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Family matters: Intergenerational and interpersonal processes of executive function and attentive behavior

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Abstract

Individual differences in self-regulation include executive function (EF) components that serve self-regulation of attentive behavior by modulating reactive responses to the environment. These factors “run in families”. The purpose of this review is to summarize a program of research that addresses familial inter-generational transmission and inter-personal processes in development. Self-regulation of attentive behavior involves inter-related aspects of executive function (EF) including attention, inhibitory control, and working memory. Individual differences in EF skills develop in systematic ways over childhood, resulting in moderately stable differences between people by early adolescence. Through complex gene-environment transactions, EF is transmitted across generations within parent-child relationships that provide powerful socialization and experiential contexts in which EF and related attentive behavior are forged and practiced. Families matter as parents regulate home environments and themselves as best they can while also supporting cognitive self-regulation of attentive behavior in their children.

Keywords

self-regulation; executive function; attention; genetics; parenting

Self-regulation of physiology, cognitions, emotions and behaviors in response to changes in our own internal states and dynamic environments is effortful, and it takes years of growth and experience to develop the skills and capacities to consistently accomplish self-regulation (Posner & Rothbart, 2006). However, it is so fundamental to surviving and thriving that we have developed exquisite and complex bio-social processes to ensure adequate self-regulation as often as possible (Calkins, 2001). As a result, we are reliably different from each other in how well regulated we are, and this variation matters. Poor self-regulation is associated with a wide variety of outcomes, spanning human capital outcomes (e.g., academic achievement), interpersonal relationships and functioning (e.g., marital discord), physical ailments and illnesses (e.g., cardiovascular disease) and psychopathologies (e.g., depression). To better understand individual differences, my colleagues and I have studied familial processes within mother-child and sibling dyads. A heuristic model is shown in

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Figure 1 that provides a framework for organizing the three major areas of our research summarized in the current paper: development, inter-generational transmission, and interpersonal processes.

Self-regulation is operationalized in many ways in psychological science. In our work, we have examined “cold” executive function (EF) involving attentional control (i.e., shifting and management of sustained attention in the face of potential distractors), inhibitory control (i.e., inhibition of prepotent responses in service to an alternative goal) and working memory (i.e., short term storage and manipulation of information). Together, these indicators reflect a general EF construct as well as sub-components that are evident over the lifespan and can be seen in people’s behavior in a variety of ways. Though explicitly defined as a set of cognitive functions that serve self-regulation, the behavioral expressions of EF include a wider variety of variables including performance on verbal and motor tasks (e.g., Stroop, n-back, dimensional card sorting; Miyake & Friedman, 2012), scores on knowledgeable informants’ ratings of effortful control (EC) of emotion and behavior (Posner & Rothbart, 2006), and objective observers’ ratings of regulated attentive persistent behavior and inhibitory control in situations such as extensive testing sessions and school classrooms, that place sustained demands on EF and other aspects of self-regulation (Deater-Deckard & Wang, 2012). Our work has focused on parents’, teachers’, testers’ and observers’ ratings of children’s well-regulated attentive persistent behavior (i.e., longer attention spans, “on task” persistence, and fewer disruptions to attention arising from switching behaviors or tasks) and EC in home and school contexts. Most recently, we have begun incorporating children’s and mothers’ performance on EF tasks. Measurement models reveal modest to moderate levels of agreement between informants and tasks/indicators, moderate consistency in behavior across home and school contexts, and modest to substantial longitudinal stability in individual differences depending on measurement and developmental period.

DEVELOPMENT

A tool shed of constructs and measures may be just what is needed, given how rapidly this wide range of capacities develops in childhood—the first area of research captured in Figure 1. The specific developmental functions vary depending on the sub-component and particular measures in question (Best & Miller, 2010; Carlson, 2005). However, several generalizations are possible in regard to both ontogeny (i.e., mean-level increases in EF capacities) and individual differences (i.e., rank order stability and change). With respect to ontogeny, from two to five years of age children improve dramatically in their performance on tasks that assess attention regulation, inhibitory control, working memory, and EC (Willoughby, Wirth, & Blair, 2012). Alongside these improvements are major enhancements in self-regulation of language, thought, emotion, and behavior seen in observations and in questionnaire ratings of knowledgeable informants such as caregivers and preschool teachers (Kochanska, Murray, & Harlan, 2000). Developmental enhancement of EF continues, albeit at a slower rate, as children navigate through middle childhood and adolescence. With the onset of puberty, a disparity emerges between surgent, reward-seeking behavior and cognitive regulatory capacities in adolescence that effectively reorganizes self-regulation for most individuals by early adulthood (Steinberg, 2005). The developmental changes in EF reflect corresponding shifts in neurological structures and

functions within brain networks that, among other things, are involved in effortful modulation of automatic reactive responses to stimuli (Blakemore & Choudhury, 2006).

