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SHORT REVIEW

Issues in the Conceptualization and Assessment of Hot Executive Functions in Childhood

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Abstract

Our review examines the current state of the research on hot executive function (EF), as contrasted with cool EF, with regard to the evidence for construct validity. Current theoretical discussions have examined the conceptual overlap among constructs such as hot EF, effortful control, self-control, and self-regulation. We explore this emerging literature with a focus on research questions, tasks, and methods. Finally, we consider the unresolved questions facing the study of hot EF, most notably the difficulty in determining the relative "heat" of a given task based on task content, testing context, and the individual differences among the participants. (*JINS*, 2014, *20*, 152–156)

Keywords: Hot and cool executive functions, Effortful control, Self-regulation, Self-control, Temperament, Prefrontal cortex

INTRODUCTION

Like many other subtopics of cognition that have been pulled "in from the cold," executive function (EF) research has flourished since embracing the goal of integrating motivational and emotional processes into the traditional EF framework to understand behavior in context. Traditionally, the study of EF has emphasized the exploration of specific processes supporting goal-directed behavior (e.g., planning, inhibition, flexibility, working memory) within a decontextualized, non-emotional (i.e., "cool") setting (Peterson & Welsh, 2014). However, real-world settings vary in motivational and emotional significance (i.e., "hot" factors) and, furthermore, individuals vary in their vulnerability to such environmentally-induced factors. Clearly, if we wish to explain either universal developmental change in the effectiveness of goal-directed behavior or individual differences across development, we must adapt our methodologies to better approximate natural contexts. The current "hot" and "cool" framework for integrating emotion and context into EF research was influenced by several independent bodies of research. Lesion studies with adults (e.g., Bechara, 2004) provided the impetus for a developmental model by demonstrating a functional dissociation of orbital and dorsolateral prefrontal cortex. Orbitofrontal damage is associated with difficulty integrating experience-based emotional representations to make adaptive decisions that require sensitivity to future reward and punishment. In developmental psychology, a few decades ahead of the rise of hot EF, Mischel developed the Delay of Gratification paradigm that involves staving off the urge for immediate gratification (eating a treat in one's sight and reach) to obtain a greater reward (two treats). Since this seminal work, longitudinal investigations have provided strong evidence that delay performance has important implications for cognitive and emotional development across the lifespan (Mischel & Ayduk, 2011).

The current interdisciplinary effort to integrate hot and cool processes is timely and important; however a close examination of the extant research makes clear that fundamental theoretical and methodological issues remain unresolved. In this brief review, focused primarily on early childhood, we highlight some of the difficult challenges facing EF research, particularly with regard to examining this hot *versus* cool distinction. We discuss recent developmental research in terms of the evidence for the construct validity of hot and cool EF, following this with the emerging discussions of the conceptual overlap among many psychological constructs closely related to the hot EF perspective. Finally, we describe our view of the unresolved issues, which currently serve as impediments to our understanding and assessment of hot and cool EF.

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THREE APPROACHES TO ASSESSING THE VALIDITY OF HOT AND COOL EF SYSTEMS

As described by Peterson and Welsh (2014), the current research does not make a compelling case for the separability of the hot and cool forms of EF in childhood, particularly when examining behavioral measures of EF (*vs.* self-reports and rating scales completed by parents). In younger children (3 to 6 years of age), both hot and cool EF tasks are typically correlated with age and do not show different rates of development or levels of difficulty (Carlson, 2005; Carlson & Wang, 2007; Hongwanishkul, Happaney, Lee, & Zelazo, 2005). In contrast, some studies with older children and adolescents support a more protracted development for hot EF (Prencipe et al., 2011). However, across-age comparisons of hot and cool task performance require equivalent difficulty which is difficult to assess.

