4 The Development of Hot and Cool Executive Functions in Childhood and Adolescence: Are We Getting Warmer?

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The domain of cognitive skills collectively referred to as executive function has intrigued and stymied researchers for the better part of a century. This chapter explores a distinction made within this general domain that has emerged only recently in the theoretical and empirical literature: hot vs. cool executive functions. Cool executive functions are defined as the goal-directed, future-oriented skills such as planning, inhibition, flexibility, working memory, and monitoring that are manifested under relatively decontextualized, nonemotional, and analytical testing conditions (e.g., Miyake, Freidman, Emerson, Witzki, & Howerter, 2000; Stuss & Benson, 1984; Welsh & Pennington, 1988). In contrast, hot executive functions are goal-directed, future-oriented cognitive processes elicited in contexts that engender emotion, motivation, and a tension between immediate gratification and long-term rewards (e.g., Zelazo & Muller, 2002; Zelazo, Qu, & Müller, 2005). Our examination of the validity of the hot/cool distinction in the context of developmental research is just one example of a burgeoning area of scientific inquiry into the intersection of cognition and emotion in the mental life and adaptive functioning of developing individuals. It is indeed startling that we are only beginning the discussion of the cognition-emotion intersection in executive functions given that arguably the most well-known case of frontal lobe damage could have served as a springboard to begin this inquiry more than 150 years ago. This story of Phineas Gage has provided a captivating opening for countless psychology chapters on the relationship between the brain and behavior; and yet until very recently, the central question that emerges from the study of frontal lobe damage—how does the prefrontal cortex contribute to cognition *and* emotion in the service of adaptive behavior—has been slighted.

In 1848, when the unfortunate railroad man, Phineas Gage, became the unwitting first case study of frontal lobe damage, the symptoms that drew the most attention were those that were the most "out of character" and disruptive to his daily life and functioning. His impulsive, profane, irresponsible, and slovenly manner was particularly difficult to fathom in the context of what seemed to be intact intellectual and language functions, albeit it is unclear to what degree his cognitive functions were actually put to the test in the way we now think about examining the neuropsychological sequelae of brain damage. As we look back on the history of this construct known as "executive function," Gage's case of frontal damage and behavioral changes illustrates two points that were largely ignored until the 1980s: the ventromedial and orbitofrontal aspects of the prefrontal cortices participate in the affective component of cognitive processes; patients with damage to these regions make very poor decisions

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and demonstrate other maladaptive behaviors despite relatively intact cognitive ability. Surprisingly, for several decades after Phineas Gage's story, classic descriptions of the frontal cortex, and prefrontal region in particular, focused exclusively on its role in cold cognition.

We begin this chapter with a historical perspective. First, we will review selectively the historical influences on cool executive function, which is essentially the history of theoretical formulations and research on the domain of executive function as it has been traditionally defined. We will not attempt a comprehensive review of the developmental research examining the traditional cool executive functions, as several reviews on this topic have been published in recent years (e.g., Anderson, 2002; Best & Miller, 2010; Espy & Kaufmann, 2002; Garon, Bryson, & Smith, 2008; Luciano, 2003; Romine & Reynolds, 2005; Welsh, 2001; Welsh, Friedman, & Spieker, 2006; Zelazo, Craik, & Booth, 2004). Our historical review finishes with a description of the emergence, or, should we say, reemergence, of hot executive functions, which reflects, at least in part, the influence of research in typical child development and recent adult neuropsychology. Following the historical discussion, our treatment of the current empirical literature will focus on studies comparing and contrasting hot and cool executive functions in children from the preschool period through adolescence. Our synthesis of the recent research examining these two aspects of executive functioning centers on a few issues related to construct validity. First, we examine the degree to which current research yields evidence of construct validity in the form of differential developmental trajectories and patterns of correlations, indicating the separability of hot and cool executive functions. Second, we examine an interesting methodological approach—altering the "temperature" of tasks (e.g., increasing the affective context of a traditionally cool task)—which allows researchers to hold task, and many of its demands, constant. In most current research on hot and cool executive functions, *different* tasks are used to measure each form of executive function making it difficult to isolate which of the multiple factors distinguishing the cool and hot tasks may be mediating task performance. By systematically isolating and varying a single factor presumed to underlie hot executive function, such as affective context or motivational significance, in a single task, one may be able to more effectively identify separable hot and cool processes. Third, we examine construct validity from the perspective of whether hot and cool executive functions differentially predict other aspects of the broader phenotype such as intelligence, temperament, and academic performance. Finally, we conclude with a discussion of some intriguing lines of research that indicate the complexity of teasing apart the domain of executive function into its potentially hot and cool characteristics, particularly as this relates to highly significant "real-world" behaviors of children and adolescents, moral behavior, and risk taking.

The Traditional Executive Function Framework: A Focus on the Cold

Our understanding of executive function and its evolution over the past century is rooted in the clinical and neuropsychological observations and assessments of individuals who had sustained frontal cortical damage. The focus of interest was on a set of goal-directed, future-oriented behaviors that were essential to adaptive behavior but largely independent of general intelligence. These deficits took on a decidedly cognitive flavor as the zeitgeist in the field of psychology also strongly emphasized cognition and information processing in the latter half of the twentieth century. In what follows, we selectively review research and theory as it relates to executive function, demonstrating the manner in which cold cognition has dominated the discussion.

Brain Damage Demands an Understanding of Frontal Lobe Function

As described by Welsh et al. (2006), the construct of executive functions, and particularly the cool version, evolved from cases of focal brain damage, typically from missile wounds incurred by soldiers in wartime. Decades of such case studies led pioneers in the field such as Tueber (1964) and Luria (1973) to describe the distinct differences in sequelae following damage to the frontal cortex vs. more posterior areas of the brain. The surprising dissociation in symptoms for these clinicians was not between affective and cognitive functions, as presumably observed in Phineas Gage, but between certain preserved cognitive functions and those particular cognitive skills that were irrevocably damaged. Although decades of observation and neuropsychological testing of individuals with focal frontal damage yielded what at first appeared to be a wide-ranging collection of symptoms, a unifying theme began to emerge. In the early reports, frontal patients were characterized as lacking the skills of anticipation, planning, and monitoring necessary for purposeful, self-initiated behavior (Luria, 1966; Stuss & Benson, 1984). Patients perseverated in tasks that required flexibility (i.e., a failure to shift mental set); they experienced difficulty maintaining effort over time and were unable to integrate feedback. Individuals with frontal lobe damage exhibited "supramodal" deficits that cut across specific cognitive, sensory, and motor domains (Lezak, 1995), a reduced appreciation of context (Fuster, 1989; Pribram, 1969), and clear impairments in novel problem solving (Duncan, Burgess, & Emslie, 1995). Essentially, these patients lacked the ability to marshal basic cognitive functions in service of a future goal. While it must have been obvious to the patients, their families, and the clinicians that these core deficits also manifested in social contexts requiring emotional regulation, social sensitivity, and daily adaptive functioning, this appreciation did not appear to impact the traditional cold cognition definition of prefrontal cortical functions in the literature.

