ABSTRACT—Knowledge of how physiological responsivity and executive functioning relate to adaptation and resilience in early childhood has improved dramatically over the last decade, yet most studies focus on only one of these processes. By highlighting new findings and ongoing research, in this article, I advocate for investigating the dynamic interplay among physiological arousal, executive functions, and contextual experiences. New analytic approaches advance the conceptualization and measurement of physiological response as a process that comprises both reactivity and recovery. I also offer strategies for capturing complexities in contextual influences through examination of stimulating experiences, unique proximal and distal pathways, nonlinear effects, and longitudinal cascade models. This work can improve our understanding of how young children cope with stressors, engage with challenges, and achieve the optimal arousal and well-regulated behavior that supports development and learning.

KEYWORDS—physiological reactivity and recovery; executive functioning; contextual influences; adaptation; resilience

Investigating the variability of developmental outcomes in the context of past or present adversity has always been the focus of resilience studies (1). Over the last decade, researchers have recognized the importance of studying resilience processes across many levels of analysis, identifying how biological, behavioral, and environmental factors enable some children to thrive despite adversity, while placing others at higher risk for health, behavioral, and academic problems. Recent studies reveal that stress physiology may play an important role in explicating environmental effects on children’s adaptation (2, 3). Separately, children’s self-regulatory capacities, and in particular, executive functioning skills, have emerged as powerful predictors of developmentally salient competencies across a diverse spectrum of risk (4, 5). In this review, I propose that examining the interplay among physiological responsivity, executive functioning, and contextual influences can advance our understanding of ways young children cope with stressors, engage with challenges, and achieve the optimal arousal and well-regulated behavior that supports development and learning.

PHYSIOLOGICAL RESPONSE AS AN INDEX OF DIFFERENTIAL SUSCEPTIBILITY

When faced with environmentally challenging or stressful situations, children’s bodies activate various neurophysiological systems, including the autonomic nervous system (ANS) and the hypothalamic-pituitary-adrenal axis (HPAA), that influence their immediate behavioral responses and short-term coping strategies, as well as long-term adaptation. Variability in physiological response serves as a marker of early exposure to adversity and a key process through which negative life experiences are biologically embedded and expressed (2, 3). Dysregulated
Executive functions (EFs) are a set of higher order cognitive skills (i.e., inhibitory control, working memory, and cognitive flexibility) that help children regulate their own attention, behavior, and emotions. As the building blocks of various age-salient competencies, EFs affect children’s social, emotional, and cognitive development. EFs contribute to early literacy and math skills, classroom behavior, prosocial behavior, and school engagement (4, 5), and promote resilience across many domains in highly disadvantaged children (13). Moreover, children with greater EF skills regulate their emotions more optimally in early childhood (14, 15). Despite the established importance of EF skills for early childhood development, few empirical studies have directly linked EF skills to physiological reactivity in young children.

Blair and Raver (2) have proposed that physiological arousal, as indexed by levels of stress hormones, may serve as a primary mechanism through which early adverse experiences and caregiving quality influence the development of self-regulation and EF skills. This model builds on extensive research with animals and adult humans showing that chronic exposure to elevated levels of stress hormones can undermine development and activation of brain regions that support EFs. Indeed, in a study of children from low-income families (16), heightened baseline cortisol levels in infancy mediated the negative effect of lower parenting quality on children’s EFs at age 3. In contrast, in studies of children’s ANS and HPAA response to laboratory tasks, physiological reactivity was associated positively or curvilinearly with performance on EF tasks (17). Children with moderate levels of arousal displayed higher levels of EF skills than those with high or low parasympathetic reactivity (18). Together, these studies reveal a pattern consistent with the inverted U-curve association between arousal and cognition in adults and animals (19): Moderate levels of arousal are apparently optimal for EF performance, whereas extremely low or extremely high levels may hinder it.

Recent research suggests that heightened susceptibility may promote EF skills in nurturing contexts, but undermine them in less resourced or less supportive contexts. Elevated parasympathetic reactivity during a parent–child interaction was associated with less optimal performance on EF tasks in 3- to 5-year-olds exposed to maltreatment, and with more optimal performance among nonmaltreated children (20). In a study of kindergarteners, cortisol response interacted robustly with family income to affect EFs (21). Heightened cortisol levels were associated with greater EFs in children from higher income families and with lesser EFs in children from lower income families. In a study (22) that uncovered a similar mechanism by which behavioral reactivity was associated longitudinally with EF skills, higher temperamental reactivity in infants was related to greater EFs in preschool in the context of low economic hardship, and to lower EFs in preschoolers in the context of chronic economic hardship. Consistent with DST (7), family experiences in these studies were related to EFs in children with high reactivity, but not those with low reactivity.

Although this work illuminates how physiological response may relate to development and practice of early EF skills by
mediating or moderating contextual influences, we still need to determine the specificity of different physiological systems and measures. We also need to investigate whether young children can learn to use EF skills to regulate their own physiological arousal and the effect of such regulation on broader behavior. Before we can examine that crucial question, we must refine the conceptualization and measurement of physiological response, which is too often captured by a single-score index that obscures differences between physiological reactivity and recovery.