The construct validity of hot and cool EF also has been examined by means of bivariate correlational patterns and more sophisticated multivariate procedures, such as confirmatory factor analyses and structural equation models. Divergent and convergent correlational patterns would indicate relatively independent constructs, such that cool tasks and hot tasks should significantly intercorrelate within but not across domain. Again, the data are mixed. Recent studies have found correlational patterns that do not align with the expected divergent and convergent validity predictions (Hongwanishkul et al., 2005; Thorell, 2007). In a meta-analysis of the convergent validity of "self-control" tasks (Delay of Gratification, and thus "hot" measures) and EF tasks ("cool" measures) across development, uniformly low correlations were obtained both within and across task domain (Duckworth & Kern, 2011). Regarding confirmatory factor analyses and structural equation models of hot and cool EF on early childhood samples, evidence supports a single factor (Allan & Lonigan, 2011; Masten et al., 2012; Sulik et al., 2010), two hot and cool factors (e.g., Brock, Rimm-Kaufman, Nathanson, & Grimm; 2009; Kim, Nordling, Yoon, Boldt, & Kochanska, 2013; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011), or one- and two-factor models demonstrating equally good fit (Denham, Warren-Khot, Bassett, Wyatt, & Perna, 2012; Kim et al., 2013). It is possible that EF is more unidimensional in early childhood and specializes into separate functions with development (Zelazo & Carlson, 2012). However, research with older children and adolescents has failed to find significant correlations between two hot EF tasks, Iowa Gambling and Delay Discounting (Lamm, Zelazo, & Lewis, 2006; Prencipe et al., 2011). Moreover, an exploratory factor analysis (Prencipe et al., 2011) did not identify dissociable cool and hot factors in their adolescent sample.

A third approach to distinguishing hot and cool EF constructs involves exploring the degree to which each gives rise to different developmental outcomes. In young children, Hongwanishkul et al. (2005) found that performance on cool EF tasks covaried with intelligence, whereas, hot EF task performance did not, and only the cool task performance correlated with the temperament dimension of effortful control. Consistent with Kim et al. (2013), both Brock et al. (2009) and Willoughby et al. (2011) found that cool task performance only was related to academic outcomes in young children, while hot effortful control task performance predicted parent-reported behavior problems at age 5. Finally, Thorell (2007) found that, for 6-year-old children diagnosed with ADHD, performance on hot and cool EF tasks predicted different sets of clinical symptoms. Therefore, the evidence for differential predictive patterns provides somewhat stronger evidence for separable hot and cool EF constructs; however, this research has primarily examined outcomes in early childhood.

BUILDING CONCEPTUAL CLARITY

The difficulty in establishing an empirical foundation that clearly delineates hot *versus* cool EF may lie squarely in the lack of conceptual clarity. Indeed, it is only in the last few years that a theoretical discussion has emerged regarding the conceptual overlaps among EF, effortful control, self-control, and self-regulation (Allan & Lonigan, 2011; Blair & Ursache, 2011; Denham et al., 2012; Duckworth & Kern, 2011; Hofmann, Schmeichel, & Baddeley, 2012; McClelland & Cameron, 2012; Zhou, Chen & Main, 2012). EF and effortful control share many cognitive components (e.g., inhibition), as well as experimental tasks, and the major difference may be the research traditions from which each evolved: cognitive neuropsychology, and personality/temperament research, respectively (Zhou et al., 2012). Similarly, the overlap between the domains of self-regulation and EF has been discussed (Hofmann et al., 2012; McClelland & Cameron, 2012), as well as the facilitation of effective self-regulatory behaviors, such as emotion regulation, by traditional EF processes (e.g., working memory; Hofmann et al., 2012). If cool EFs are recruited in "hot" contexts such as emotion regulation (Rueda & Paz-Alonzo, 2013) and delay of gratification tasks (Anderson & Reidy, 2012), teasing apart the two putative constructs will be challenging.

A striking example of this conceptual confusion is evidenced by the differing descriptions of "hot processes" provided by the cognitive-affective model (CAPS, Mischel & Ayduk, 2011; see also Metcalfe & Mischel, 1999) as compared to hot EF, introduced by Zelazo and Müller (2002). The similarity of language ("hot") and the shared task, the seminal Delay of Gratification paradigm, led to an inaccurate melding of these two models that are actually quite distinct. The hot processes of CAPS are bottom-up affective, automatic, and stimulus-driven responses to the environment, evident early in development, primarily mediated by the amygdala, and steadily dominated and controlled by the more adaptive cool processes of the prefrontal systems across development. In contrast, hot EF involves top-down, goal-oriented, and deliberative responses to "hot" tasks and situations, shows a protracted period of development, involves the orbitofrontal cortex, and coordinates with cool EF processes, depending on task conditions.