The Understanding of Executive Function Becomes Even Cooler

The frameworks that emerged to explain the constellation of deficits consequent to frontal lobe damage illustrate several strong influences of the cognitive revolution that began in the 1960s. For example, one influential information processing perspective on executive function was proposed by Norman and Shallice (1986) to characterize the neuropsychological deficits typical of frontal lobe damage. In their Supervisory Attention System (SAS) model, these authors highlight the distinction between routine and nonroutine environmental contingencies when defining the essence of executive function. In this framework, SAS is recruited in novel situations requiring an analysis of the problem at hand, followed by strategy generation, monitoring, and flexible revision of these strategies based on feedback. In their view, frontal lobe and executive function represented a domain of conscious, effortful, cognitive processes that reflected the models of information flow and processing (e.g., Atkinson & Shiffrin, 1968) of the era.

This emphasis on the cognitive functions mediated by the prefrontal cortex was also a consequence of the development of neuropsychological tests during this period. For example, in the early 1960s, Milner utilized a card-sorting task originally developed by Grant and Berg (1948) to identify deficits following frontal lobe damage, and the Wisconsin Card Sorting Task quickly became the yardstick by which individual differences in frontal function were measured (e.g., Milner, 1963). This task requires inhibition and flexibility of mental set, as well as inductive reasoning. The fact that adult levels of performance were not observed until about age 10 years (e.g., Chelune & Baer, 1986; Welsh, Pennington, & Groisser, 1991) led many neuropsychologists and researchers to suggest that the prefrontal cortex did not effectively "turn on" and influence behavior until preadolescence (Golden, 1981). Such a proposition dovetailed nicely with the dominant cognitive development theory of the time in which the systematic cognitive functions of formal operations emerged at about the same age (Piaget, 1972). However, how one defines, and therefore *assesses*, executive functions as a reflection of prefrontal activity will determine when in development one is likely to observe the putative cognitive functions. Welsh and Pennington (1988) pointed out the many potential manifestations of rudimentary executive functions that are exhibited by infants and toddlers, and the relatively recent appreciation of the emotion-based hot executive functions (Zelazo et al., 2005) has created a renewed interest in the early development of this behavioral domain (e.g., Garon et al., 2008).

Unitary or Multifaceted: Cold Cognition Remains the Emphasis

New computer technologies and statistical techniques in the past 2 decades have also served to shape the definition of executive function, but again emphasizing its cognitive components. An important debate of this period in the evolution of the executive function construct concerned whether a unitary or multifactorial view on this domain was a more accurate representation. Well-known computational or connectionist models of the sequelae observed after frontal lobe damage supported a unitary view of executive function, emphasizing either a limited capacity working memory system (Kimberg & Farah, 1993) or a system that effectively represents and maintains contextual information (Cohen & Servan-Schreiber, 1992). Consistent with this "single function" perspective, Zelazo and Frye (1998) proposed the Cognitive Complexity and Control Theory of executive function. This theory likens executive function to mental representation of logical rules (if-then) that are needed to solve novel, goal-oriented problems, and indeed, it was examined in research using the non-affective, decontextualized, "cool" task known as the Dimensional Card Sorting Task.

In contrast to this univariate definition of executive function, multivariate statistical techniques have supported a multifactorial construct with independent factors that nonetheless work together depending upon the particular task or situation. Early factor-analytic studies of school-aged children found separable factors that reflected cognitive processes such as "fluency and organized responding," "planning," and "hypothesis testing" (Brookshire, Levin, Song, & Zhang, 2004; Welsh et al., 1991). One of the most influential structural models of executive function, developed from an adult sample, demonstrated both the "unity" (correlated factors) and "diversity" (three factors of working memory, shifting, and inhibition) of executive function (Miyake et al., 2000). This model has subsequently been examined in developmental samples with mixed results. Lehto, Juujärvi, Kooistra, and Pulkkinen (2003) found the three-factor Miyake model to be the best fitting model for a sample of 8–13-year-olds; however, Huizinga, Dolan, and van der Molen (2006) found the best fitting model data across the age range from 7 to 21 years included only shifting and working memory. It is important to note here that, as in the early neuropsychological studies of executive functions, the tasks one uses to measure the construct will determine one's findings and can lead to inconsistency across studies. These multivariate statistical approaches and attempts to model executive function will depend on the tasks researchers select to represent the hypothesized components of executive function. Throughout our discussion of the new method of dichotomizing executive function, hot vs. cool, we will find that the very definition of each of these concepts is inextricably connected to the instruments one uses for measurement purposes.

Recent Status of Cool Executive Function in the Developmental Literature

Current reviews of executive function development have focused on the three independent yet interrelated constructs of working memory, inhibition, and shifting identified by Miyake et al. (2000) in their structural model, despite the fact that the model has not been adequately tested in developmental samples. Garon et al. (2008) discussed evidence for an early emergence of these executive function components in infancy but with a dynamic period of development between 3 and 5 years of age. These authors suggest that development of attentional mechanisms may underlie improvements in more complex executive function tasks that require the integration of the three components and the need to resolve conflict. In their review of studies focused on school-aged children, also organized according to the Miyake et al. (2000) tripartite model, Best and Miller (2010) concluded that there is substantial improvement across this developmental period, with differences in the trajectories depending upon the component examined. In their meta-analysis of classic neuropsychological tests of cool executive functions, Romine and Reynolds (2005) identified developmental trajectories indicating the most rapid development from 5 to 8 years, moderate to strong development in the age periods of 8–14 years, and slowing development during adolescence (14–17 years). The fact remains, however, that the majority of comprehensive reviews of executive function development across childhood and adolescent have maintained a laser focus on cool, cognitive processes.

The degree to which our current conceptualization of cool executive function is task dependent is an important question that must be addressed. Although there is some consistency in the executive function tasks used for preschoolers, school-age children, and adolescents, these age-appropriate sets of tasks are generally *different* across age groups, so both cross-sectional and longitudinal research findings addressing stability and change in executive functions must be tempered with questions of task equivalency related to content and difficulty. The search for "clean" measures of core cognitive processes comprising executive function that can be used with little or no modification across development has represented the "holy grail" of executive function research. It is unclear whether the often contradictory findings regarding convergence of executive function measures, even within the cool domain, as well as the predictive associations between executive functions and "real-world" behaviors, are an indictment of the tasks currently used or the construct itself (or both). Finally, decades of clinical and experimental analysis of cool executive functions, across several levels of analysis (e.g., brain damage, computational models), have brought clear consensus that the dorsolateral prefrontal cortical system mediates this complex set of goal-oriented cognitive processes, although the precise neural mechanisms underlying these phenomena are still in question (e.g., Duncan & Owen, 2000; Miller & Cohen, 2001; O'Reilly, 2010). As we will see in what follows, these central conceptual questions are now doubled, at the minimum, with the introduction of the construct of hot executive function.

