show parallels in at least three ways. First, hot and cool regulation involve both top-down and bottom-up processes. The abilities listed as hot in Figure 2 include DoG and advantageous decision making, and those listed in cool top-down regulation include working memory, set shifting and response inhibition, all of which have beeen considered to be EF abilities in the literature. In contrast, abilities such as ‘formation of a stimulus-value set’ (listed in bottom-up hot regulation), and ‘forming an attention set’ (listed in bottom-up cool regulation) have not typically been considered

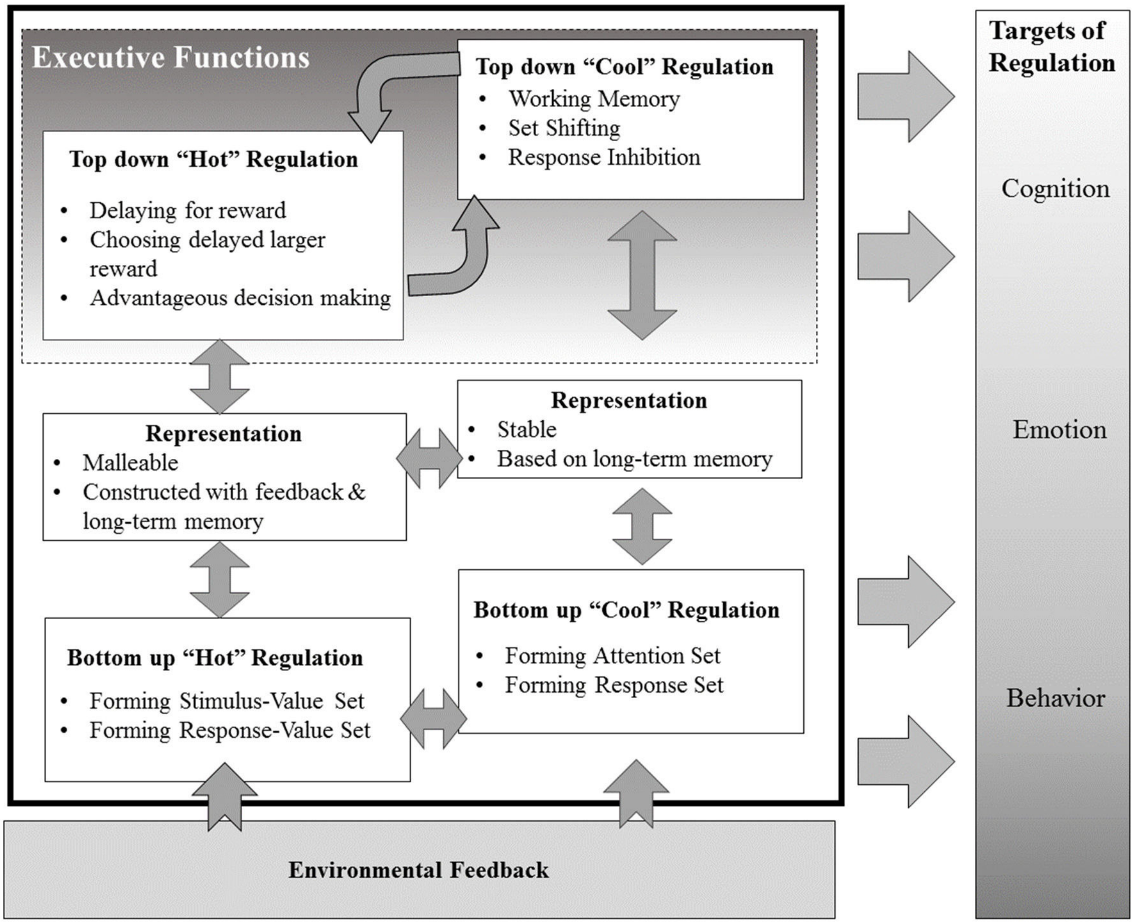
EF abilities. A second similarity between the two types of EF involves conflict regulation. Hot EF tasks involve the resolution of conflicts involving motivation, whereas cool EF tasks entail the resolution of conflicts involving cognition, behavioral response or both (see Garon et al. 2008, for a review). A third similarity involves the reliance of both types of EF on representations held in long-term memory, as shown on Figure 2. Each, however, relies on a different kind of representation.