We become much better at EF and sustained and nimble attentive behavior as we “grow up”, but what is the story for individual differences? Individual rank-order stability over time is modest in early childhood, although this may reflect in part the difficulties we face in measuring the skills in youngsters (Cuevas et al., 2014). In theory, as development proceeds, annual longitudinal “test-retest” stability coefficients should increase in magnitude and reach adult-like levels (i.e., .5 to .7 range) by early adolescence. In our work using multi-informant composite scores of well-regulated attentive behavior, the annual stability coefficient shifts from around .3 at three years of age to around .7 by eleven years of age (Deater-Deckard & Wang, 2012). It is important to emphasize that our research utilizes composites that yield reliable constructs that capture stable variance between individuals, but it does so at the expense of identifying sources of systematic change and context/task/construct specificity of the various subcomponents of EF, attentive behavior and self-regulation more broadly. This is an important limitation to bear in mind, given that there is considerable domain, method, and time specific variance in measures of EF and attentive behavior, along with considerable overlap (e.g., Miyake & Friedman, 2012).

In addition to its link with attentive behaviors, EF has an important connection with less impulsive reactive behavior that is apparent early in life. By the preschool years, there is a link between weaker EF capacities and greater emotional reactivity, such as being easily provoked to anger. This has major implications for the development of psychopathology, particularly with respect to growth in externalizing behavior problems such as aggression, opposition/defiance, and delinquency (Cole, Michel, & Teti, 1994). In our research, we have shown that growth in problem behaviors in childhood is fueled in part by growth in negative emotional reactivity coupled with lower levels of regulated attentive behavior (Kim & Deater-Deckard, 2011). Subsequent longitudinal analyses spanning middle childhood suggest shifting patterns of genetic overlap between poorer self-regulation and more behavior problems, perhaps reflecting developmental changes in genetic influences as well as increasing demands on children’s self-regulation as they grow older (Wang, Deater-Deckard, Petrill, & Thompson, 2012).

GENE-ENVIRONMENT INTERPLAY

The second area of research in the conceptual model emphasizes that individual differences in EF are transmitted from the parents’ generation to their offspring via transactions between genetic and nongenetic factors (Figure 1, path ‘a’). Also as indicated in the figure, these processes are likely to be altered as a function of the broader family context, with chronic stressors disrupting healthy development of EF and related skills (Blair, 2010). Experimental animal studies point to the critical roles that caregiving behavior and well-regulated attention and memory skills play. Stronger parental EF capacities are associated with more engaged and responsive caregiving that promotes stronger regulatory capacities and higher quality caregiving in the offspring, mediated in part by epigenetic modifications of genes that produce changes in neural structures and neurotransmitter functioning that influence stress reactivity and self-regulation (Barrett & Fleming, 2011; Weaver et al., 2004). In

humans, psychology and biology intersect to account for the wide variation seen in caregiving behaviors that are in part reflective of the parent's own self-regulation capacities, as well as her or his skills at regulating the environment and behavior of the child (Calkins, 2001). Evidence from cross-sectional and longitudinal studies points to the importance of warm, sensitive, and responsive parenting in the etiology of EF and related self-regulation capacities in children (e.g., Bernier, Carlson, Deschenes, & Matte-Gagne, 2012; Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone, 2012; Hughes, 2011).

Signs of intergenerational transmission of EF emerge early in life. In a longitudinal correlational study of genetically related mother-child dyads, we found a moderate-sized correlation (.41) between maternal and preschool-aged child EF task performance (Cuevas et al., 2014). Is this due to shared genes, environments, or both? Parent- offspring and sibling behavioral genetic designs can be used to provide a preliminary answer. In these designs, the behavioral resemblance of family members can be compared to see if similarity in EF varies as a function of the genetic similarity of those family members. For instance, in unpublished data on forward and backward digit span performance of children (4–12 year olds), I found correlations from .35 to .44 for first-degree biological relatives (parent-offspring or sibling), but correlations near 0 for adoptive siblings and parent-child pairs (Deater-Deckard, 2011). This pattern is consistent with previous behavioral genetic studies in childhood and adolescence examining various aspects of cognitive regulation and functioning (e.g., Plomin, Fulker, Corley, & DeFries, 1997).

