Early Childhood Executive Functions: Components, risk factors, and interventions

by

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Introduction

Cognitive and social-emotional development occurs rapidly during early childhood, and positive experiences during these years can have long-lasting benefits. During these early years, children attending a good preschool program experience short-term benefits like smoother transitions to school and reported higher cognitive and social abilities in kindergarten (Andersson, 1987). For children from low-income families who attended preschool, long-term benefits included higher academic scores, more total years of education attainment, better health, higher wages, and fewer committed crimes (Campbell, Ramey, Pungello, Sparling, & Miller-Johnson, 2002; Muennig et al., 2011; Schweinhart et al., 2005). These results suggest that children benefit greatly from attending a quality preschool program. Preschools are advantageous for the children who pass through them and the surrounding society. Increased tax revenues and decreased spending on remedial education and criminal justice are two ways societies benefit from preschools (Reynolds, Temple, Robertson, & Mann, 2002; Temple & Reynolds, 2007).

Developmental researchers and educational practitioners recognize the value of preschools to children and society are investigating the essential components of a high quality program which can be widely implemented in preschools. Researchers are studying the non-academic cognitive processes of executive functions (EFs) for applications to early childhood education. EFs allow individuals to form goals, plan, stay focused, and effectively execute actions. These skills are essential for success in school and work situations where people need to control their thoughts and manipulate problems in their mind (Jurado & Rosselli, 2007). During the early

development of EF skills in the preschool years, there is potential to intervene and promote a positive trajectory for these functions (Anderson, 2002).

Despite research in the past few decades on EFs, questions persist about EFs in early childhood. One important question is how researchers should categorize EFs in young children. Conflicting structural models argue for either a singular EF ability or a diversity of skills under an EF umbrella. Neuroimaging studies supplement the various behavioral measures used to investigate EFs. Another question is on the direction of causality in the relationship between EFs and academic achievement, which have an established positive association. Researchers identified environmental and biological factors negatively associated with the development of EFs. The association between EFs and academic success and the possibility that EFs influence academics prompt researchers to explore EF interventions as a way to indirectly improve academic achievement. Through greater understanding of EF development, programs can be created and used in early childhood education settings to help children, especially those facing environmental and biological risk factors, to improve these skills for greater success in school and life. This thesis reviews the findings on early childhood EFs in order to highlight gaps and areas of contention for future studies.

Chapter 1

The Structure, Measures, and Importance of Executive Functions in Early Childhood

Introduction

Executive functions (EFs) are higher order processing skills necessary for cognitive control of behavior and thoughts. Researchers study EFs in all ages and in relation to a number of disorders, such as attention-deficit/hyperactivity disorder and schizophrenia (Hutton et al., 1998; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). While researchers have established a model for the components of EFs in adults, the structure in children remains controversial. The lack of a model for EFs is one of a number of limitations to the development and application of behavioral measurements in EF studies. By establishing the structure of EFs, study measures will improve which, combined with findings from recent brain-imaging techniques, will add to the understanding of EFs in early development. This understanding is valuable for future studies determining the direction of causation between EFs and academic achievement. These two variables are positively associated, but whether training EFs will improve academics is undecided. Researchers need to address the gaps in the study of EF development, particularly the structure of EFs and the relationship with academic achievement, in order to provide a strong basis for future studies on EFs and interventions in early childhood.

Executive Function Structure

There are two conceptualizations in the categorization of EF structure. One focuses on the unity and diversity of EF cognitive skills. It proposes that EFs in adults are composed of a uniting factor underlying divergent subsets of skills, including working memory, inhibition, and cognitive flexibility. Researchers disagree on the

united and diverse nature of EFs in children, proposing three different models. The other more controversial EF conceptualization distinguishes between EFs that involve affective cognitive behavior, or hot EFs, and EFs based in abstract cognitive processing, or cool EFs. Understanding the structure of EFs in young children will give insight into EF development and improve EF measurements. The improved measurements will make the results of future studies more representative of children's cognitive abilities.

Unity and Diversity of Executive Functions in Adults

Initial investigations on EFs led to a discussion on whether an individual's executive control behavior is due to one general skill factor or multiple factors. In one theoretical model, individuals recruit a single united EF factor to accomplish EF tasks. In the other model, EFs are separated into three cognitive factors, with different tasks calling on these factors independently. The current EF model for adults is a compromise of these two theories. In this model, EFs have an underlying executive control component, but the subsets of working memory, inhibition, and cognitive flexibility are distinguishable (Miyake et al., 2000).

Working Memory

Working memory, one of the subsets of EFs, allows an individual to maintain and manipulate information in mind. The manipulation of information differentiates working memory from short-term memory which only holds recent stimuli in mind. Working memory has a limited amount of items which can be held and worked with at one time, called working memory capacity (Jacob & Parkinson, 2015). Two types of working memory, verbal and visuospatial, are differentiated by context. Using

working memory, individuals can comprehend language, solve math problems, update thoughts, compare distinct items, follow rules to complete actions, and behave with the integration of new information (Diamond, 2013).

Inhibition

Individuals use inhibition every day to deliberately stop automatic responses. Behavioral and emotional control, selective attention, and cognitive inhibition are examples of inhibitory control (Diamond, 2013). Inhibition of behaviors prevents acting out impulsively and allows for delaying gratification (Garon, Bryson, & Smith, 2008). Individuals using selective attention ignore distractors and focus on specific stimuli. Cognitive inhibition is the suppression of dominant or unwanted thoughts. Without these skills, individuals would not be able to control their behavioral and cognitive impulses, ignore irrelevant stimuli, repress unwanted thoughts, or act beyond typical habits (Diamond, 2013).

Cognitive Flexibility

The final subset of EFs is cognitive flexibility. Also referred to as set-shifting, cognitive flexibility describes one's ability to switch between tasks or perspectives (Miyake et al., 2000; Wiebe et al., 2011). Individuals switch perspectives either spatially, to mentally manipulate an object to look at it from a different angle, or interpersonally, to see a problem from another person's point of view (Diamond, 2013). Beyond these skills, individuals use cognitive flexibility to come up with creative solutions. Some researchers propose that this subset comes later in development since it incorporates working memory and inhibition in the process of manipulating problems, focusing attention, and inhibiting the initial response

(Diamond, 2013; Garon et al., 2008). The adaptive nature of cognitive flexibility supports human creativity and complex problem solving.

Unity and Diversity of Executive Functions in Children

While the structure of EFs in adults is established with the three subsets and an underlying factor described above, there is disagreement on the structure of EFs in children (Collette & Van der Linden, 2002; Miyake et al., 2000). Results from some studies support a single latent EF factor supporting cognitive functions in children (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al., 2011; Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, & Greenberg, 2010). After conducting a number of EF tasks on preschool-aged children, researchers found the scores of the entire battery more strongly supported a unity model of EF. According to this model, the subsets differentiate during development in the following years (Wiebe et al., 2011).

In the studies concluding a unity model, testing an inadequate number of EF tasks and using tests with overlaps in demand for EF subsets are limitations possibly affecting results (Miller et al., 2012). These limitations lead to erroneous results if tests do not fully capture distinct cognitive processes of working memory, inhibition, and cognitive flexibility. Using multiple EF tasks would minimize this problem because multiple tests of each subset would provide more comprehensive results on the contribution of each factor separately or a possible shared factor.

Studies using multiple EF measures with minimal task demand overlap find support for a two factor model of working memory and inhibition with an underlying singular factor (Garon et al., 2014; Miller et al., 2012; Senn et al., 2004). Researchers

concluded that cognitive flexibility is either not distinguishable in young children or is built upon the other two subsets of EFs during development (Garon et al., 2014; Miller et al., 2012; Senn et al., 2004).