The Rise of Hot Executive Functions

The separation of cognition and emotion and the favored status of mentalistic, cognitive processes like reason and will over the "lower" emotional processes have a long history in Western thought. In 1980, Robert Zajonc offered the first serious critique of this position, arguing instead for the independence and primacy of affect over cognition (Zajonc, 1980), giving rise to a new era in emotion research. Given the historical study of frontal lobe damage beginning with Phineas Gage and the ascendance of emotion/cognition interaction across the past few decades, it is interesting to note that the clear emergence of "hot executive functions" occurred as late as the mid-2000s. Although many factors likely contributed to this recent direction, in the review below we discuss just two important influences: the developmental research involving delay of gratification (Mischel Ebbesen, & Zeiss, 1972; Mischel, Shoda, & Rodriguez, 1989) and the adult neuropsychological work examining patients with ventromedial and orbitofrontal damage (Bechara, 2004; Bechara & Damasio, 2000).

The Development of Delay of Gratification: Hot Before Its Time

Decades before the emergence of hot executive functions, Mischel and colleagues (e.g., Mischel & Metzner, 1962; Mischel et al. 1972) examined the child's ability to delay immediate reward in an affective context. In one series of experiments (e.g., Mischel & Metzner, 1962), children were tested in a paradigm that involved choosing between an immediate reward and a reward of greater value at some distant time (e.g., a week). In essence, the task assessed the relationship between the length of delay before receiving the deferred reward and the degree to which the participant discounts its value as measured by the choice of the immediate lesser award. Consistent with Mischel's (Mischel & Metzner, 1962) original observation, the task is sensitive to both development and individual differences in general intelligence (Green, Fry, & Myerson, 1994; Shamosh & Gray, 2008). It is easy to imagine real-world scenarios in which individuals may discount the value of a delayed reward in favor of some form of immediate payoff. It is not surprising, therefore, that the delay discounting paradigm has been adapted for the study of human behavior across a range of disciplines (for review, see Shamosh & Gray, 2008).

In a conceptually similar paradigm, Mischel examined young children's ability to delay gratification within reach of an immediate reward. In the classic delay of gratification paradigm, each child was offered a treat, a single marshmallow, with the opportunity to double the reward to two marshmallows if the child could resist the urge for immediate gratification. The importance of these seminal investigations was very recently demonstrated in a follow-up study in which a group of middle-aged participants, originally tested as preschoolers in the marshmallow study, was retested in hot and cool versions of a go/no-go paradigm (Casey et al., 2011). Participants who showed relatively weaker delay of gratification when tested as preschoolers, 4 decades ago, showed increased difficulty in the no-go condition involving a happy emotion face. Importantly, their relatively poor performance in a task involving inhibition was selectively impaired in an emotional context (an emotion face relative to a neutral face).

Mischel's seminal research preceded by decades the current interest in integrating hot and cool executive development. However, more recently Metcalfe and Mischel (1999) articulated an explanatory model involving hot and cool processes that has since been cited by many developmental reviews of hot and cool executive development. It should be noted that the 1999 paper did not actually reference the notion of executive function. In their framework, maturation reflects a gradual shift of dominance such that immature hot processes are regulated by later maturing cool processes. As will be clear below, this perspective stands in contrast to the more contemporary view of hot executive processes that continue to mature with age (like cool processes) and facilitate performance in more emotionally challenging contexts.

The Adult Neuropsychological Framework: A Model for the Development of Hot Executive Functions

Perhaps the strongest influence on the current goal of integrating hot and cool executive processes comes from the study of adults with brain damage in the orbitofrontal and ventromedial cortices (Bechara, 2004). These two largely overlapping brain regions are richly connected with limbic areas associated with emotional and social processing (Bechara, 2004; Beer, 2006). The systematic study of such patients with orbital and ventromedial prefrontal damage, as opposed to dorsolateral damage, has provided strong support for the notion that adaptive decision making and related goal-oriented behavior cannot be explained entirely by "cold" cognitive processes. In spite of relatively intact general cognitive abilities, such patients display a range of behaviors that can be characterized by poor social regulation and an inability to consider future consequences when making decisions. In essence, such individuals suffer from poor "social executive functioning" (Beers, 2006). In an effort to provide a neurocognitive explanation for this dissociation, Bechara & Damasio (2000) proposed the "somatic marker hypothesis"; they posited that in the process of making decisions about the future, neurotypical individuals access a positive or negative emotion-based representation from past experience, a somatic marker, that guides the selection of future-oriented choices. To test this hypothesized role of the ventromedial cortex, they created the Iowa Gambling Task (IGT). In this task, participants choose cards from across four possible decks and are either rewarded or penalized with each card. Two of the decks are disadvantageous, coupling high immediate rewards with unpredictable large losses that outweigh early gains. The other two decks are advantageous, yielding smaller initial gains but also smaller losses for a net profit across the game.

Using the IGT, these investigators have amassed a body of research demonstrating that patients with ventromedial damage have particular difficulty integrating future positive or negative consequences in the service of making adaptive decisions (Bechara, Damásio, Damásio, & Anderson, 1994). Unlike healthy adults, they remain with the disadvantageous decks even as the high reward of the initial cards has been replaced by large punishing losses. Importantly, such deficits can be observed without significant impairment in traditional cognitive control processes like working memory and planning associated with dorsolateral prefrontal cortex. As an explanation, the somatic marker hypothesis was supported by an investigation involving skin conductance response (SCR). Like neurotypical control participants, ventromedial patients generated appropriate SCRs after experiencing the reward or punishment following selection. However, unlike the control participants, they did not develop *anticipatory* SCRs ahead of the card selection, particularly from the risky deck. Presumably, the feeling experience that soon precedes card selection influences healthy controls to avoid excessive risk. In essence, the IGT is assumed to provide an adequate laboratory analogue of real-life situations in which one must perform an implicit cost/benefit analysis between immediate reward and future consequences that may involve punishment. Importantly, in real-life social contexts, choices cannot often be subjected to a precise rational analysis but rather must be assessed by “gut” feeling (Bechara, 2004).

In summary, more than 3 decades before the first use of the term “hot executive functions,” Mischel and colleagues appreciated the importance of understanding a less “purely cognitive” development, the capacity to resist an impulse in a highly motivational context toward the goal of a greater long-term reward. Metcalfe and Mischel (1999) did not consider neural mechanisms that might mediate either individual differences at a given age or the gradual normative change with maturation. Instead, the primary influence on the current thinking about a neural substrate for developmental change in hot executive functioning came from the adult neuropsychological work with ventromedial patients.

The Emergence of Hot Executive Functions

The study of adult lesion patients soon provided a framework for conceptualizing a range of behavioral developments that can each be related to the interaction of neural mechanisms mediating hot and cool processes (e.g., morality: Green & Haidt, 2002; risk taking in adolescence: Steinberg, 2005; atypical development: Zelazo & Muller, 2002). In 2004, the journal *Brain and Cognition* published a special issue dedicated to placing the developing orbitofrontal region within the prefrontal cortex of the developing child (e.g., Bechara, 2004; Happaney, Zelazo, & Stuss, 2004; Kerr & Zelazo, 2004). Although hot and cool executive processes in development had been discussed earlier (Zelazo & Muller, 2002), this special issue likely influenced the burgeoning literature that would follow. Many developmental researchers (e.g., Crone, 2009; Crone, Bullens, Van der Plas, Kijkuit, & Zelazo, 2008; Crone & van der Molen, 2004) have since developed tasks modeled after the IGT.