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Consistent with the theoretical and conceptual overlap among EF, effortful control, and self-regulation, the domains have shared specific tasks. Indeed, the tasks in Kochanska's (e.g., 2002) 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 EFs in recent research (Brock et al., 2009). Moreover, many early childhood tasks have been considered "cool" in EF or effortful control research because they do not include an "extrinsic or proximal reward for performance" (Allan & Lonigan, 2011, p. 906). However, one could argue that these tasks do have heightened motivational or emotional significance, thus qualifying as hot EF measures (Zelazo & Müller, 2002). For example, game-like tasks with strong conflict and prepotent responses, such Heads-Toes-Knees-Shoulders (McClelland & Cameron, 2012), Simon Says (Carlson, 2005), Walk-a-Line-Slowly (Allan & Lonigan, 2011), and Statue (Klenberg, Korkman, & Lahti-Nuuttila, 2001) are presumed to be cool; however, one need only test young children once on such tasks to appreciate the emotional experience for young children (e.g., giggling, grimacing, hooting, and hollering, particularly when they err). Moreover, different tasks may be relatively warmer or cooler across individuals. As an illustration, Garon, Longard, Bryson, and Moore (2012) offered a thoughtful, *post hoc* discussion of their unexpected finding that preschool age boys delayed gratification longer than the girls in their sample. During testing, they observed that the boys did not enjoy interacting with the female experimenter or playing with the stickers as much as the girls. Thus, as the authors noted, the experimental setting may have been less hot for the boys.

The challenge of unequivocally labeling a task as hot or cool has implications for the research findings from which we draw our conclusions. For example, Allan and Lonigan (2011) found that their hot effortful control tasks (delay and conflict tasks with rewards) and cool effortful control tasks (Heads-Toe and Walk-a-Line-Slowly) loaded on one common factor, perhaps reflecting that their cool tasks were "hotter" than they suspected. Alternatively, separable factors for hot and cool EF may reflect other unmeasured non-EF processes (e.g., motor demands; Denham et al., 2012).

UNRESOLVED ISSUES IN HOT *VERSUS* COOL EF

Whereas the past few years has seen an explosion in the theoretical discussion of the intersections among research traditions and domains, thorny issues remain that have substantial implications for developing valid measures of hot EF across childhood and adolescence. The fundamental question remains: What constitutes a hot EF task? It is our position that the answer is: It depends. The "heat" of a task, which presumably varies along a continuum, may depend on age, task demands and context, and individual differences such as temperament and personality. Moreover, we suggest that there are complex interactions among these variables in determining the relative heat of a given task (Somerville & Casey, 2010). As an example of the current lack of consensus, there is disagreement whether a hot EF task must include rewards or some type of appetitive stimulus (Allan & Lonigan, 2011) or that it need only elicit emotional arousal or heightened motivation (Zelazo & Müller, 2002).

As reviewed in Peterson and Welsh (2014), an interesting approach to overcoming some of the problems associated with contrasting performance in hot and cool tasks is to manipulate the temperature of a single task (e.g., increasing or decreasing reward salience). This approach enables researchers to contrast performance in the presumably warmer *versus* cooler conditions while holding cognitive demands and overall difficulty level constant. Following the seminal methods of Mischel (Mischel & Ayduk, 2011), recent research on hot EF modifies the salience of various reward conditions with the "hotter" versions of tasks resulting in impaired performance in young children (Carlson, Davis, & Leach, 2005; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006) and greater risk taking in adolescents (Crone, Bullens, van der Plas, Kijkuit, & Zelazo, 2008; Figner, Mackinley, Wilkening, & Weber, 2009). While temperature manipulation studies have certainly advanced our knowledge, the methodology does highlight an assumption that may not always be true. Should decreased task performance be interpreted as reflecting a hotter temperature? While heating a task is expected to impair performance in young children, Somerville and Casey (2010) review evidence demonstrating that rewards ("heat") may impair or facilitate task performance in adolescence depending upon task demands to either focus on, or suppress attention to, these rewards, respectively. Furthermore, it may be that the effect of a given manipulation is influenced by a range of factors such as gender (Garon et al., 2012), age (Lewis et al., 2006), and individual differences in personality.

Temperament research has shown that children vary in the degree to which they experience arousal within a given context. In some studies (Kagan, Snidman, Zentner, & Peterson, 1999), children are presented with presumably-cool tasks such as Matching Familiar Figures, requiring reflection rather than impulsive responses. By measuring behavior and physiology, researchers have demonstrated that children vary in their response to an experimental context. In EF research, consider how many presumably cool EF tasks involve rich face-to-face interaction (Simon Says, Statue). It may be fruitful to consider two lessons from the temperament literature: The heat of a context varies across individuals; by combining behavioral and psychophysiological measures, as well as task and context manipulations, we can explore both task and person factors.