Another group of researchers propose inhibition, working memory, and shifting are unrelated until integration during the preschool years (Howard, Okely, & Ellis, 2015). Testing the three subsets of EFs in three and four year olds, correlation coefficients between task performance scores in three year olds were lower compared to four year olds. Interpreting these results, Howard et al. (2015) concluded that EFs are distinct in young children and become integrated during development.

With three conflicting models, one suggesting a general EF skill, another suggesting an underlying EF factor to working memory and inhibitory control, and the final suggesting diversity until integration, conceptualizing the structure of EFs in young children is challenging. Clearly, more research in this area is needed.

Hot and Cool Executive Functions

A controversial theory posits EFs are distinguishable by the presence or absence of motivational and emotional salience in a situation (Zelazo & Müller, 2002). According to this theory, when there is an extrinsic reward or affective nature to a task, an individual recruits hot EFs. An example of this is when a child is asked to choose between a small immediate treat or wait longer for a larger treat (Mischel, Shoda, & Rodriguez, 1989). In contrast, cool EFs, the other half of this theory, emerge in situations requiring abstract problem solving without motivational salience to the individual. Children use this skill in situations like when they have to figure out the rule to follow while sorting a deck of cards (Zelazo, 2006).

In adults, researchers found distinct but interconnected neural regions responsible for hot and cool EFs. The ventromedial region of the prefrontal cortex (PFC) and the orbitofrontal cortex are more closely tied with the emotional regulation of hot EFs, while the dorsolateral PFC is associated with cool EFs (Bechara, Damasio, Damasio, & Anderson, 1994; Hongwanishkul et al., 2005; Rolls, Hornak, Wade, & McGrath, 1994; Schulz et al., 2009; see Figure 1 in Chapter 1 Appendix). Few imaging studies, however, explored this difference in young children.

While looking at behavioral aspects of hot and cool EFs in children between the ages of three and five, researchers disagree whether or not there is a difference between the two. Allan and Lonigan (2011) found support for the unidimensionality of EFs. Preschoolers completed eight tasks measuring either hot or cool EFs, and the results were analyzed using a confirmatory factor analysis. Over a multiple factor model, the one factor model fit best (Allan & Lonigan, 2011). In contrast, other researchers concluded a two factor model with moderate correlations between hot and cool EFs best fit their results (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Hongwanishkul et al., 2005). A possible explanation for the conflicting results is during the ages three to five the differences between hot and cool EFs may emerge (Zelazo & Carlson, 2012). Another possibility is the likely overlap in the neural networks of hot and cool EFs early in development.

In a number of studies hot and cool EFs were separated with regard to their association to academic success and their ability to be trained. When tested independently, cool EFs in preschool were associated with academic achievement, math achievement, and learning related behaviors, while hot EFs were not (Beck,

Schaefer, Pang, & Carlson, 2011; Brock et al., 2009; Willoughby, Kupersmidt,

Voegler-Lee, & Bryant, 2011). Furthermore, in a group training program of five year

olds, Traverso et al. (2015) found different effects of the training program on hot and

cool EFs. While the children after the intervention performed higher than controls on

cool EF tasks, children did not consistently perform higher on hot EF tasks (Traverso

et al., 2015). A possible explanation is the hot EF tasks measured the ability to deal

with frustration, while the training did not include activities to help children learn

how to handle frustration (Traverso et al., 2015). Despite these differences, age

related improvements are found in both hot and cool tasks between the ages of three

and five, demonstrating development in both types (Hongwanishkul et al., 2005; Kerr

& Zelazo, 2004).

Since there appears to be strong evidence in support of the theory of a two-

factor model distinguishing hot and cool EFs in young children, future research on the

early development of hot and cool EFs, both behaviorally and in imaging studies,

should continue to investigate the understanding of these components.

Conclusion

These two conceptualizations of EFs— the cognitive component models and

the affective models — appear to be supported in adults, while there are still mixed

results in children. Researchers propose three models for how cognitive components

of working memory, inhibition, and cognitive flexibility relate to each other in early

development. One suggests that working memory and inhibitory control are distinct

processes with moderate correlations between, and cognitive flexibility builds upon

these two skills. Another model proposes a single EF process that becomes

differentiated with age. The final suggested model, which is greatly understudied, states that the three subsets are distinguishable until integration during development. The research on the conceptualization of affective EFs demonstrates mixed results and remains controversial. Yet, more studies point to a two-factor model of separating hot and cool EFs in young children. Once the structure of early developmental EFs is established, studies will improve because of measurements more accurately reflecting the cognitive processes of children.

Measuring Executive Functions

Studies use a number of different tasks and surveys to assess EFs in children; however, there are a number of complications with the various tests. With a lack of clarity on the structure of EFs in children, researchers use measurements which may not fully capture the subsets or whole aspect of EFs. Most EF tasks are impure in their measurement, either testing other EF subsets or requiring other abilities like motor skills. EF tasks need to be appropriate for the targeted age range, leading to further challenges. Furthermore, ecological validity and reliability are two concerns for EF tasks. When conducting studies on children's EFs, researchers must consider these challenges and limitations to measurements.

Some of the tasks assigned to children are derived from adult versions. For example, the TRAILS-P task is a preschool appropriate version of the Trail Making Test (Espy & Cwik, 2004). Developing tasks in this way leads to a number of problems. Most importantly, as discussed above, the EF structure in adults differs from the structure in children. Depending on whether EFs are unitary or divergent in

preschoolers, researchers approach testing EFs in different ways. If EFs are a single factor, then measures should incorporate all aspects of EFs. If instead EFs are divergent with preschoolers demonstrating distinct capacities for working memory, inhibition, cognitive flexibility, then researchers should give tasks that measure these subsets separately.

When attempting to test working memory and inhibitory control independently, researchers struggle to create tasks that require the use of only one skill. A task measuring working memory requires inhibition to stay focused, while a task measuring inhibition requires working memory to hold the goal in mind (Diamond, 2013). This task impurity, in which a confounding factor is inadvertently measured, is not limited to the two subsets of EFs. Task impurity may persist when tests tap into non-executive processes like motor skills (Anderson, 2002). Researchers can create tasks to minimize or control for these potential confounding variables, but this is challenging.

Another problem with modifying adult tests to use with children is accounting for children's needs. Tasks need to be engaging, short, and appropriate for children. If tasks are boring, children will lose interest and incompletely finish the task. If the tasks are too intensive, a fatigue effect will affect the results by causing some children to fail to complete the task. Finally, the task must also accommodate children's limited verbal skills. Considering these aspects in the development of a task will ensure that children can perform to their best cognitive ability.

In the development of EF tests, researchers must also consider the ecological validity, or the ability of the test results to reflect a child's typical behavior (Jurado &

Rosselli, 2007). Children often take EF tasks in one-on-one situations within the quiet context of a lab. This environment differs from children's everyday experience at home and school. As a consequence, children's performance on tasks in a lab environment may not reflect their typical behavior in more distracting environments and skew a study's results.

Therefore, measures like the Behavior Rating Inventory of Executive Functions (BRIEF) are valuable to include in studies in order to capture children's typical behavior. On the BRIEF survey, parents or teachers report the behavior of children on the scales of Working Memory, Inhibit, Shift, Emotional Control, and Planning (Sherman & Brooks, 2010). Studies found a weak correlation between reported scores on BRIEF and lab-based performance tasks like Trail Making and Stop-Signal (McAuley, Chen, Goos, Schachar, & Crosbie, 2010; Vriezen & Pigott, 2010). This finding suggests that assessments like BRIEF, which measure behavior in social environments, evaluate EFs differently compared to lab performance tests. Anderson (2002) suggested an alternative way to measure children's behavior. By measuring the strategies used by a child while completing a lab-based task, the researchers would gain insight into the process a child takes to get their final results. In studies, including these other types of measurements will address ecological validity limitations.