Today, numerous tasks exist for examining the relative contributions of cooler and warmer processes across development, and many investigators are committed to such an integrative framework. Clearly, the goal of a more comprehensive explanation of development with an appreciation of context represents a positive and important direction. However, the central questions outlined at the conclusion of the review of traditional cool executive functioning pertain equally to the study of hot processes. For example, the degree to which hot and cool processes are mediated by separate dissociable systems (as suggested by the adult neuropsychological framework) parallels the cool question regarding a single unitary system vs. multiple interacting processes. Progress in such a fundamental question remains constrained by the available tasks. As will be clear in the review below, this limits our examination of the dissociation of hot and cool executive functions.

Construct Validity of Hot and Cool Executive Function: A View from Developmental Research

While the literature on the development of cool executive functions is vast, the published research on the development of hot executive functions is but a decade old. Clearly, any attempt at integration will not easily be resolved. However, evidence for the slow developmental maturational gradient of prefrontal cortex (e.g., Giedd et al., 1999; Sowell, Thompson, Tessner, & Toga, 2001) suggests that a continued examination of hot and cool processes across development should be fruitful. In this section, we explore three questions that, collectively, examine the current status of our understanding of this exciting new direction. First, we focus on the degree to which patterns of correlations and developmental differences provide evidence of construct validity. As a second approach to the issue of construct validity, we review research in which a single task is manipulated. In several studies, researchers have either amplified or attenuated the affective component of a task, effectively changing its temperature. This approach to exploring hot and cool executive processes within a single task allows researchers to minimize the messy issues associated with across-task comparisons. Finally, we examine the degree to which hot and cool executive functions differentially predict real-world developmental phenomena, another set of evidence that would suggest separability.

Do Developmental Trajectories and Correlational Patterns Support the Independence of Hot and Cool Executive Functions?

While this question may seem straightforward, our review below highlights a number of difficult and challenging issues. As echoed throughout other sections, we are limited by our tasks. While many tasks have been used to measure cool executive functions, the newer construct of hot executive functions has been probed by a relatively small set of tasks, in a relatively small number of research groups. The cool executive function tasks primarily tap the skills of working memory, inhibition, and flexibility/switching and include measures such as the Dimensional Card Sorting Task, Self-Ordered Pointing Task, and a variety of conflict tasks (e.g., Pencil Tapping, Bear/Dragon, Grass/Snow) for young children, whereas tasks such as the Wisconsin Card Sorting Task, tower tasks, and more complex working memory and inhibition tasks have been administered to older children and adolescents. The hot executive function tasks for young children involve decision making in a reward-loss context with strong motivational significance, such as the Children's Gambling Task, patterned after the IGT. A second set of tests involve delay and prohibitions when the child is faced with an attractive, desired, appetitive stimulus, as in the classic delay of gratification task (Mischel et al. 1972). As described earlier, the classic hot executive function tasks for older children and adolescents include the IGT and delay discounting paradigms. Not only do tasks differ across hot and cool executive function, they differ across age, which complicates the assessment of developmental trajectories across wider ranges of age.

Therefore, addressing the construct validity issue by inspecting patterns of correlations, as well as differential developmental trajectories, is severely compromised by this task issue. Although the adult neuropsychological evidence (e.g., Bechara, 2004) is consistent with the hypothesis of separate developmental mechanisms for hot and cool executive functions, it may not follow that tasks can be designed to tap one or the other system exclusively. Indeed, Hongwanishkul, Happaney, Lee, and Zelazo (2005) emphasized that most tasks are likely to elicit aspects of both hot and cool executive function, with the shared contributions of various genetic and environmental factors increasing the cross-domain correlations. This dichotomy would be demonstrated by a convergent-divergent validity approach in which cool and hot executive function tasks should be more highly correlated within domain than across domain. Further, if the constructs do represent different underlying neurocognitive processes, we might expect to observe different developmental trajectories, for example, one system maturing ahead of the other.

Examining the development of both hot and cool executive functions in a sample of 3–5-year-olds, Hongwanishkul et al. (2005) hypothesized that both correlational patterns and differential developmental trajectories would provide evidence for the independence of these two constructs. Using the Dimensional Card Sorting and Self-Ordered Pointing Task as measures of cool executive function and the Children's Gambling Task and delay of gratification to tap hot executive function, the authors did not find substantively different developmental trajectories across the two domains of executive function. All four tasks demonstrated relatively similar improvements after age 3. Their findings for the Children's Gambling Task replicated the earlier reports of Kerr and Zelazo (2004), however; the delay of gratification results were inconsistent with the absence of age effects reported by Peake, Hebl, and Mischel (2002). Moreover, the tasks did not covary in a way that provided strong evidence for the dissociation of the two types of executive function. With age and intelligence controlled, the two cool tasks intercorrelated; however, both cool tasks correlated with one hot task (Children's Gambling Task), and the two hot tasks *negatively* correlated, clearly contrary to predictions. The authors provide several explanations for the unexpected negative correlation between the scores on the two hot tasks; however, the finding that the hot Children's Gambling Task correlated more predictably with the two cool tasks, than with another hot task, severely weakens the argument for two distinct executive function constructs.

Recent research conducted by Carlson and colleagues (Carlson, Davis, & Leach, 2005; Carlson & Wang, 2007) examined two types of inhibitory control: delay vs. conflict. Although they did not discuss their tasks within the cool vs. hot framework, their delay tasks bear a strong resemblance to the tasks used to measure hot executive function in other laboratories. Similarly, their conflict tasks, such as Simon Says, Bear/Dragon, and Dimensional Card Sort, are the very tasks used as cool executive function measures in the Zelazo laboratory. In the Carlson and Wang (2007) study, age significantly correlated with performance on the cool executive function task (Simon Says) and two of the hot tasks (Gift Delay and Disappointing Gift) across the age range of 4–6 years. Performance on Simon Says was uncorrelated with the hot executive function tasks (Disappointing Gift, Gift Delay, Secret Keeping, and Forbidden Toy) indicating some independence of the two constructs; however, only two of the hot tasks (Gift Delay and Forbidden Toy) significantly correlated with each other. On balance, the reported patterns of correlations do not strongly support independent constructs of hot and cool executive function. Their main hot executive function task, Less is More, which requires children to select the smaller reward to gain the larger one, correlated with *both* cool executive function tasks *and* the other hot, delay task. However, it is important to note these correlations disappeared when age and verbal intelligence were controlled in the analyses.