In spite of these similarities, there are essential differences between hot and cool EF. First, an important distinction is the type of representation each relies upon. Cool EF tend to rely on stable long-term memories, but although cool EF such as working memory may be involved in activating and strengthening of associations in long term memory (Blumenfeld/Ranganath 2007 for review), they do not change these long-term representations. In contrast, the representations utilized by hot EF tend be more malleable (Damasio 1994). In fact, the hot EF brain network appears to be actively involved in learning and forming new value-based representations (Murray et al. 2015; Pujara et al. 2016). For instance, research indicates that patients with VMPFC lesions have difficulty integrating new information into long-term memory representations (Ghosh et al. 2014). Spalding, Jones et al. (2015) argued that that these patients' difficulty with integrating new experiences into memory parallel young children's difficulty with assimilation (Piaget 1952). Use of this type of malleable representation no doubt allows for quicker responses to environmental change, but also makes behavioral response more variable.

A second important distinction between hot and cool EF is their positions in the EF processing hierarchy (Lewis/Todd 2007; Zelazo 2015). Figure 2 shows cool EF placed at a higher level than hot EF. As a result of this arrangement, hot and cool EF networks may participate in the resolution of hot EF problems. The involvement of both EFs and the nature of their interaction has caused much difficulty in the literature. For instance, some researchers have argued that hot EF brain networks are essential for hot EF tasks such as temporal discounting (Motzkin et al. 2014; Sellitto et al. 2010), whereas others have argued that the brain networks associated with cool EF (e.g. DLPFC) are critical for making choices on DoGT (McClure et al. 2004). Finally, others have argued that it is the interaction between these two systems that is important for performance on hot EF tasks such as IGT and DoGT (Hare et al. 2009; Hare et al. 2014; Peters/Buchel 2010; Reyna/Huettel 2014).

The evidence reviewed in the current paper suggests two possible mechanisms for making an advantageous choice: one involving just the hot EF network, and the other, both hot and cool EF networks. When only the hot EF network is involved, the choice would depend on the hot EF network's ability to integrate value information across time, activate the value-based information in response to cues, and adjust the delayed option's value. In a situation in which both hot and cool EF networks operate, choice would rely on the cool EF network's ability to augment the functioning of the hot EF network by providing information about goals and context to update values. As reviewed earlier regarding IGT and DoG, both mechanisms can operate in decision making. Furthermore, these two types of hot tasks likely differ in the extent to which they activate both hot and cool EF processes. For instance, it is possible that DoGT activate both processes moe strongly as the task structure is more explicit than in IGT and its variants. Similarly, it is likely that the second stage of the IGT depends more on both processes than the first stage, due the participant's increasing knowledge of the game.

Figure 2: A model of hot and cool self-regulation.



Note: The diagram shows a simplified model of hot and cool EF and their association with bottom-up regulatory processes and long-term representations. While all the processes would be considered self-regulation, only the top-down regulatory processes would be defined as executive functions.

Source: Own representation.

4 Summary and Suggestions for Future Directions

The research reviewed in this paper permits some tentative conclusions about early cool and hot EF. First, the evidence thus far largely supports a distinction between hot and cool EF measures during early childhood. Second, in spite of this distinction, evidence suggests that performance on hot EF tasks depends on both hot and cool EF processes. Third, considerable development of hot EF appears to occur during the preschool years. Each of these points is discussed in turn below.

Several lines of evidence indicate that hot and cool EF are distinct in preschoolers. First, the majority of studies using EFA or CFA distinguish between hot from cool EF tasks. Furthermore, the association between the hot and cool EF factors in such studies is usually moderate, rather than the strong associations typically among cool EF factors (Willoughby et al. 2012). This result contrasts with a failure to find a consistent distinction between cool EF components such as working memory and inhibition in preschoolers using CFA (e.g. Wiebe et al. 2008; Wiebe et al. 2011). Another line of research reveals different patterns of associations between preschoolers' performance on hot and cool EF tasks and other behavioral characteristics (e.g. Bassett et al. 2012). Future research should therefore investigate more systematically what types of outcomes are predicted by cool versus hot EF abilities.