Establishing psychometric reliability is challenging in most EF tasks. One way to test reliability is by testing an individual on the same test multiple times and ensuring consistent results. Yet, because of a practice effect, the results may be skewed if an individual is tested multiple times (Beck et al., 2011). The practice

effect would mean that an individual who has done the task before would score higher the second time due to previous experience with the task (Anderson, 2002). If responses are practiced or automatic, they do not reflect the use of EFs since EFs inherently require cognitive control. The possibility of a practice effect has implications for a number of studies that conduct pre-tests and post-tests. Part of an increase in scores at the post-test may be due to familiarity with the test, and therefore, control groups are necessary to account for this effect. The practice effect leads to challenges in assessing if a task is reliable when tested multiple times on the same individual.

Researchers use a number of common tests in EF studies in children. Tests theorized to measure inhibition include Go/No-Go, Stroop Card variations, Delay of Gratification, Flanker, and Stop-Signal (Carver, Livesey, & Charles, 2009; Eriksen & Eriksen, 1974; Howard & Okely, 2015; Lagattuta, Sayfan, & Monsour, 2011; Mischel et al., 1989). To assess working memory, a Corsi block test or backward digit span task is typically used (Farrell Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006; Jacob & Parkinson, 2015). Measures that assess executive functions more as a whole include Head-Toes-Knees-Shoulders, Dimensional Change Card Sort, Shape School, Trail Making Task, and Tower of Hanoi (Bull, Espy, & Senn, 2004; Espy & Cwik, 2004; Espy, 1997; McClelland et al., 2014; Zelazo, 2006). Some studies have utilized a battery of tests like the Cambridge Neuropsychological Test Automated Battery to assess a wide array of EF skills (Luciana & Nelson, 1998). Willoughby et al. (2010) reported another battery of EF tasks which includes a Simon, Stroop-like, and Go/No-

Go tasks for inhibitory control, span-like task for working memory, and an attention shifting task.

Task impurity, ecological validity, and practice effect are three task design challenges affecting EF measures. Researchers need to consider these factors when conducting EF studies. Until the development of a standardized measurement approach accounting for these issues, researchers will have difficulty in comparing results across studies and have results that only partially reflect children's typical behavior. In other words, two studies investigating the same topic but using unlike tests would get inconsistent results because the tests measured EFs differently. Potentially, both studies would also have misleading results if the tests were affected by limitations like task impurity or poor ecological validity.

To solve these problems, a widely accepted set of measures should be established and used by researchers. The identification of appropriate measures is partially dependent on establishing the EF structure, but in order to establish the EF structure, comprehensive measures are needed. A possible solution to this conundrum is to conduct a study using a wide variety of the current measures and analyze the results to identify the best fitting structural model. This model will then inform the development of more representative measures without requiring a long battery of tests. With the greater precision in measuring, researchers will be able to better understand the developing brain-behavior relationship and investigate further environmental and biological influences (Blair, Zelazo, & Greenberg, 2005).

Neuroimaging Studies

Previously, researchers primarily used behavioral studies to investigate EFs over the course of development. More recently, neuroscientists have been able to use imaging techniques to identify brain regions activated during cognitive control tasks. Two regions of particular interest are the frontal and parietal cortices.

As the brain develops, a number of structural and functional changes occur simultaneously with behavioral and cognitive changes. Structurally, the volume of gray matter, which is mainly made up of neuronal cell bodies, increases into adolescence (Giedd et al., 1999). In contrast, white matter volume, which consists of axons transmitting signals between neurons throughout the brain, continues to increase into adulthood (Giedd et al., 1999). Functionally, there is a shift from diffuse cortical activation, or the activation of larger regions of neurons in the cortex, to more focal activation. This shift in activation parallels the development of EFs (Durston et al., 2006; Perlman, Huppert, & Luna, 2015; Tsujimoto, Yamamoto, Kawaguchi, Koizumi, & Sawaguchi, 2004).

There are numerous imaging studies examining the activation of neurons in response to EF tasks in adults. Results consistently find activation in the dorsolateral PFC, the anterior cingulate cortex in the medial PFC, the insular cortex, and the intraparietal cortex (Booth et al., 2003; Braver et al., 1997; Casey et al., 1998; Olesen, Macoveanu, Tegnér, & Klingberg, 2007; Wager & Smith, 2003; see Figure 1 in Chapter 1 Appendix).

While there is evidence depicting the neural structure of EFs in adults and behavioral EF development in young children, challenges in imaging neural

activation in children cause limitations in studying the parallel neural development of EFs (Davidson, Amso, Anderson, & Diamond, 2006; Luciana & Nelson, 1998; Moriguchi & Hiraki, 2011). The development of functional near-infrared spectroscopy (fNIRS), a brain imaging technique, led to more opportunities to study EFs in young children. fNIRS consists of sensors within a head cap, making the experience quieter and more comfortable than other imaging techniques. Unlike MRI, children do not need to sit completely still to get accurate measures. As a consequence, fNIRS is the preferable imaging technique for young children. fNIRS measures oxygenated and deoxygenated hemoglobin flowing through the blood in the cerebral hemispheres (Masataka, Perlovsky, & Hiraki, 2015). Neural areas of activity are associated with changes to the blood flow, which fNIRS is able to identify. Limitations of this technique include less spatial and depth sensitivity, as well as conflicting inputs from the blood flowing through the skin on the forehead (Masataka et al., 2015; Moriguchi & Hiraki, 2013). Technical manipulation can mostly address the issue of conflicting inputs, however the sensitivity remains limited. For now, fNIRS is a promising technique to measure neural activity in young children.

Recent functional fNIRS studies demonstrate that children activate similar neural regions as adults, specifically the frontal and parietal cortices. Activity in the lateral PFC was associated with performance on working memory tasks (Perlman et al., 2015; Tsujimoto et al., 2004). In fact, there was a load dependency, in which the level of activation in the lateral PFC corresponded with the amount of items held in working memory (Perlman et al., 2015; Tsujimoto et al., 2004). In looking at response inhibition, young children have immature activation of the frontoparietal

regions corresponding with poorer performance on inhibition tasks (Mehnert et al., 2013). Meanwhile, on a cognitive shifting task, greater activation of the inferior PFC corresponded with higher performance scores (Moriguchi & Hiraki, 2011).

A number of cross-sectional studies have explored the association between EF development and structural or functional brain changes across a wide age range. One study found that age-related changes to working memory capacity are positively associated with activity in the superior frontal cortex and intraparietal cortex (Klingberg, Forssberg, & Westerberg, 2002). Further exploration on working memory development revealed a neural shift from greater reliance on the basal ganglia and other subcortical structures, towards more use of the anterior cingulate cortex and other frontal regions (Scherf, Sweeney, & Luna, 2006). The subcortical structures are more closely associated with behaviors that are emotional and less controlled. In contrast, the frontal cortex is typically associated with more complex cognitive processes. Therefore, the shift from the former to the latter during development of working memory is significant in demonstrating increased sophistication of cognitive abilities. Another component of working memory development is the complexity of the frontoparietal and frontostriatal white matter networks (Darki & Klingberg, 2015; Østby, Tamnes, Fjell, & Walhovd, 2011). The complexity of these networks, measured by fractional anisotropy, predicts future working memory capacity (Darki & Klingberg, 2015).