In the studies reviewed above, there is substantial evidence for development of *both* hot and cool executive function skills in the age period of 3–5 years, although there is not clear evidence for different developmental trajectories for the two executive function domains. For example, in a secondary analysis of data collected in her own laboratory, Carlson (2005) found no evidence that tasks labeled as "cool" due to non-affective, arbitrary rules and demands could be differentiated from affective, reward-sensitive "hot" tasks in terms of difficulty levels for samples of children ages 2–6 years. Additionally, there was not a clear pattern of correlations that demonstrated separable domains of hot and cool executive function. Although one would expect a modicum of shared variance between these two sets of tasks, since they both assess goal-directed behavior, one does expect the correlations to indicate some degree of convergent and divergent validity. As stated earlier, a small number of laboratories are engaged in the investigation of hot and cool executive functions in young children, notably the Zelazo group, and thus, the constructs are defined by the particular tasks that have been selected to examine cool executive function (e.g., DCCS) and hot executive function (e.g., Children's Gambling Task). It will be a challenge for future work in this area to extricate the definition of these two forms of executive functions from the limited number of tasks currently utilized in order to develop an understanding of hot and cool processes that is relatively task independent.

Studies involving adolescent samples are important as evidence that different developmental trajectories of hot and cool executive processes may emerge beyond early childhood. Hooper, Luciana, Conklin, and Yarger (2004) compared a large sample of children and adolescents (9–17 years of age) on three tasks: two traditional cool tasks (digit span and go/no-go) that tap memory and inhibition and one hot task (IGT). Performance increases with age were observed for all three tasks. However, the IGT showed the most protracted developmental trajectory (superior performance by the oldest children tested). After controlling for age, gender, and intellectual ability, performance on the IGT was not predicted by the two cool measures. Thus, these findings are consistent with the hypothesis that, in adolescence, the IGT taps additional cognitive processes that do not mediate performance in the cool tasks. Crone and van der Molen (2004) also examined a wide age range of participants using an adaptation of the IGT. They obtained evidence of improvement through the oldest age group tested (18–25 years). Importantly, developmental change in performance did not reflect changes in either working memory as indexed by backward digit span or inductive reasoning as measured by Raven Standard Progressive Matrices. Thus, taken together, these studies support a protracted development through adolescence on the presumably hot process that mediates performance in the IGT.

Two more studies examined developmental performance changes on the IGT in comparison to traditional cool executive tasks (Lamm, Zelazo, & Lewis, 2006; Prencipe et al., 2011). Because these studies also included an additional hot task, delay discounting, their results may provide a better test of the relationship among cooler and warmer tasks. On balance, the results did not yield strong support for dissociable systems. For example, across both studies, performance on the IGT did not correlate with delay discounting. Across an age range of 7–16 years, Lamm et al. found no evidence for age-related performance change in delay discounting though performance on the IGT positively correlated with age. After partialling for age, none of the tasks, cool or warm, were correlated with each other. Prencipe et al. (2011) examined children across a similar age range. Notably, the two cool tasks (Stroop and Digit Span) correlated with each other and with the IGT, consistent with the findings of Hongwanishkul et al. (2005) in 3–5-year-olds. Prencipe et al. did obtain some evidence consistent with the hypothesis that cool executive functions matured ahead of hot executive functions; performance differences between the youngest and oldest groups were evident in delay discounting and the IGT. Of course, it is important to remember that overall task difficulty (e.g., Stroop vs. IGT) is not equated, so we should be cautious when drawing conclusions about different developmental trajectories. Of interest to the overarching question of whether or not hot and cool executive functions are mediated by separate brain functions (as suggested by the adult neuropsychological model), the authors performed an exploratory factor analysis and did not obtain evidence of dissociable hot and cool processes.

In summary, studies involving adolescence have shown that performance on the IGT develops across adolescence, consistent with a model in which cool processes mature ahead of hot processes. However, the failure to obtain evidence of a correlation between IGT and delay discounting is not suggestive of separable mechanisms. Again, it is important to consider the problem of individual task difficulty when making inferences about differing developmental trajectories. With this caveat in mind, these results suggest that future studies with adolescent samples should include cool and warm tasks in order to continue to explore the possibility that some hot processes are later developing.

Can We Manipulate the "Temperature" of Our Tasks to Probe the Nature of Hot and Cold Processes?

As discussed above, the degree to which hot and cool executive functions reflect somewhat dissociable systems remains unclear, and again, our progress on this question is constrained by our tasks. Presumably, some of the cool tasks may evoke a stronger affective response than others (and vice versa). As discussed by Garon et al. (2008), a promising methodological direction has been the manipulation of the affective context within a single task.

In a preschool study, Carlson et al. (2005) "cooled down" the Less is More task, replacing the appetitive stimulus (i.e., candy) with a symbolic representation, such as a picture. This manipulation improved the performance of 3-year-olds, particularly when the picture was further removed from the candy stimulus. Therefore, although the delay and prohibition tasks in the Carlson and colleagues work can be considered "hot," in contrast to the "cooler" conflict inhibition tasks, the consequences of the manipulation suggest that the "temperature" of an executive function task depends to a large extent on the task demands and conditions.

Lewis, Lamm, Segalowitz, Stieben, and Zelazo (2006) studied children from 5 to 16 years of age using a go/no task that included an emotion manipulation. In addition to behavioral measures, event-related potentials were collected. The paradigm was divided into three blocks. By design, in the middle block, participants steadily lost points. Therefore, the third block provided insight into how children performed immediately after a negative emotion inducement. Consistent with the slow development of adaptive regulation in frustrating circumstances, older children were relatively less impaired by the emotion inducement. Consistent with the behavioral data, electrophysiological evidence supported the hypothesis of increased inhibitory control mediated by prefrontal cortex across development. Figner, Mackinlay, Wilkening, and Weber (2009) manipulated the affective context of the Columbia Card Task using an older sample (13–19 years of age). Each trial of this task begins with a set of cards faced down such that each card's value (magnitude of win or loss) is unknown. The quantity of loss cards as well as the total loss value is indicated. Participants have the chance to turn over cards, one after the other, for points until either they elect to stop the trial to accept the current winnings or they hit a loss card which both costs points and terminates the trial. In the cool version of the task, participants indicated in advance the total number of cards they elected to turn over and did not receive any feedback until the end of the trial. Alternatively, in the hot version of the task, participants made stepwise incremental decisions and received ongoing feedback; that is, after each trial, the points gained or lost were revealed and, assuming a loss card was not encountered, the participant needed to decide again to continue or stop. Evidence that the hot/cool manipulation was successful was supported by measures of electrodermal activity in each condition (i.e., greater activity during hot tasks). The hot version of the task was associated with greater risk taking in adolescents but not in the adult comparison sample.

Crone, Bullens, Van der Plas, and Zelazo (2008) altered the temperature of a gambling task by manipulating whether the participants were playing for themselves (hot) or another (cooler). Children made less risky choices with age (8–18 years). More important, across all age groups, participants made less risky choices when they were playing for another. The asymmetry of risky choices between the self and other condition was largest for the youngest group (8–9-year-olds). Crone, Bunge, Latenstein, and van der Molen (2005) studied children between 7 and 12 years of age using a children's version of the gambling task. Across different versions, the authors manipulated the task to examine whether development is associated with increased capacity for task difficulty (two-choice vs. four-choice options), the ability to switch response set, or a decrease in the sensitivity to punishment frequency. Development was associated with an increased ability to make adaptive choices with infrequent punishment, a finding that is consistent with the notion that children continue to develop sensitivity to somatic markers such that frequent punishment is less necessary for learning from experience.