An interesting developmental story is seen in gene-environment interplay. Cross-sectional data utilizing a multi-informant (parents, teachers, testers, and observers) composite measure of attentive persistent behavior (see Figure 2a) suggest that the behavioral similarity of genetically identical twins and fraternal twins (who share on average 50% of alleles identical by descent) diverges in the transition to schooling, with increasingly similarity for identical twins and decreasing similarity for fraternal twins. This pattern indicates an increase in the magnitude of genetic influences, including the developmental emergence of statistical interaction between the two copies of the same genes (i.e., genetic dominance). Subsequent longitudinal analyses of this sample showed that the temporal stability of individual differences was accounted for by stable genetic influences (Deater-Deckard & Wang, 2012). These results are consistent with the literature showing age-based increases in heritabilities for EC and EF (Mullineaux et al., 2009), resulting in very substantial heritability and genetic overlap between sub-components of EF by early adulthood along with distinct genetic variances for subdomains of EF (Miyake & Friedman, 2012).

Turning to the genotypic level of analysis, we have examined variation in a 48-base pair (bp) repeat sequence in the D4 dopamine receptor gene. The 48-bp candidate gene has been implicated in the regulation of dopamine and norepinephrine, both of which are involved in modulation of brain activity in frontal regions of the brain that are critical to cognitive self-regulation (Barnes, Dean, Nandam, O'Connell, & Bellgrove, 2011). There are numerous alleles or different variants of this candidate gene, with the 2-, 4-, and 7-repeat alleles being most common. Like others, we have focused on the 7-repeat allele because of its association with lower in vitro D4 receptor expression and decreased efficiency in neurotransmission in the frontal cortex, where D4 receptors are highly expressed (Oak, Oldenhof, Hubert, & Van

Tol, 2000). Utilizing a multi-informant attentive behavior composite score in data from the national longitudinal NICHD Study of Early Child Care and Youth Development or SECCYD, we have found a developmentally emergent genetic dominance effect (see Figure 2b) that mirrors the behavioral genetic findings shown in Fig. 2a (Deater-Deckard & Wang, 2012). Children with two copies of the 7-repeat allele showed increasing problems in attentive persistent behavior, whereas those with only one copy or no copies showed no change.

Given the possibility of gene-environment interaction, we also considered potential environmental modulators in the SECCYD study. To exemplify those findings, results from the analysis of teachers' ratings of attentive behavior are shown in Figure 2c. We found that the presence of the 7-repeat allele was more strongly associated with poorer attentive persistent behavior in school *only* for children who received less sensitive and responsive maternal caregiving in early childhood (Berry, Deater-Deckard, McCartney, Wang, & Petrill, 2013). In addition, when we examined a wider variety of indicators of cognitive and behavioral self-regulation at 4.5 years of age, we found a similar interaction based instead on early nonparental childcare. For those with the 7-repeat allele, fewer hours of childcare were associated with stronger self-regulation but no association was found for those who lacked the allele (Berry, McCartney, Petrill, Deater-Deckard, & Blair, 2013). The results are consistent with human experimental evidence showing an interaction between change in childrearing and presence of the 7-repeat allele in the reduction of child behavioral problems (Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, & Juffer, 2008). These findings provide impetus for further work to replicate and extend these initial results to more fully explain intergenerational transmission mechanisms.

INTERPERSONAL PROCESSES

Self-regulation develops and operates within psychologically powerful parent-child relationships (Dix, 1991)—the third area of research addressed in the conceptual model (Fig. 1). Each individual expresses reactions to the other's behavior, and those reactions influence the other person (path 'b' in Figure 1). Furthermore, EF may mediate the effects of a dyadic partner's behavior on one's own behavior, and vice versa (path 'c'). For instance, when the child's behavior is challenging and becomes a stressor for the parent, this invokes self-regulatory processes in the adult that, when functioning well, are more likely to lead to non-reactive behavioral responses.

In addition, EF may work by modulating (i.e., statistically moderating) responses to the aversive behaviors of a partner (path 'd' in Fig. 1), whereby EF strengthens or weakens the effect of the partner's behavior on one's own behavioral responses. A number of investigators have focused on the "child" side of the model in Figure 1, regarding whether and how children's EF or related self-regulation skills moderate their responses to caregiving behavior. That work suggests that children with the poorest self-regulation skills are more likely to exhibit behavioral and emotional problems in the face of harsher caregiving (Kiff, Lengua, & Zalewski, 2011).