There is controversy over the ability to assign specific cognitive functions to distinct regions of the brain because human behavior and the brain are complex. If a region is activated during a specific cognitive process, the function of that area may

include other cognitive processes not measured (Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). Assigning functions to regions has limitations, but understanding the age-related structural and functional changes in the brain will give insight into the parallel behavioral changes in EFs.

Results from investigations into the neural basis of EFs during development have a few potential applications, including exploring comorbidities and understanding the EF structure in young children. Comorbidity, or the higher prevalence of one disorder with the presence of another, exists between EF deficits and other disorders like attention-deficit/hyperactivity disorder, schizophrenia, and autism (Ozonoff & Jensen, 1999; Velligan & Bow-Thomas, 1999). An additional application is to address the dispute, described above, on the theoretical EF structure in young children. By understanding the neural activation patterns, researchers may reach a conclusion on how best to model EFs as unitary or diverse. Despite the limitation on assigning cognitive skills to specific neural regions, studying children's neural activity during EF development is a promising avenue for improving the understanding of EFs.

Executive Functions and Academic Success

Numerous studies establish an association between children's performance on EF tasks and their academic achievement. Working memory, shifting attention, inhibition, goal-monitoring, and behavioral regulation in preschoolers and kindergarteners predict academic achievement or general learning ability in the years following (Alloway & Alloway, 2010; Bull, Espy, & Wiebe, 2008; McClelland et al.,

2007; Sektnan, McClelland, Acock, & Morrison, 2010). Moreover, the gains in EFs

over the course of preschool and kindergarten are associated with academic gains

(Fuhs, Nesbitt, Farran, & Dong, 2014). Studies reflecting distinct aspects of

academics, like math and literacy, find more complicated results.

The association between subsets of EFs and mathematics is complex. Findings

support an association between general EF abilities and numeracy (McClelland et al.,

2014; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). Evidence for the

bidirectionality in the relationship between these two factors emphasizes the strength

of the relationship. Early EF skills predict later math ability and early math ability

predicts later EFs (Welsh, Nix, Blair, Bierman, & Nelson, 2010). Yet, studies

contradict each other on whether inhibitory control or working memory is more

predictive of numeracy ability. When children took the math test in kindergarten,

inhibitory control predicted math achievement (Blair & Razza, 2007; Clark,

Pritchard, & Woodward, 2010; Espy et al., 2004). In contrast, when children took the

math test between first and third grade, working memory more strongly predicted

math achievement (Bull et al., 2008; Van der Ven, Kroesbergen, Boom, & Leseman,

2012; Viterbori, Usai, Traverso, & De Franchis, 2015).

The difference between EF subsets is possibly due to changes in the demands

of math tasks. In early childhood, math tests mainly measure simple addition and

subtraction, basic numeracy and relative size (Blair & Razza, 2007; Clark et al.,

2010). As a child advances in math levels, working memory is required more to solve

complex problems (Fuhs et al., 2014; Viterbori et al., 2015). EF skills, whether

working memory or inhibitory control, appear to predict later numeracy skills.

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Studies show a positive association between EFs in preschool and literacy, but the association is weaker than that of EFs and numeracy. Working memory and attentional control predicted growth in literacy abilities when controlling for initial literacy levels (Welsh et al., 2010). Preschool EFs, especially inhibitory control, predict letter knowledge and vocabulary performance in kindergarten (Blair & Razza, 2007; Weiland, Barata, & Yoshikawa, 2014). However, literacy and EFs do not have the bidirectional relationship that was found between numeracy and EFs (Weiland et al., 2014; Welsh et al., 2010). A possible explanation for the lack of this bidirectional relationship between literacy and EFs is that literacy abilities become automatic as reading and verbal skills become easier with practice.

Some studies mentioned above suggest that the association between EFs and academics imply improving EFs would improve academic success. There are a few training studies which demonstrate that improving EFs results in improved academics (Blair & Raver, 2014; Blakey & Carroll, 2015; Holmes, Gathercole, & Dunning, 2009). Yet, some researchers caution against jumping to the conclusion of a causal relationship until more studies directly test the direction of causation (Fuhs et al., 2014; Willoughby, Kupersmidt, & Voegler-Lee, 2012).

There are a few suggested reasons why there may be evidence for an association between EFs and academic ability even if there is no causal relationship. Firstly, the development of neural circuits for EFs may coincide with the development of similar circuits for academic skills (Blair & Razza, 2007; Clark et al., 2010; Espy et al., 2004; Weiland et al., 2014). Secondly, EFs may indirectly affect performance by improving learning-related behaviors and the ability to adapt to

preschool (Best, Miller, & Naglieri, 2011; Bull et al., 2008; Fuhs et al., 2014; Nesbitt, Farran, & Fuhs, 2015). Researchers must further investigate the causal relationship of EFs and academic achievement, in order to understand if it is possible to improve academic achievement through the training of EF skills.

Conclusion

While there are still a number of gaps in the study of early childhood EFs, the current understanding allows for some insight into the neural and behavioral development of EFs, as well as its association with success. The most important aspect of EFs that needs to be addressed in studies is the nature of the EF structure in young children. Determining whether the subsets of working memory, inhibition, and cognitive flexibility are united or distinct in early childhood will inform other areas of EF research. Particularly, this knowledge will aid in the development of appropriate behavioral measurements in studies. Concurrent neuroimaging research will provide insight into the neural basis of EFs. The understanding of EF development is valuable in moving forward to further investigate the association between EFs and academic achievement.

Chapter 1 Appendix
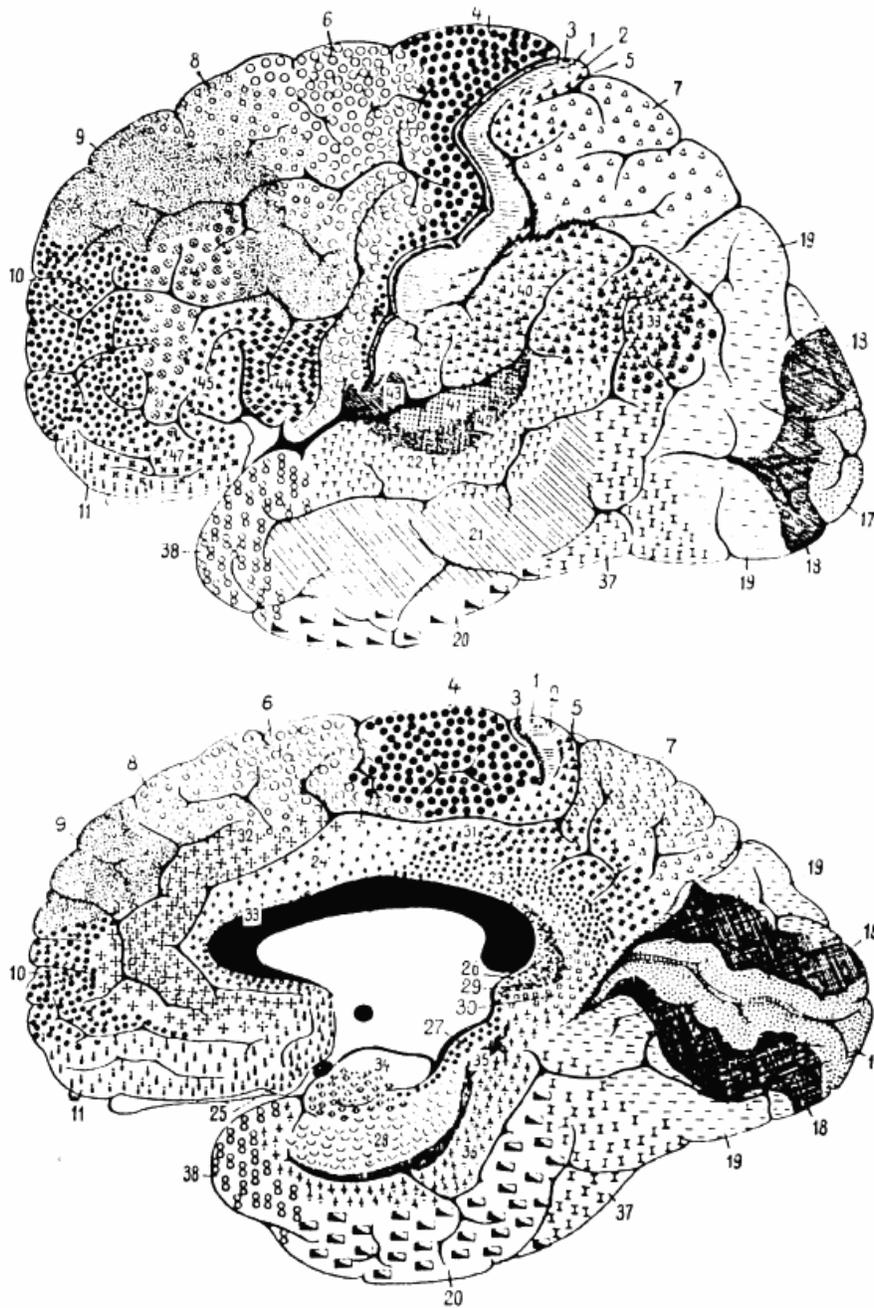
Figure 1. Lateral and medial views of the human brain numbered with Brodmann's areas. Listed here are brain regions associated with EFs and their general area based on the numbers for Brodmann's areas. Dorsolateral PFC- 9. Ventromedial PFC-medial parts of 10, 11, and 12; ventral parts of 24, 25, and 32. Orbitofrontal cortex-10, 11, and 47. Anterior cingulate cortex- 24 and 32. Insular cortex 24 and 31. Intraparietal cortex- 7. Image from (Brodmann, 1909). Areas from (Clark et al., 2008; MacDonald, 2000; Mosier, Liu, Maldjian, Shah, & Modi, 1999).