Although it has been acknowledged that any single task presumably taps both hot and cool processes to some degree, it remains a challenge for the field to determine precisely which elements of a task should be manipulated systematically to elicit one process preferentially. Several studies have demonstrated that systematic task manipulation is a promising method for supporting specific hypotheses regarding mechanisms presumed to mediate development. To date, this small emerging literature suggests that temperature manipulations yield age effects consistent with the hypothesis that hot executive functions show a protracted development.

Do Hot and Cool Executive Processes Differentially Relate to Adaptive Behaviors of "Real-World" Significance?

A longtime challenge for executive function research is to connect developments as indexed by task performance with real-world consequences. From this perspective, we assume that the recent integration of hot executive functions promises to provide a more comprehensive framework for prediction across a range of settings beyond the laboratory.

Hongwanishkul et al. (2005) did find some evidence for divergent validity. Performance on the two cool executive functions correlated significantly with measures of intelligence, whereas performance on the hot executive function tasks did not. These results are consistent with a conceptualization in which cool executive function tasks recruit cognitive functions to a greater degree than do hot executive function measures. Cool executive function performance was correlated with some aspects of temperament, such as effortful control, whereas the hot executive function scores were not related to any measures of temperament. Although the authors used this latter finding as evidence for the independence of hot and cool executive function, they originally hypothesized that hot executive function would significantly covary with the negative affect measure of temperament. Thus, although there is some evidence for a dissociation between hot and cold, the findings, particularly for hot executive findings, were not consistent with predictions.

In two somewhat similar studies, Brock et al. (2009) and Willoughby, Kupersmidt, Voegler-Lee, and Bryant (2011) examined the associations between sets of tasks measuring cool and hot executive functions and behavioral and academic outcomes. Both Brock et al. (2009) and Willoughby et al. (2011) utilized the Balance Beam and Pencil Tapping tasks as their cool executive function measures for their 3–5-year-olds and kindergarten children, respectively. These might be seen as unusual choices of cool executive function tasks, given that both rely much more on motor planning than on cold cognition executive functions such as working memory, goal planning, and flexibility. Both studies involved self-regulation tasks characterized by prohibition and delay as their measures of hot executive function. The findings of the two studies were remarkably similar as well, despite the different age groups (3–5 years vs. kindergarten) and some differences in the specific tasks utilized. In both studies, confirmatory factor analysis indicated separate factors aligning with cool and hot executive function; however, the factors were moderately correlated. Additionally, both studies reported that cool executive function performance, but not hot, predicted academic outcomes in the children studied. It is important to highlight that the cool executive function tasks represented a departure from the typical measures of this construct, and in fact, it may be the case that these cool tasks tell us less about executive function, per se, and more about overall neural integrity. It is well established that motor dysfunction symptomatology is consistent with a range of developmental disorders that would be associated with academic deficits (e.g., Piek & Dyck, 2004; Visser, 2003). Therefore, in both the Brock et al. (2009) and the Willoughby et al. (2011) studies, the separate factors representing their two sets of tasks may, or may not, reflect a dissociation between cool and hot executive functions, depending upon whether one would accept these motor-based tasks as appropriate exemplars of cool executive function.

Several studies have provided support for the assumption that tasks assumed to measure hot executive processes predict outcomes in real-world settings. In an investigation aimed at predicting academic performance among eighth graders, Duckworth and Seligman (2005) supported and extended Mischel's initial evidence (e.g., Mischel, Shoda, & Peak, 1988) that the ability to delay gratification has greater value than IQ for predicting academic outcome. These authors created a composite of self-discipline that included questionnaire data obtained from student, parent, and teacher. Most important for the present review, the measure also included performance on two versions of a basic delay discounting paradigm. Each of the delay discounting paradigms correlated with pencil and paper ratings obtained by eighth grade participant, parent, and teacher (all r's > .50). Of course, a challenge for future research is to continue to explore the variables that drive a relationship between performance on hot tasks and behavioral outcomes. Current evidence suggests that at least some of the variance associated with the relationship between delaying reward and outcome may be associated with general intelligence. For example, meta-analytical evidence has demonstrated a negative correlation between intelligence and delay discounting performance (Shamosh et al., 2008; Shamosh & Gray, 2008). That is, greater intelligence is associated with an increased ability to defer acceptance of a smaller reward in order to obtain a reward of greater value.

In summary, there are mixed results yielded by studies with regard to the extent to which hot and cool executive processes differentially predict real-world behaviors in children and adolescents. Whereas it has been hypothesized that cool executive function would better predict academic achievement and hot executive function contribute to "warmer" behaviors such as temperament and self-regulation, the findings of the few studies reviewed do not clearly align with these predictions. Moreover, the fact that two hot tasks, delay of gratification and delay discounting, predict current or later academic outcomes among adolescents serves to point out the difficulty of determining the "hotness" or "coolness" of particular real-world behaviors. For example, most would agree that achievement in high school and college demands both cold cognition and hot emotion regulation abilities. Therefore, more clarity in the definitions of hot and cool processes, in both experimental measures and real-world contexts, is needed.

Intriguing Intersections with Other Developmental Questions

Our previous review of developmental research examining hot and cool executive functions highlighted recent studies that specifically compared sets of tasks identified by authors as putatively tapping the two domains, or by examining the consequences of manipulating a single executive function task. In what follows, we examine the potential intersections between the hot and cool distinction in two areas of developmental research involving cognition/emotion interaction in which executive function is only peripherally mentioned, if at all. The children's compliance research by Kochanska and colleagues is particularly intriguing given that many of her behavioral measures have been incorporated into the hot executive function testing batteries of other researchers. The adolescent risk-taking literature is interesting to consider in light of the risky decision-making tasks (e.g., IGT) that are typically used to measure hot executive function in adolescents, as well as the emerging evidence regarding sex differences in task performance and the development and function of the orbitofrontal cortex.

Compliance and Moral Development in Young Children

A recent example of an investigation of the cognition-emotion intersection in the development of adaptive behavior is the seminal work of Kochanska and colleagues in which they trace the roots of compliance and moral behavior in young children. In the early years of this investigation, Kochanska does not explicitly connect compliance behavior to executive functions, let alone to hot vs. cool executive functions, although she acknowledges that compliance clearly is a manifestation of self-regulation, autonomy, and assertiveness that characterize early childhood development (Kuczynski & Kochanska, 1990; Kuczynski, Kochanska, Radke-Yarrow, & Girnius-Brown, 1987). The goal of her early work was to move beyond the primarily "cold cognition" perspective on compliance behavior expressed by Grusec and Goodnow (1994; as cited in Kochanska, 1994), who pointed out that internalization of parents' rules for appropriate behavior may have "executive" aspects. She aimed to include the social, emotional, and temperamental underpinnings of how young children learned right from wrong.