**REACTIVITY, RECOVERY, AND SELF-REGULATION AS A DYNAMIC PROCESS**

From a resilience perspective, I have argued that the most adaptive physiological phenotype would be characterized by a fast and efficient physiological recovery in addition to the elevated reactivity that is often associated with exposure to adversity (3). Such a physiological response would allow resilient children to maintain the vigilance necessary for coping with environmental threats without prolonged exposure to deleterious levels of stress hormones, while providing greater biological sensitivity to protective factors in the environment. Supporting this hypothesis, in a recent study (23), infants with higher levels of emotional reactivity and regulation had greater EF skills in preschool, whereas infants with higher reactivity but lower regulation had lesser EFs. The authors proposed that modulation of physiological arousal may be the underlying mechanism linking regulation of emotional reactivity to the development of EFs.

Furthermore, emergent EF skills may enable young children to actively regulate their own physiological reactivity and recovery by shifting their attention away from distressing stimuli, inhibiting negative affect, or recalling and applying specific strategies to regulate emotions. New dynamic analytic strategies have enabled researchers to identify factors that contribute to variability of physiological response trajectory in children (24). For example, in one study that used latent growth curve modeling (25), the quadratic slope of the physiological response varied as a function of the child’s temperament and parenting practices. Using piecewise growth curve modeling, we examined how EF skills related to distinct components of children’s physiological response trajectory—anticipation, reactivity, and recovery in response to a laboratory challenge task (26). More optimal EFs were associated with a steeper reactivity trajectory during the challenge and greater recovery afterward. Consistent with previous studies of parasympathetic reactivity (27, 28), we hypothesized that EF skills enabled children to regulate their emotions and behavior to achieve the greater arousal needed to successfully engage and cope with the sociocognitive challenge, but also to recover after the challenge. Our findings also corroborated a study showing lower parasympathetic recovery in young children who displayed negative emotions or focused on the delay object when attempting to delay gratification (29). However, more work is needed to test the timing and directionality of the interplay between EF skills and physiological response in children.

Physiological arousal, emotion regulation, and EF skills are not linked in a fixed linear pattern, but represent a complex dynamic system. For example, greater EF skills have been associated with suppressing emotions and using reappraisal strategies, which in turn have been linked to young adults’ parasympathetic recovery (30, 31). Similarly, the ability to reappraise heightened arousal as a performance-enhancing experience moderated the link between actual physiological arousal and performance on cognitive tests in college students (32). In our recent work, the link between cortisol reactivity and EFs varied as a function of family income, which may be linked to differences in children’s appraisal of arousal or their experience of the testing environment (21). We need a better sense of when and how children can learn to reappraise physiological arousal, and how their subjective experiences can affect their emotions and behavior.

Despite a rich body of research linking temperamentally based reactive and effortful control processes to physiological arousal, expression of negative affect, and symptoms of psychopathology in early childhood (6, 14), little is known about how implicit and explicit strategies to regulate emotions relate to physiological responsivity and EFs. Researchers should examine how young children use EFs to manage and change the intensity and duration of emotional expression and accompanying arousal and, conversely, how the subjective appraisal of arousal and emotional situations may affect children’s use of EF skills. Given the growing number of evidence-based interventions that promote EF skills (5) and emotion-regulation strategies (14, 33) in early childhood, we should use experimental manipulation to test the effect of improved skills and strategies on physiological reactivity and recovery.

**THE IMPORTANCE OF CAREGIVING AND EDUCATIONAL CONTEXTS**

The quality of the early childrearing environment has been implicated in the development and expression of both physiological responsivity and executive functioning, and these associations are dynamic and nonlinear. According to DST, high-sensitivity phenotypes should emerge most often in contexts of low and high exposure to adversity because they enable children to engage with stimulating influences, in the first case, and to maintain the vigilance necessary for survival, in the second (7). Furthermore, supportive caregiving and education contexts may play a key role in enabling physiologically reactive children to develop well-regulated behaviors through modulating their arousal and associated neurological activity; in such contexts, these children respond to stimulation reflectively rather than reactively (19). However, common measures of childrearing context are predominantly unidimensional, linear, and static, preventing us from uncovering new mechanisms by which context con-
tributes to and interacts with reactivity and regulation to promote resilience.

Children from disadvantaged socioeconomic backgrounds display lower EF skills than their more advantaged peers (4). Although researchers have progressed in identifying specific parenting strategies, such as scaffolding, stimulation, and sensitivity, that support early EF skills (34), fewer studies test how these processes mediate the effect of socioeconomic adversity. In recent studies, positive parenting practices and home enrichment mediated the effects of family socioeconomic risk on EF skills in early childhood (15, 16, 35). My colleagues and I extended these findings globally by studying highly disadvantaged 4-year-olds in rural Pakistan. The effects of family factors such as wealth, food insecurity, maternal education, and cognitive capacity on EF skills operated through more proximal indices of home stimulation and maternal scaffolding (36). More researchers need to address the role of stress physiology in explaining the longitudinal association between various family factors and EF skills (see 16).