Chapter 2

Environmental and Biological Influences on Executive Functions

Introduction

External and internal factors affect the development of social behaviors and cognitive processes, including EFs. Environmental factors like the parent-child relationship, home environment, and quality of play are associated with EFs. Some aspects of children's environment influence their physiology, particularly the stress response, weight management, and gene expression. These biological factors affect EF performance through the hormones, neurotransmitters, and enzymes of the body. By understanding how these environmental and biological factors affect development, researchers will have insight into the mechanisms by which EFs develop and how they may be improved.

Environmental Factors

Factors like parent-child relationship, home environment, socioeconomic status, and unstructured time are integral components in the development of cognitive skills like EFs. The largest gap in the research of environmental factors related to EFs is that most studies are associational, meaning it is unclear whether one variable causes the other and if so, in what direction. Future studies need to address this issue in order to understand the aspects of an early environment that may cause harm to the development of EFs.

Parental Influences on Executive Functions

Parents have a large influence on children during the first few years of life. Parents may positively influence EF development by establishing a secure

attachment, providing verbal scaffolding, and being responsive. Negative caregiving styles and familial chaos are two factors negatively associated with EFs.

Attachment Security

Attachment theory is a well-recognized index of the emotional aspect of a parent-child relationship. A secure attachment forms when a child is confident in his or her parent's ability to provide safety and regulation. When a child is securely attached, they are comfortable and explore a new environment in the presence of a parent and become distressed when the parent leaves (Myers, 2007). In contrast, a child with an insecure attachment often clings to a parent and explores less in novel situations, and when the parent leaves, the child becomes upset or indifferent (Myers, 2007).

Social-emotional and cognitive development benefit from a secure attachment (Ding, Xu, Wang, Li, & Wang, 2014). For children between the ages of one and two, secure attachments predict greater EFs and self-regulation at an older age (Bernier, Beauchamp, Carlson, & Lalonde, 2015; Drake, Belsky, & Fearon, 2014; von der Lippe, Eilertsen, Hartmann, & Killen, 2010). However, the direction of causality is unclear. Children with higher EFs and self-regulation possibly encourage a more secure attachment from their parents because the children's behavior is easier to manage. Meanwhile, insecure attachment is one risk factor amongst many associated with the development of disorders like attention-deficit/hyperactivity disorder and autism spectrum disorders later in childhood (Bohlin, Eninger, Brocki, & Thorell, 2012).

Attachment security is mainly determined by environmental factors with a modest role of genetics, as demonstrated by a twin study (Bokhorst et al., 2003). This means that a child does not inherit a predisposition to have one type of attachment. Therefore, changing the parent-child relationship could promote a more secure attachment. In turn, the more secure attachment has the potential to improve the child's EFs.

Parental Scaffolding

Another aspect of the parent-child relationship is the way in which parents instruct and help their children work through problems. Scaffolding, a type of instruction, is when a caregiver supplements a child's immature cognitive abilities through guidance in solving an advanced problem without directly giving the answer (Hughes & Ensor, 2009; Landry, Miller-Loncar, Smith, & Swank, 2002). Maternal scaffolding predicts children's working memory at 18 months and their general EFs at four years (Bernier, Carlson, & Whipple, 2010; Hughes & Ensor, 2009).

Some researchers have investigated how parental scaffolding may support EF development. One theory posits that scaffolding has an indirect effect on EFs, because exposing the child to more complex language improves language skills important for EFs (Landry et al., 2002). Exploring this further by looking at the timing of scaffolding statements, Bibok et al. (2009) reached a different conclusion. When the scaffolding statements coincide with the actions and cognitive processes of the child, there was a stronger association between parental scaffolding and children's EFs (Bibok et al., 2009). When the instructional statements spoken did not coincide with the child's activities, there was not a significant association between parental

scaffolding and children's EFs (Bibok et al., 2009). In this situation, children are unable to connect the words to their thoughts and actions. This suggests children gain more when incorporating the given scaffolding of the parents with their current cognitive state, compared to when they just hear the elaborate guiding statements. With the current understanding, scaffolding is significantly associated with EFs and one way in which parents positively influence the development of their children's EFs.

Parental Control and Sensitivity

In a few ways, more universal aspects of the caregiving style are related to EFs. Paternal control, maternal negative affect, and limited physical stimulation are examples of negative caregiving and are associated with poorer EFs (Cuevas et al., 2014; Meuwissen & Carlson, 2015). In contrast, positive control through guidance in disciplining and limited assertion of power were best for aiding the development of self-regulatory behaviors (Karreman, van Tuijl, van Aken, & Deković, 2006). Studies found maternal sensitivity and responsiveness were related to inhibitory control in preschool aged children (Bernier et al., 2010; Linebarger, Barr, Lapierre, & Piotrowski, 2014; Lucassen et al., 2015).

Findings from Linebarger et al. (2014) suggest the effects of parental responsiveness and consistency differ by demographic risk. A cumulative analysis measured demographic risk on factors including maternal education, child's race/ethnicity, and socioeconomic status. Children at low-risk experienced benefits from responsive parents and negative consequences with inconsistent parents on their EF performance (Linebarger et al., 2014). Children at high-risk were only sensitive to

the negative influence of inconsistency (Linebarger et al., 2014). These studies demonstrate an association between EFs and parent's disciplining strategies and responsiveness, possibly affected by demographic risk.