Of relevance to this chapter, Kochanska (2002) identified two types of compliance: (1) "don't compliance" involves following rules in emotionally charged contexts requiring delay of gratification and prohibition to touch attractive toys and (2) "do compliance" involves relatively neutral contexts, such as following the mothers' directives to clean up toys. Her findings indicated that "don't compliance" behaviors were associated with individual differences in temperament, specifically fearfulness, while the "do compliance" behaviors were, instead, associated with attention. Moreover, the "don't compliance" behaviors appeared to emerge earlier in development than the "do compliance" behaviors, and manifestations of the two types of compliance were only weakly correlated. Although never explicitly linked to the hot vs. cool distinction in executive function, there are intriguing parallels with both "hot" delay and prohibition contexts of "don't compliance" and the "cooler" contexts of "do compliance." Specifically, the contexts that elicit "don't compliance" are emotionally laden, motivationally significant situations presumed to tap hot executive function. Furthermore, performance on these "don't compliance" tasks is correlated with temperamental characteristics. The "don't" vs. "do" compliance behaviors were found to be somewhat independent, and each exhibited different developmental trajectories.

In essence, Kochanska and her colleagues have explored the "hotter" components of compliance and moral behavior of young children in much the same way that researchers have, in the past decade, begun to examine the "hotter" manifestations of executive function. Indeed, the tasks that Kochanska (1997, 2002) has used, as well as developed, for her investigations of early compliance and moral behavior of children—delay of gratification and prohibition tasks—are precisely the measures that have been used to assess hot executive functions in recent research. Interestingly, Kochanska (2002) found that "committed compliance" during the age range of 14–45 months in "don't contexts," but *not* "do contexts," predicted measures of the "moral self" and moral behavior at 56 months, and *only for boys*. Given that "don't compliance" is measured via the same tasks that are referred to as hot executive function measures in the contemporary literature, do these findings suggest that hot executive functions may predict later rule-guided, compliant, and moral behavior in male children?

To our knowledge, no one has explicitly connected the Kochanska research to the hot vs. cool executive function literature, except to incorporate several of her prohibition tasks, such as the Gift Wrap Task (Brock et al., 2009), into the current batteries of hot executive function tests. It will be of great interest to examine the degree to which particularly hot aspects of "effortful control," as measured by Kochanska, Aksan, Penney, and Doobay (2007), are similar to, or the same as, hot executive function as described in this chapter. Based on Kochanska's work, there may be substantial implications for individual differences in hot executive function as predictors of later rule-based moral behavior in children and adolescents, particularly males. This is a provocative direction for future research as it may dovetail with emerging research on the links between hot executive function and risk-taking behavior (often characterized as the breaking of rules) and the seemingly counterintuitive findings with regard to a male superiority.

Male Superiority in Hot Executive Function in the Context of Gender Differences in Adolescent Risk Taking

An examination of sex differences in hot executive function is of interest in light of the potential implications of this domain of functioning for everyday behaviors, such as moral decision-making, as explored by Kochanska, and risk-taking activities exhibited by adolescents. Whereas research has indicated associations between individual differences in executive function skills and risk taking in adolescents (e.g., Pharo, Sim, Graham, Gross, & Hayne, 2011; White et al., 1994), there is a paucity of studies examining whether hot and cool processes *differentially* predict risk behavior. Intuitively, if hot executive function involves decision making in highly charged emotional contexts, typified by reinforcement and motivational forces, real-world risk-taking contexts should provide a fertile field to observe hot executive function in action during adolescence.

As described earlier in the chapter, the orbitofrontal cortex mediates hot executive function, and the Object Reversal Task has been found to be sensitive to the integrity of this brain system in both monkeys and young children (Overman et al., 2004), whereas the IGT is the prototypical hot executive function test for adolescents and adults. In the case of both experimental measures, a male superiority has been found in young children, adolescents, and adults, with the suggestion that this reflects earlier development of the orbitofrontal cortex in males as a result of androgen activity (Overman, Bachevalier, Schuhmann, & Ryan, 1996). While young male children outperform their female counterparts on the Object Reversal Test (Overman et al., 2004), evidence for sex differences on the Child Gambling Task is less clear. Kerr and Zelazo (2004) predicted a male superiority in performance on the Child Gambling Task but only found nonsignificant statistical trends in which 3-year-old boys outperformed 3-year-old girls on two of the five blocks of the task. In a later study, Hongwanishkul et al. (2005) found no main effect of sex or sex by age interaction on Child Gambling Task performance for 3–5-year-olds.

Sex differences have been somewhat clearer in adolescent performance on the IGT with males making more advantageous choices than females (e.g., Crone et al., 2005); however, this finding was not replicated by Hooper et al. (2004). In a fascinating study reported by Overman, Graham, Redmond, Eubank, and Boettcher (2006), the researchers tested several hypotheses posed to explain the male superiority that had been found on this measure of hot executive function. The results indicated that requiring participants to consider "personal moral dilemmas" concurrently with decision making on the IGT brought female performance more in line with male performance. That is, the typical male superiority in the selection of advantageous cards (i.e., less risky decision making) disappeared when deliberation of personal moral dilemmas was coincident with the task. The authors speculate that brain regions involved in moral decision making, specifically the dorsolateral prefrontal cortex, were activated in this experimental condition. Moreover, the recruitment of this prefrontal cortical region, associated with cool executive functions, facilitated the performance on the IGT, the most commonly used measure of hot executive functions. This finding is consistent with a theme permeating this chapter: a single task associated with either hot or cool executive function will likely recruit the cognitive and neurologic mechanisms underlying *both* types of executive function to greater or lesser degrees depending on the particular testing contexts. In this case, females' use of the more "emotional" processing of the orbitofrontal cortex did not serve them well on the IGT, and instead the activation of more "cognitive" processes involved in imagining future consequences facilitated their performance (Overman et al., 2006). Essentially, it appears that the "temperature" of an experimental task not only depends on the testing contexts, but the *perception of these contexts* may likely vary with gender, as well as with other as yet un-identified individual differences.

Finally, one must examine the degree to which the male superiority on hot executive function tasks, such as the IGT, which involve decision making in risk/reward contexts, aligns with evidence regarding gender differences in risk taking in the real world. More advanced maturation of the orbitofrontal cortex coupled with superior performance on some measures of hot executive function would suggest that males should engage in less risky decision making, or at least more calculated risky decision making, than females. However, one need only look at the statistics regarding accidental death rates by gender (e.g., Centre for Accident Research and Road Safety—Queensland) to question this assumption. In a 1999 meta-analysis of 150 studies examining gender differences in risk taking, Byrnes, Miller, and Schafer found evidence for greater risk taking in males than in females on 14 of 16 indicators. In addition, the researchers found evidence that the gender gap may be diminishing, a finding corroborated by an Australian study demonstrating higher levels of risk taking among females as compared to their mothers' generation (Abbott-Chapman, Denholm, & Wyld, 2008). In fact, contemporary research examining the nature of gender differences in risk-taking behavior has focused less on biological sex and more on the influence of sex role socialization factors (Granié, 2009) and gender-typed beliefs about the developmental tasks of emerging adulthood (Cheah, Trinder, & Govaki, 2010). Therefore, although the current evidence of a male advantage on measures of hot executive function does not appear to converge with our anecdotal or empirical evidence of higher levels of adolescent male risk taking, this picture is complicated by generational and socialization factors that undoubtedly interact in complex ways with the biological differences between males and females.