On the parent side of the process, EF is likely to function as a modulator of parents' emotional and behavioral reactions to the child's behavior. If true, the role of parental EF would be most apparent within the context of child behavior problems that cause an emotional stress response in the parent (Dix, 1991; Lorber & O'Leary, 2005). Recent evidence for this idea comes from a variety of theories and methodological approaches, including studies showing differential emotional reactions to infant crying (Leerkes, Parade, & Gudmundsun, 2011), and distinct profiles of maternal physiological modulation of positive and negative affect and control in parenting (Skowron et al., 2011).

We have examined mothers' EF as potential modulators. In one study we observed differential maternal negativity toward 4–7 year old twins or adoptive siblings, and whether that differential parenting was predicted by sibling differences in behavior problems. We found that the child with more challenging behavior (compared to the sibling) also received greater maternal negativity, but only among mothers with poor working memory. This implicated working memory as a modulator of reactive caregiver negativity in the face of aversive child behavior (Deater-Deckard et al., 2010).

In a subsequent study we sampled mothers with 3–7 year old singletons and assessed a broader set of EF skills spanning attention, inhibitory control, and working memory. Like the first study, the link between higher levels of child problem behaviors and harsher caregiving was present only among mothers with poorer EF (Deater-Deckard et al., 2012). In further analyses, we found that this EF modulating effect essentially disappeared in households that were highly chaotic—lacking in routines, noisy, and crowded. Furthermore, in low socioeconomic status households, mothers' EF and household chaos were very substantially correlated. Parental regulatory processes may break down in chaotic environments, particularly when facing multiple socioeconomic stressors.

FAMILY MATTERS

EF, attentive behavior and their connections to healthy functioning operate as part of a systematic set of processes involving intergenerational transmission and interpersonal relationships within families. Stable individual differences represent observable features of underlying biological, psychological, and ecological processes. The differences between people in these features can be assessed from early in life, and become moderately to substantially stable by the end of middle childhood, while average self-regulatory capacity also improves. Through correlated and interacting biological and environmental factors, parents transmit EF and regulated attentive behavior to their children. At the same time, parents' own EF and attentive behaviors are affected by their children's behaviors and functioning, while children are affected by their parents' caregiving behavior. For parents and children alike, strong EF can break the link between aversive behavior in the dyadic partner and one's own reactive response to those behaviors. However, these regulatory processes are vulnerable in contexts that are rife with chronic stressors such as socioeconomic risks and a chaotic household environment. The challenge for parents is to regulate the home environment as best they can, while regulating themselves and helping regulate their children. An emerging literature points to the importance of parent-child

relationships as the foundational context for development and inter-generational transmission of EF, well-regulated attentive behavior, and self-regulation more broadly.

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Figure 1. Intergenerational transmission and interpersonal processes of self-regulation

Self-regulation capacities, including those attributable to EF and well-regulated attentive behavior, develop in systematic ways over childhood into adulthood. Parents transmit self-regulation to their children directly through interacting socialization and biological mechanisms (*a*). In addition, parents' and children's verbal and nonverbal emotional and behavioral responses evoke responses in each other (*b*). These responses are directly related to (*c*) and moderated by (*d*) self-regulation of thoughts, emotions and behaviors. These dyadic and inter-generational transmission processes change as a function of development of both individuals and their relationship, and are altered by contextual features of the broader family and home context (e.g., socioeconomic risks, household chaos, cultural factors).

Figure 2. Developmental changes in gene-environment processes underlying regulated attentive behavior, shown as function of age in years

a) Intra-class correlations for same-sex twin similarity in attentive behavior (MZ = monozygotic, genetically identical; DZ = dizygotic, genetically fraternal; cross-sectional data), showing increase in heritable variance in transition to formal schooling (adapted from Deater-Deckard & Wang, 2012); b) means of multi-informant composite z-score of

inattentive behavior for DRD4 7-repeat allele (1 copy vs. 2 copies), showing increase in effect of homozygous (2 copies of allele) status (adapted from Deater-Deckard & Wang, 2012); and c) means of teacher-rated inattentive behavior, interaction between presence (+) vs. absence (–) of DRD4 7-repeat allele by low vs. high maternal sensitivity in early childhood, showing increase in effect of combination of 7-repeat allele and low maternal sensitivity (see Berry, Deater-Deckard et al., 2013).