Familial Chaos

Another possible influence on EFs is the stability of the home environment, where children spend the majority of their early years. Household noise, clutter, and unpredictability are features that define disorganized chaos and instability in the home. A chaotic home environment for preschoolers was associated with lower EFs, less developmental improvement in EFs, and poorer school readiness (Brown, Ackerman, & Moore, 2013; Hughes & Ensor, 2009; Vernon-Feagans, Willoughby, & Garrett-Peters, 2016).

Vernon-Feagans et al. (2016) suggest familial chaos affects children's EFs indirectly. The instability and disorganization distracts parents from their children, thus decreasing parental responsiveness (Vernon-Feagans et al., 2016). This unresponsiveness in turn has a direct negative impact on children's EFs, as described above (Linebarger et al., 2014; Vernon-Feagans et al., 2016). The association between familial chaos and EFs is separable from the influence of income (Brown et al., 2013).

Conclusion

Parents affect their children's development of EFs through a number of ways. Most important are those relating to the parent-child relationship, like attachment security, scaffolding, and responsiveness. While familial chaos affects EF skills, the effect is likely indirect through a weakened parent-child relationship.

Socioeconomic Status

Underlying many of the above environmental risk factors is familial

socioeconomic status (SES). Family income and parental education, indicators of

SES, are inversely related to the volume of neural structures related to cognitive

functions. Gray matter thickness and volume in frontal and parietal lobes, regions

associated with EFs, were smaller in children from low SES backgrounds (Hanson et

al., 2013; Lawson, Duda, Avants, Wu, & Farah, 2013). The volume of the

hippocampus and amygdala, structures associated with emotions and memory, were

also positively associated with SES (Jednoróg et al., 2012; Luby et al., 2013; Noble,

Houston, Kan, & Sowell, 2012). These neural structural differences related to SES

parallel EF behavioral differences. On EF tasks and executive attention and orienting

tasks, poorer performance was associated with lower SES (Ardila, Rosselli, Matute,

& Guajardo, 2005; Mezzacappa, 2004; Wanless, McClelland, Tominey, & Acock,

2011).

Other factors may explain the association between these biological and

behavioral differences and SES. Single parenthood, parental responsiveness, home

enrichment, and parental scaffolding mediate the relationship between familial SES

and children's EFs (Hackman, Gallop, Evans, & Farah, 2015; Lengua et al., 2014;

Sarsour et al., 2010). For children from a low socioeconomic background, there is an

increased risk for poor EFs due to a higher presence of these effects. Low SES

parents face challenges which may limit the time and resources they have available

for their children. Therefore, while there is an association between low SES and poor

EFs, this is most likely due to the moderation of environmental factors (Hackman et al., 2015; Lupien, King, Meaney, & McEwen, 2001).

Play and Unstructured Time

Children enter early childhood education, a structured environment, as EFs are still developing The benefits of structured versus unstructured time are under studied, but results indicate that pretend play is important for cognitive development in skills like theory of mind, problem solving, and linguistic complexity (Bergen, 2001). While unstructured time allows children to choose their own activities, and in the process practice EFs, children also need to be exposed to the concepts and structure that will follow later in school (Barker et al., 2014). Thus, educational practitioners and researchers face difficulties in deciding upon a beneficial balance of structured and unstructured time in early childhood education schedules.

Overall, studies demonstrate an association between play and executive function development. Lillard (2013) in a meta-analysis of correlational and experimental studies did not find strong support for a causal association between play and EFs. However, more recent studies identified a positive correlational relationship between child-directed play and EFs (Barker et al., 2014; Carlson, White, & Davis-Unger, 2014; Thibodeau, Gilpin, Brown, & Meyer, 2016). Imaginative play is related to the development of EFs, especially inhibition (Carlson et al., 2014; Kelly, Hammond, Dissanayake, & Ihsen, 2011; Thibodeau et al., 2016). During structured and unstructured play sessions, observations on children's symbolic understanding, or the ability to acknowledge the real and symbolic aspects of an object, were positively correlated with performance on a number of EF measures (Carlson et al., 2014; Kelly

et al., 2011).

Different aspects of pretend play may explain the improvements to EFs. For example, a child may practice self-distancing during role-playing in an imagination play scenario and this skill may be helpful in EF tasks. Self-distancing during EF tasks forces children to use different language to reach the solution and to remove any emotional components of the problem, which may disrupt the cognitive process. This theory is supported by the demonstration of children performing higher on EF tasks while role playing or thinking in third person (White & Carlson, 2015).

Another possibility suggests that during imaginary playtime children shift between reality and pretend, in both their roles, as well as the representation of objects (Carlson et al., 2014; Thibodeau et al., 2016). As a consequence, children and objects have their normal role and purpose in addition to new ones designed by the children. Children's connections between reality and pretend may practice cognitive control and shifting. Furthermore, a child is likely inhibiting their usual response in order to remain in character (Kelly et al., 2011). This practice would shape EFs, particularly inhibitory control. Findings from a randomized controlled trial support the theory that imaginative play practices EFs through holding dual representations. In the study, the fantastical-oriented play condition lead to the most improved performances on a battery of EF tasks compared to the non-imaginary pretend condition and the business-as-usual condition (Thibodeau et al., 2016). In fantastical-oriented play, children were encouraged to act out elaborate and non-realistic situations like using magic. This challenges EFs more than when they were told to do everyday actions like going to the grocery store or were not given additional time to

play.

The role of play time and more broadly, less-structured time when the child decides what to do, are associated with higher self-directed EFs (Barker et al., 2014). While it remains unclear what aspects of play enhance EFs, self-distancing and shifting between reality and imaginary are two processes which may affect development.

Conclusion

From parent-child relationships to structured time at school, aspects of children's environments are associated with EF performance. Secure attachment, maternal scaffolding at the right moments, and positive parenting style, especially through responsive behavior, are the main paths through which parents influence their children's EFs. In the home environment, familial chaos leads to distractions and may indirectly cause poor EFs. And while SES is associated with EFs, this association is likely caused by the higher prevalence of other risk factors. At school, unstructured time allows children to practice cognitive control, inhibition, and self-dissociation. All of these environmental factors add to the understanding of EF development, but more studies are needed to determine directions of causation.

Biological Factors

The interaction between the environment and biology is important to consider when investigating cognitive development. Hormones, neurotransmitters, and neural circuits within the body are precise in their functioning and sensitive to the external environment. Some of the environmental factors mentioned in the previous section

are associated with dysregulation of biological factors such as the stress response, obesity risk, and genetics. Research studying the physiological factors associated with EF deficits, as well as how the factors interact with early environments will add to the understanding of the development of EFs.

The Stress Response and Executive Functions

Certain environments mentioned above, like familial chaos, may cause stress to a young child, activating the stress response. Following this activation is a series of physiological events which impacts cognitive functions. Stress can be classified as acute or chronic, with similar physiological activations, but different consequences. An example of an acute stressor is seeing a snake a few feet away. This causes the body to shut down unnecessary information and activities, in order to best respond to the threatening situation. Chronic stress is common in the modern world, with causes like jobs with demanding workloads and limited social supports.

The physiological response to acute stress involves a number of components. When an organism is presented with a stressor, the hypothalamic-pituitary-adrenal (HPA) axis is stimulated (Hellhammer, Wüst, & Kudielka, 2009). The activation of the HPA axis causes the release of neurotransmitters and hormones, which focus attention on the stressor and increase cardiac output and breathing (Tsigos & Chrousos, 2002). As part of this process, adrenal glands release cortisol, a glucocorticoid (Herman & Cullinan, 1997). Measuring salivary cortisol levels is a valuable and non-invasive method used in studies to monitor the stress response (Hellhammer et al., 2009). In order to return the organism to a homeostatic level when the stress has passed, the medial prefrontal cortex (PFC) and the hippocampus

act to inhibit the stress response (Herman & Cullinan, 1997). These two brain regions have glucocorticoid receptors that respond to elevated levels of cortisol and start a negative feedback loop that diminishes the stress response (Ulrich-Lai & Herman, 2009). The medial PFC and hippocampus are integral components of the regulation of the stress response, in addition to other behavioral and cognitive tasks, such as visual memory and response inhibition (Catani, Dell'acqua, & Thiebaut de Schotten, 2013).