Summary

In discussing the research areas of compliance and moral development in young children and gender differences in adolescent risk taking, we have selected two lines of research that intersect in interesting ways with hot and cool executive functions, irrespective of whether the specific term "executive function" is ever mentioned. The research by Kochanska and colleagues utilizes tasks involving delay of gratification and prohibition, many of which are the very measures that have become synonymous with hot executive function in early childhood. Their studies have yielded compelling evidence that task performance of young children predicts behaviors in contexts that challenge their moral understanding and decision making. The child's sense of "right and wrong" on these moral decision-making tasks, such as cheating and rule breaking, can be linked to risk-taking behaviors of adolescents in which there is often an element of pushing boundaries, rule violation, and future negative consequences. The adolescent risk-taking research likewise incorporates hot executive function tasks, such as the IGT and delay discounting, into the methodology; however, the nature of the gender differences is so far contradictory in the two research areas. This begs the question: to what extent do hot executive functions, as defined in current research, underlie early compliance and moral development, as well as a tendency towards risky behaviors? Longitudinal studies examining the predictive relationships between both hot and cool executive functions and these important real-world behaviors will be illuminating in this regard.

Conclusions and Future Directions

In spite of the clinical evidence provided by Phineas Gage and countless other frontal patients, the long history of executive function research has stressed cool cognitive control processes that can be observed in laboratory settings with tasks that minimize emotional incentive. Today, however, psychological scientists across a wide range of subdisciplines take seriously the notion that adaptive behavior in real-world contexts involves continuous interactions between emotional and cognitive processes. While many influences likely converged to support this current zeitgeist, the neuropsychological studies highlighting the differing roles of the orbitofrontal/ventromedial and dorsolateral aspects of frontal cortex have played a critical role. The notion of a "dual route" involving a thoughtful, cognitive pathway and a more automatic, emotional pathway has been posited across a range of literatures. Given such a hypothetical neural framework, executive functions researchers have embraced the difficult challenge of examining the full range of hot and cool processes that support adaptive behavior across contexts. This more integrative approach to understanding the goal-directed skills of executive functions in more natural settings represents a new and exciting direction for research that has wide-ranging implications. However, some of the most intractable questions that have long challenged executive functions researchers remain.

Our review of current studies specifically comparing hot and cool executive functions in preschool-aged children suggests that, thus far, this research has not yielded strong behavioral evidence for dissociable constructs. The case for separable hot and cool executive functions in older children and adolescents is somewhat more compelling, as reflected by a more protracted developmental trajectory for IGT, as compared to cool tasks; however, it is unclear whether task differences other than "temperature," such as cognitive demands, may be responsible for the later maturation of the hot task. Studies in children and adolescents that have included both the IGT and a delay discounting task highlight some of the limitations of our current tasks. Across several studies, performance on these two presumably hot tasks has not been correlated. Further, they have not consistently both yielded the same degree of evidence for development.

A close examination of the presumably hot task, delay discounting, may illustrate some problems for resolution in future research. That delay discounting has important predictive value for outcome is very clear. Although our review focused on research involving children and adolescents, a review of delay discounting among participants in college or beyond makes clear that this measure relates to both academic outcome (e.g., grade point average, Kirby, Winston, & Santiesteban, 2005) and broader adaptive functioning (e.g., likelihood of having substance abuse problem, Kollins, 2003). However, meta-analytic evidence has established clearly that general intelligence contributes to individual differences in discounting behavior (Shamosh & Gray, 2008; see also, Shamosh et al., 2008). A more recent developmental study (Anokhin, Golosheykin, Grant, & Heath, 2011) demonstrated that discounting behavior is associated with personality (e.g., novelty seeking) and family socioeconomic status. Thus, it seems clear that discounting behavior involves both cool and hot processes and the relative contribution of each may differ within an individual. Presumably, other tasks like the IGT also involve hot and cool processes mediated by different neural regions, an assumption that is consistent with the appreciation that executive tasks are likely to involve both hot and cool processes to differing degrees (e.g., Hongwanishkulh, Happeney, Lee & Zelazo, 2005). Clearly, in the absence of a more precise understanding of the component processes that contribute to overall performance in each task, across-task comparisons are difficult.

The evidence for differential associations between cool and hot task performance and real-world behaviors, such as academic performance and behavioral regulation, respectively, also has not clearly aligned with predictions in childhood or adolescence (e.g., Brock et al., 2009; Duckworth & Seligman, 2005; Willoughby et al., 2011). Again, the hypotheses regarding which real-world behaviors and contexts should be predicted by hot and cool executive functions presume that we have a clear and unambiguous definition of the nature of these behaviors and contexts in terms of affective and motivational significance. It is likely that the temperature of both the experimental tasks and these adaptive behaviors will vary across individuals and situations. In light of this, the most promising direction for research may be the use of paradigms in which the specific task is held constant, and contextual features are manipulated in order to systematically turn up, or down, the temperature of the task. The small set of studies that have utilized this strategy have demonstrated that cooling down a hot executive function task improves young children's performance (Carlson et al., 2005) and heating up tasks have a more substantial negative impact on older children's performance, relative to adolescents (e.g., Crone, Bullens, van der Plas, & Zelazo, 2008). A powerful approach to addressing the hypothesized differential development of hot and cool processes would be to administer the same task (e.g., a hot task such as IGT) across a wide age span with systematic temperature manipulations. The ages at which these manipulations significantly impact performance on the task would be illuminating with regard to whether the two executive function processes demonstrate different trajectories. Moreover, examining the associations between these manipulated versions of the executive function task and an outcome, such as academic performance, that itself has identified hot and cool components, holds promise for establishing links between executive function and successful behavior in real-world contexts.

A limitation of this review is that our focus centered on behavioral studies, and not on research examining the dissociability of the processes on a neurophysiological level. As described in our historical review, the genesis of the hot vs. cool distinction was the neuropsychological examination of adults with dorsolateral vs. orbitofrontal damage. To date, some studies (e.g., Eshel, Nelson, Blair, Pine, & Ernst, 2007; Galvan et al., 2006; Perlman & Pelphrey, 2011) have examined brain mechanisms that correlate with behavior during task performance. This is an important direction for continued research. Studies in which temperature is manipulated within task may be particularly revealing with the addition of direct measures of brain activation.

While acknowledging the many theoretical and empirical impediments to research examining the validity of the hot and cool executive function constructs, the *value* of the integration of cold cognition with emotional and motivational forces in our conceptualization of this critically important ability should not be dismissed. Our review of two exemplar areas of research, young children's compliance and moral behavior and adolescent risk taking, highlights the need for a more comprehensive perspective on executive function to understand the complex interweaving of cognitive skill, emotional impetus, and motivational drive that undoubtedly comprise the developmental and individual differences observed. Current and future examinations of executive function, in all its rich complexity, will not only inform our understanding of brain function and development, but also our appreciation for the mechanisms underlying an individual's ability to consider the consequences of decisions made in natural contexts that potentially optimize or impede adaptive development.

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