There is also evidence that hot EF tasks rely on both hot and cool EF processes. For the IGT, cool EF processes may be more important in the second stage of decision making, when the magnitude and probabilities of values associated with each option have become explicit. For preschoolers, encouraging cool reflective processes (by asking which option is best) significantly improves performance (Garon/Moore 2007a). For DoGTchoice, supporting cool processes such as emphasing differences in reward magnitudes for the delayed choice, also improves performance in 3-year-olds, who typically struggle with this task (Imuta et al. 2014). For DoGTwait, encouraging children to focus on abstract qualities of the reward improves their ability to delay (Mischel et al. 1989). Future research should further explore the dependence of each of these tasks on hot and cool EF processes by manipulating the use of hot- versus cool-based EF strategies.

On the whole, evidence implicates cool EF processes in the two main types of hot EF tasks. What is lacking, however, is evidence that these tasks measure a similar construct. Whereas some correlations are seen between performance on different types of DoG tasks, little association is found between IGT variants and any DoG tasks. Part of the problem is that relatively little research has been done using IGT and DoG tasks in parallel. Another difficulty may be the complexity of the various tasks and their dependence on cool EF as well as pure hot EF abilities. Hot EF tasks that load on a single factor are almost exclusively DoG variants. Future research needs to include hot EF tasks that incorporate IGT-type learning and different DoG paradigms. The use of other tasks to assess hot EF would also be helpful to further deconstruct hot EF. For instance, Fellows (2011) reviewed evidence that patients with VMPFC lesions have difficulty maintaining consistency in their preference judgments, a task that could easily be adapted for preschoolers.

This review indicates gradual improvement in four abilities associated with hot EF tasks during the preschool period. First, the ability to integrate frequency and magnitudes of contingencies over time is present in a very basic form as early as 3 years old. What seems to develop after this age is an ability to integrate multiple features over time (i.e. frequencies, conflicting wins and losses). Note that this ability may be more reflective of "pure" hot EF development, as integrating magnitude and probability across time has been most strongly associated with the VMPFC rather than the DLPFC (Venkatraman et al. 2009). Second, there is evidence of development from age 3 to 4 in the ability to translate implicit value-based representations to more explicit knowledge. Third, evidence from the second stage of IGT variants and from the DoG choice task indicates improvemed ability to activate and use value-based representations (e.g. imagining the future self) to make good decisions. Fourth, research on the DoG wait and temptation tasks indicates an improvement in the ability to inhibit or suppress a rewarding activity for longer periods. The ability to increase waiting time may reflect increasing integration of cool and hot EF processes, as findings consistently suggest the critical role of attention control in reducing the salience of the immediate reward (Mischel 2014).

In conclusion, this review showcases the remarkable body of work to date in early EF and its possible underlying mechanisms. Although our understanding of EF has improved significantly in recent decades, a number of unresolved issues remain to be addressed in order for the field to move forward. In particular, the area of early hot EF is only just emerging, being partly hampered by definitional issues regarding what processes constitute self-regulation versus EF, and what constitutes hot versus cool EF measures. Another difficulty is the hierarchical relation between hot and cool EF processes. As a result, whereas a cool EF task may engage primarily cool EF processes, a hot EF task may engage both hot and cool EF processes to different degrees. The nature of the interaction between hot and cool EF processes during hot EF tasks is unresolved. Some theorists have argued for an antagonistic relation, but others have proposed a co-operative relation. It is likely that the nature of this interaction will vary for different hot EF tasks, and perhaps even for different phases of a task. Finally, the issue of how hot and cool EF work together to yield adaptive behavior still remains an unexplored and potentially important area. Rather than being determined by hot or cool EF abilities, adaptive functioning may be more strongly determined by an intricate interplay between these two critical abilities.

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