SUMMARY

Across the past decade or so, EF researchers have embraced the challenges presented by emotion-laden, real-world contexts. Today, previously disparate fields acknowledge the

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commonalities across our questions, constructs, and methods. For researchers interested in mechanisms supporting goal-directed behavior both in the laboratory and across the full range of potential contexts, this is an exciting time. Currently, there is consensus that some level of heightened motivation must exist for hot EF processes to be engaged, but here is where the agreement ends. By its very nature, motivation is an individual-difference construct; contextual manipulations that will heighten motivation differ across person and situation, and these factors have not been considered comprehensively in the research to date. Whereas the most well-established hot EF tasks include a "reward," either immediate or promised, the degree to which a hot task *must* involve a reward is in dispute, and how one operationalizes "reward" will be task-, person-, and situation-specific. Consistent with the equivocal findings regarding a single- or dual-factor model of hot and cool EF, evidence supports some shared cognitive processes across hot and cool tasks; however, the degree to which cognitive processes contribute uniquely to the two types of tasks remains unclear. Finally, the genesis of the hot *versus* cool EF discussion began with the neuropsychological evidence of a functional dissociation between two prefrontal cortical regions in adult brain damage cases. Systematic, longitudinal, cross-level studies of children and adolescents will provide a richer understanding of the brain basis of hot and cool EF across development.

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REFERENCES

Allan, N.P., & Lonigan, C.J. (2011). Examining the dimensionality of effortful control in preschool children and its relation to academic and socioemotional indicators. *Developmental Psychology*, *47*(4), 905–915. doi:10.1037/a0023748

Anderson, P.J., & Reidy, N. (2012). Assessing executive function in preschoolers. *Neuropsychological Review*, *22*, 345–360. doi: 10.1007/s11065-012-9220-3

Bechara, A. (2004). The role of emotion in decision making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition*, *55*, 30–40. doi:10.1016/j.bandc.2003.04.001

Blair, C., & Ursache, A. (2011). A bidirectional model of executive functions and self-regulation. In R.F. Baumeister & K.D. Vohs (Eds.), *Handbook of self-regulation* (2nd ed., pp. 300–320. New York, NY: Guilford Press.

Brock, L.L., Rimm-Kaufman, S.E., Nathanson, L., & Grimm, K.J. (2009). The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly*, *24*, 337–349. doi:10.1016/j.ecresq.2009.06.001

Carlson, S.M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*(2), 595–616. doi:10.1207/s15326942dn2802_3

Carlson, S.M., Davis, A.C., & Leach, J.G. (2005). Less is more: Executive function and symbolic representation in preschool children. *Psychological Science*, *16*(8), 609–616.

Carlson, S.M., & Wang, T.S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, *22*, 489–510. doi:10.1016/j.cogdev.2007.08.002

Crone, E.A., Bullens, L., van der Plas, E.A.A., Kijkuit, E.J., & Zelazo, P.D. (2008). Developmental changes and individual differences in risk and perspective taking in adolescence. *Development and Psychopathology*, *20*(4), 1213–1229. doi:http://0-dx.doi.org.source.unco.edu/10.1017/S0954579408000588

Denham, S.A., Warren-Khot, H.K., Bassett, H.H., Wyatt, T., & Perna, A. (2012). Factor structure of self-regulation in preschoolers: Testing models of a field-based assessment for predicting early school readiness. *Journal of Experimental Child Psychology*, *111*(3), 386–404. doi:10.1016/j.jecp.2011.10.002

Duckworth, A.L., & Kern, M.L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, *45*(3), 259–268. doi:10.1016/j.jrp.2011.02.004

Figner, B., Mackinlay, R.J., Wilkening, F., & Weber, E.U. (2009). affective and deliberative processes in risky choice: Age differences in risk taking in the Columbia Card Task. *Journal of Experimental Psychology*, *35*(3), 709–730. doi:10.1037/a0014983

Garon, N.M., Longard, J., Bryson, S.E., & Moore, C. (2012). Making decisions about now and later: Development of future-oriented self control. *Cognitive Development*, *27*, 314–322. doi:http://dx.doi.org/10.1016/j.cogdev.2012.05.003

Hofmann, W., Schmeichel, B.J., & Baddeley, A.D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174–180. doi:10.1016/j.tics.2012.01.006

Hongwanishkul, D., Happaney, K.R., Lee, W.S.C., & Zelazo, P.D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*(2), 617–644. doi:10.1207/s15326942dn2802_4

Kagan, J., Snidman, N., Zentner, M., & Peterson, E. (1999). Infant temperament and anxious symptoms in school age children. *Development and Psychopathology*, *11*(2), 209–224. doi:http://0-dx.doi.org.source.unco.edu/