Chronic stress dysregulates the negative feedback loop with the inhibition of further production of cortisol. When an organism experiences chronic stress, the HPA axis becomes hypersensitive with elevated levels of glucocorticoids (Tsigos & Chrousos, 2002). While under acute stress, the glucocorticoids stimulate the negative feedback loop and inhibit further production of glucocorticoids, under chronic stress this does not happen (Ulrich-Lai & Herman, 2009). In fact, chronic stress causes the spine density of neurons in a rat's medial PFC to decrease (Radley et al., 2008). The spine density of neurons is reflective of the number of synapses a neuron has, with more synapses signifying greater development (Moser, Trommald, & Andersen, 1994).This finding may point to a mechanism in which chronic stress causes a neural change in the medial PFC, diminishing the inhibition component of the feedback loop and possibly affecting cognitive processes.

In studies on human adults, acute and chronic stresses cause different cognitive impairments. Acute stress can be induced by the injection of hydrocortisone or the presentation of a stressor, like the immersion of an arm in cold water (Lupien, Gillin, & Hauger, 1999; Schoofs, Wolf, & Smeets, 2009). Meanwhile, chronic stress is identified in individuals through measurements of basal levels of cortisol, with high

levels being associated with chronic stress (Ulrich-Lai & Herman, 2009). Under acute stress, working memory is impaired, while under chronic stress language, processing speed, verbal memory, and visual memory are impaired (Lee et al., 2007). Shields et al. (2015) explored this further by demonstrating an increase in cortisol immediately leads to a decrease in working memory performance and an increase in inhibition. This effect is reversed over time so that the constant activation of the stress response by high cortisol levels led to impaired inhibition and enhanced working memory (Shields et al., 2015). Researchers need to investigate the effects of chronic stress on cognition to reconcile these results.

Effects of elevated cortisol on mental tasks differed depending on the cognitive process measured. On EF tasks such as the letter fluency task and the Wisconsin Card Sorting Test, elevated salivary cortisol levels were associated with poorer performance (Hendrawan, Yamakawa, Kimura, Murakami, & Ohira, 2012; McCormick, Lewis, Somley, & Kahan, 2007). In contrast, performance on a mental rotation task was not impaired by chronic stress (McCormick et al., 2007). This suggests that the negative impact of high cortisol levels is selective towards cognitive functions that are more demanding of the PFC, like EFs (McCormick et al., 2007).

With the understanding of how cortisol affects EFs in adults, a few studies have investigated the relationship in children. These studies mainly focus on the association between childcare and cortisol. At home, young children typically experienced a decrease in cortisol levels throughout the day, while at daycare, cortisol levels typically elevated (Geoffroy, Côté, Parent, & Séguin, 2006; Watamura, Donzella, Alwin, & Gunnar, 2003). This effect was greater for children at poor

quality daycares (Geoffroy et al., 2006). Characteristics such as neglectful caregivers and less positive interactions between the children indicated poor quality programs (Geoffroy et al., 2006). In addition, children with difficult temperaments, such as negative affectivity and lower effortful control, exhibited a greater rise in cortisol levels (Dettling, Parker, Lane, Sebanc, & Gunnar, 2000). Meanwhile, children who played more with other children demonstrated lower levels (Watamura et al., 2003). Based on these results, socializing may affect cortisol, and children with agreeable temperaments at daycares encouraging positive peer interactions may have lower cortisol levels as a consequence.

Beyond childcare situations and children's temperaments, insecure maternal attachment, lower socioeconomic status, and higher reported parental stress are associated with elevated levels of cortisol in young children (Badanes, Dmitrieva, & Watamura, 2012; Ursache, Noble, & Blair, 2015; Wagner et al., 2015). The risk of higher cortisol levels and greater stress in certain environmental conditions may be a mechanism through which these factors affect EFs (Blair & Raver, 2012).

With regard to cognitive abilities in young children, cortisol levels are negatively associated with performance on EF tasks measuring selective attention and working memory (Blair et al., 2011; Wagner et al., 2015). Complicating the picture are the results from a study indicating that the association between cortisol and EF performance differed depending on family income (Obradović, Portilla, & Ballard, 2016). Obradović et al. (2016) found that high cortisol in children from high income families had greater EF skills, while children from low income families with high cortisol performed poorly on EF tasks. In children with lower cortisol levels, family

income did not affect EF performance (Obradović et al., 2016). These findings suggest that children with a stronger stress response who live in early adverse environments may be more sensitive to their enviornment, which impacts their EFs. Meanwhile, lower cortisol levels could act as a buffer for children in low-income families.

Stress, as measured by cortisol levels, affects the cognitive abilities of adults and children. Acute and chronic stresses have different effects on the cognitive processes. The level of cortisol in children is associated with daycare and demographic factors. These effects and associations have implications for young children and the development of EFs. Like with many relationships with EFs, the directionality between stress and EFs remains unclear. On one hand, greater EF skills might allow for a greater ability to respond to stress. On the other hand, more stress may cause poorer performance on EF tasks (Hendrawan et al., 2012). The direction of causality needs to be further investigated in order to understand the relationship between stress and EFs, especially in young children who are rapidly developing EFs.

Obesity and Executive Functions

The high prevalence of obesity in American children and adults, 16.9% and 34.9% respectively, is a major health problem, with diagnoses occurring in children as young as four (Anderson & Whitaker, 2009; Ogden, Carroll, Kit, & Flegal, 2014). A negative association exists between obesity and cognitive functions, especially inhibitory control (Guxens et al., 2009; Liang, Matheson, Kaye, & Boutelle, 2014). Since preschoolers are at an age when EFs are beginning to develop, the presence of

obesity in these children leads to concerns about the interaction between the two variables (Liang et al., 2014; Reinert, Po'e, & Barkin, 2013).

The physiology of obesity involves interactions between hormones, fat tissue, and regions of the brain dealing with memory and cognition (Miller, Lee, & Lumeng, 2015). In obese individuals, hormones that regulate metabolism become dysregulated (Miller et al., 2015). Leptin, one of these hormones, is heavily involved in eating behaviors and is related to higher order cognitive processes (Morrison, 2009). Among average adults, elevated leptin levels are associated with poorer performance on the Trail Making Test, an EF measure (Gunstad et al., 2008). Abnormally high levels of leptin are typically found in obese subjects (Considine, 2005). Therefore, the elevated leptin levels in obese individuals could explain their poor performance on attention and EF tasks (Gunstad et al., 2007).

Another physiological aspect of obesity involves structural brain differences. Compared to average adults, obese individuals have a number of neural differences, most notably, a decreased density of gray matter in the middle frontal gyrus, an area activated during EF tasks (Booth et al., 2003; Carnell, Gibson, Benson, Ochner, & Geliebter, 2012; Pannacciulli et al., 2006). The altered structure may impact the functionality of this brain region, impairing executive control.