Other studies have demonstrated the importance of family financial resources over and above other family characteristics, such as race, parents’ education, marital status, and quality of parenting and home environment (21, 22, 37). These studies highlight a need to develop more nuanced measures of family context that capture financial investment in stimulation experiences that strengthen EF skills, especially outside the home (e.g., extracurricular programs, high-quality child care). Researchers should also investigate the interplay of physiological response and EFs within educational settings, where children are expected to show well-regulated arousal and behavior to succeed. Children’s physiological and emotional reactivity moderated the longitudinal effects of early teacher–child relationship quality on later mental health symptoms in a manner that is consistent with DST (38). In recent studies, classroom climate and instructional quality contributed to the growth of EF skills in preschoolers (39, 40) and children who exhibited poor self-regulation at school entry could change the quality of the classroom experience, as indexed by a persistent increase in conflict with teachers during early grades (41). These findings could be extended by assessing physiological responsivity within educational settings and by examining outcomes during middle childhood and adolescence, when the salience of school and peer effects may intensify.

Together, these studies highlight the need to move away from characterizing contextual influences with a single score, as was done in many early studies of differential susceptibility. Knowledge of unique and common pathways between distal and proximal risk and protective factors could help identify causal processes that would be effective targets for intervention. Also important for intervention efforts is a deeper understanding of nonlinear effects and thresholds between beneficial and deleterious contextual effects. Recently, in a study of kindergarteners, we found an inverted U-shape relation between emotional adversity and EF skills that was independent of the negative linear effect of socioeconomic adversity (42). We hypothesized that mild-to-moderate exposure to family emotional stressors provided opportunities for children to apply and practice their emotion-regulation skills.

Finally, researchers should use longitudinal models to identify when and how differential susceptibility may change as a result of the maturation of physiological systems, the development of children’s agency, and the evolution of contextual influences, from intense, early dyadic relationships to the complex interplay of family, peer, and school settings. Early experiences are important determinants of emerging physiological response patterns, which in turn exert lasting mediating and moderating effects on developing EF skills and related behavior (6, 16, 38). While age-related increases in cognitive capacities, including EFs, may enable children to exercise more control over their environment and arousal (30, 31), puberty brings new transitions, including heightened physiological responsivity and less effective parental buffers (43). Researchers should use developmental cascade models to test changes in the strength of transactional and interactive effects among physiology, self-regulation, and environment across time. Since the effect of biological sensitivity on adaptation differs along the continuum of adversity (3, 7), we need to use analyses such as moderated mediation and multilevel modeling to identify how both the stability of physiological response and its time-varying effect differ for low- and high-risk groups (44).

CONCLUSION

Knowledge of how physiological responsivity and executive functioning relate to adaptation and resilience in early childhood has improved dramatically over the last decade, yet most studies focus on only one of these processes. In highlighting these promising new findings and ongoing work, I encourage researchers to investigate the transactional effects among physiological arousal, EF skills, and contextual experiences. By applying new analytic strategies, we can advance our understanding of physiological stress response as a process that comprises both reactivity and recovery, and identify how attentional and behavioral self-regulation explains variability in trajectory components. In examining the interplay between physiology and EF skills, we need to address the role of identification, appraisal, and regulation of emotions, as well as test the effect of interventions involving emotion socialization.

We must also attend to functional differences across the various systems and stimuli eliciting the arousal as we refine our understanding of physiological response as a susceptibility marker (3, 10, 45). Indices of both ANS and HPA systems have been used to demonstrate differential susceptibility (3, 8, 9), and have been linked to children’s EF skills (16–18, 20, 21, 26) and strategies regulating emotions (29, 31, 32). Yet these systems have distinct roles in helping children engage with and
adapt to environmental demands, opportunities, and threats. Parasympathetic response promotes sustained attention, self-regulation, and social engagement in the face of mild positive and negative challenges, whereas sympathetic response supports flight-or-fight behaviors, and HPAA response is activated most reliably by social-evaluative threats, interpersonal conflict, uncontrollable events, and chronic adversity (27, 46). Different patterns in the coactivation of these systems may contribute further to adaptation (27). As such, these systems may promote sensitivity to different kinds of experiences, encode specific information about the environment, and affect unique behavioral outcomes. Del Giudice, Ellis, and Shirtcliff (46) proposed a model of how different physiological systems may act as informational filters that modulate an organism’s openness to contextual input and shape learning, relationships, and health through feedback loops over time. However, more empirical research is needed to identify domain-general and domain-specific mechanisms underlying the proposed physiological responsivity profiles in early childhood.

Through these lines of inquiry, researchers can uncover distinct pathways through which biological sensitivity promotes resilience, and may identify new possibilities for intervention (45). Since resilience emerges over time through a combination of both positive and negative experiences, we need to study these processes across a range of contexts. As we focus on new approaches to linking physiological responsivity and EF skills with adaptation and resilience, we must also improve our assessment of contextual influences. Complexities in children’s caregiving and educational environments should be captured through innovative indices of stimulating experiences, unique proximal and distal pathways, nonlinear effects, and longitudinal models.

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