Kim, S., Nordling, J., Yoon, J., Boldt, L., & Kochanska, G. (2013). Effortful control in "hot" and "cool" tasks differentially predicts children's behavior problems and academic performance. *Journal of Abnormal Child Psychology*, *41*, 43–56. doi:10.1007/s10802-012-9661-4

Klenberg, L., Korkman, M., & Lahti-Nuuttila, P. (2001). Differential development of attention and executive functions in 3- to 12-year old Finnish children. *Developmental Neuropsychology*, *20*(1), 407–428. DOI:10.1207/S15326942DN2001_6

Kochanska, G. (2002). Committed compliance, moral self, and internalization: A mediational model. *Developmental Psychology*, *38*, 339–351. doi:10.1037/0012-1649.38.3.339

Lamm, C., Zelazo, P.D., & Lewis, M.D. (2006). Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*, *44*(11), 2139–2148. doi:10.1016/j.neuropsychologia.2005.10.013

Lewis, M.D., Lamm, C., Segalowitz, S.J., Stieben, J., & Zelazo, P.D. (2006). Neurophysiological correlates of emotion regulation in children and adolescents. *Journal of Cognitive Neuroscience*, *18*(3), 430–443.

Masten, A., Herbers, J., Desjardins, C., Cutuli, J., McCormick, C., Sapienza, J., … Zelazo, P. (2012). Executive function skills and school success in young children experiencing homelessness. *Educational Researcher*, *41*(9), 375–384. doi:10.3102/0013189X12459883

McClelland, M.M., & Cameron, C.E. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Development Perspectives*, *6*(2), 136–142. doi:10.1111/j.1750-8606.2011.00191.x

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review*, *106*(1), 3–19. doi:10.1037/0033-295X. 106.1.3

Mischel, W., & Ayduk, O. (2011). Willpower in a cognitive affective system: The dynamics of delay of gratification. In R.F. Baumeister & K.D. Vohs (Eds.), *Handbook of self-regulation* (2nd ed., pp. 83–105). New York, NY: Guilford Press.

Peterson, E., & Welsh, M. (2014). The development of hot and cool executive functions: Are we getting warmer? In S. Goldstein & J.A. Naglieri (Eds.), *Handbook of executive functions* (pp. 45–68). New York, NY: Springer.

Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M.D., & Zelazo, P.D. (2011). Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology*, *108*, 621–637. doi:10.1016/j.jecp.2010.09.008

Rueda, M.R., & Paz-Alonzo, P.M. (2013). *Executive function and emotional development*. Retrieved from http://www.child-encyclopedia.com/en-ca/cognitive-stimulation-executive-functions-children/key-messages.html

Somerville, L.H., & Casey, B.J. (2010). Developmental neurobiology of cognitive control and motivational systems. *Current Opinion in Neurobiology*, *20*, 236–241. doi:10.1016/j.conb.2010.01.006

Sulik, M.J., Huerta, S., Zerr, A.A., Eisenberg, N., Spinrad, T.L., Valiente, C., … Taylor, H.B. (2010). The factor structure of effortful control and measurement invariance across ethnicity and sex in a high-risk sample. *Journal of Psychopathology and Behavioral Assessment*, *32*(1), 8–22. doi:10.1007/s10862-009-9164-y

Thorell, L.B. (2007). Do delay aversion and executive function deficits make distinct contributions to the functional impact of ADHD symptoms? A study of early academic skill deficits. *Journal of Child Psychology and Psychiatry*, *48*(11), 1061–1070. doi:10.1111/j.1469-7610.2007.01777.x

Willoughby, M., Kupersmidt, J., Voegler-Lee, M., & Bryant, D. (2011). Contributions of hot and cool self-regulation to preschool disruptive behavior and academic achievement. *Developmental Neuropsychology*, *36*(2), 162–180. doi:10.1080/87565641.2010.549980

Zelazo, P.D., & Carlson, S.M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*(4), 354–360. doi:10.1111/j.1750-8606.2012.00246.x

Zelazo, P.D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 445–469). Malden, MA: Blackwell Publishers, Inc. doi:10.1002/9780470996652.ch20

Zhou, Q., Chen, S.H., & Main, A. (2012). Commonalities and differences in the research on children's effortful control and executive function: A call for an integrated model of self-regulation. *Child Development Perspectives*, *6*(2), 112–121. doi:10.1111/j.1750-8606.2011.00176.x