Children, adolescents, and adults have a similar pattern of obesity being associated with poor EFs. When looking at children ages three to six, Pieper and Laugero (2013) determined no significant relationship exists between tests of eating in the absence of hunger, on the one hand, and EFs, on the other. In this study, a delay of gratification task, children's gambling task, Flanker task, and Dots task, as well as

parent and teacher reports measured EFs (Pieper & Laugero, 2013). From their

findings, the researchers suggested that emotional regulation, and not EFs, play a role

causing excessive eating in some children (Pieper & Laugero, 2013). In contrast to

these findings, children with either poor inhibitory control, emotional regulation, or

self-regulation at age two were more likely to be found overweight at age five

(Graziano, Calkins, & Keane, 2010). In support of this latter finding and in slight

opposition to Pieper and Laugero's findings, a recent meta-analysis demonstrated an

overall negative relationship between weight and inhibition in children and

adolescents (Liang et al., 2014). Furthermore, four year olds who scored poorly on

the EF subset of a general cognitive test were at a greater risk to become overweight

at age six (Guxens et al., 2009). The inverse relationship, in which the BMI at four

years of age predicted cognitive function at six years old, was not found to be

significant (Guxens et al., 2009). These findings suggest that low EFs may temporally

precede, and possibly cause, obesity.

Complicating the relationship, EF and obesity share some common risk

factors like SES and insecure attachment (Anderson & Whitaker, 2011; Bernier et al.,

2015; Guxens et al., 2009; Hackman et al., 2015). Most of the association studies

controlled for these related risk factors (Graziano et al., 2010; Guxens et al., 2009).

However, one study did not control for related risk factors and could strengthen the

results by including the factors in the analysis (Pieper & Laugero, 2013).

The behavioral evidence above shows an association between obesity,

emotional regulation, and EFs in early childhood. But, the causality remains unclear.

In typical adults elevated levels of leptin negatively impacted performance on EF

tasks (Gunstad et al., 2008). Yet, in children EFs predicted BMI, but the reverse relationship was not found (Guxens et al., 2009). While the first study suggests that obese related factors like leptin cause cognitive impairments, the second study suggests that poor EFs may cause the development of obesity. Further complicating interpretation of results are shared risk factors, which need to be consistently controlled for in analyses. More studies are needed to further investigate the relationship between obesity and EFs since obesity is a prevalent problem with numerous health issues. Depending on the direction of causation between obesity and EFs, targeting one may be a way to improve the other.

Genetics and Executive Functions

Researchers are conducting studies on gene- environment interactions to understand how genetic modification may occur in early childhood and the consequences on behavior and cognition. During development, genes and experiences work together to shape the personal characteristics and physiological aspects of an individual (Myers, 2007). With regard to EFs, the interaction of the gene catechol-O-methyltransferase (COMT) and early childhood environments influence performance on EF tasks.

Neurotransmitters are fundamental to the proper functioning of the brain, and their dysregulation leads to deficits on cognitive functions. Dopamine (DA) and norepinephrine (NE), two types of catecholamines, are neurotransmitters necessary for correct functioning of the prefrontal cortex (Arnsten & Li, 2005). In rhesus monkeys, depletion of DA and NE cause cognitive deficits almost as severe as the complete removal of the frontal lobe (Brozoski, Brown, Rosvold, & Goldman, 1979).

Humans with less DA and NE show cognitive deficits in set-shifting and attention, while humans with less NE have deficits in response inhibition and reversal learning (Logue & Gould, 2014). At moderate levels, catecholamines allow for proper PFC functioning, but high or low levels cause cognitive impairments (Arnsten & Li, 2005). This optimization at moderate levels is described by an inverted "U" shape (Blair et al., 2015).

The enzyme COMT, which has been associated with attention-deficit/hyperactivity disorder, degrades catecholamines (Eisenberg et al., 1999). A functional single nucleotide polymorphism of COMT, Val158Met (rs4680), changes the structure of the enzyme slightly leading to either more or less efficiency (Mier, Kirsch, & Meyer-Lindenberg, 2010). The three possible genotype variations are Val/Val, Met/Val, and Met/Met. Studies mainly focus on the first and last genotypes due to the greater difference in enzyme activity between the two. Val/Val is the more efficient form of COMT, causing lower levels of DA in the medial PFC, while Met/Met works at a slower rate leaving greater amounts of DA (Blair et al., 2015; Mier et al., 2010). Additionally, studies identified structural differences in the cortical thickness of frontal and temporal gyri and the maturity of white matter (Shaw et al., 2009; Thomason et al., 2010). The different genotypes, which at a biological level change the amount of DA available, are associated with differences in behavioral and cognitive functioning.

In adults and children, there is a cognitive and affective trade-off between the genotypes, in which the Met/Met genotype enhances cognitive skills, while the Val/Val genotype provides greater emotional stability (Papaleo et al., 2008). Studies

demonstrate that individuals with Met/Met perform better on tasks related to attentional control and higher order processes (Blasi et al., 2005; Bruder et al., 2005). Meanwhile, those with Val/Val have greater cognitive flexibility, social skills, and control under emotional distraction (Bishop, Cohen, Fossella, Casey, & Farah, 2006; Colzato, Waszak, Nieuwenhuis, Posthuma, & Hommel, 2010; Hoth et al., 2006). In children ages 7 to 14, greater performance on an EF task was associated with Met/Met, while the stress response was better regulated by those with Val/Val (Armbruster et al., 2012; Diamond, Briand, Fossella, & Gehlbach, 2004).

Only a few studies have looked at the effect of these genotypes in children younger than seven. Findings showed that the risk of the child's environment, measured by maternal education, family income and prenatal maternal stress amongst other factors, moderates the effect the genotype has on cognitive functions (Blair et al., 2015; Thompson et al., 2012). Greater EF development and less risk for behavioral problems was associated with children exposed to high-risk environments who had the Val/Val genotype (Blair et al., 2015; Thompson et al., 2012). These findings suggest that Val/Val has a protective effect for young children in early high-risk environments. The studies did not investigate the impact of the genotype on emotional and stress management abilities.

The more efficient variation of COMT (i.e., Val/Val) is associated with more beneficial outcomes in high-risk environments. This effect could be explained by a shift in the optimal functioning range of the catecholamine system. In this situation, the Met/Met genotype does not clear enough DA, while Val/Val removes DA at a rate that benefits cognitive functions. The shift of the optimal range could be caused by an

increase in catecholamine levels. The enzyme efficiency with Val/Val would bring the catecholamine levels back to the ideal range. Or the shift could be due to an altered sensitivity of the receptors in the neural circuit so that they respond more easily to the neurotransmitters and thus need less catecholamines in the system (Blair et al., 2015). Future studies will need to determine which these theories explains the benefits of Val/Val.

In early adverse environments, Val/Val has a protective effect on cognitive and behavioral outcomes, while Met/Met does not provide the same cognitive benefits seen in typical adults and children. This gene x environment risk factor related to EFs can guide researchers to an understanding of how a genetic predisposition may affect the development of EFs.

Conclusion

Through different biological mechanisms, stress, obesity, and genetics are associated with EFs. Understanding how acute and chronic stress impact the body through the release of cortisol may explain the mechanism in how early stressful environments impact EF development. Obesity may influence cognitive functions through leptin or be caused by poor self-regulation. In addition to these situational or induced physiological states, genetics also play a role in EFs. This is particularly evident in early high-risk environments where some children can be disproportionately affected due to a genetic predisposition. These identified relationships between biological factors and EFs are often moderated by the environment and demonstrate the importance of understanding the effect physiological differences may have on developing cognitive processes.

Conclusion

Investigations of biological and environmental risk factors, as well as the interaction between the two, lead to a greater understanding of the development of EFs. Many environmental factors influence or are associated with the biological factors. For example, low SES is associated with elevated basal cortisol levels and higher obesity rates (Chung et al., 2015; Lupien et al., 2001). Therefore, a possible explanation for the association between the environmental factors and EFs is that the environment causes physiological changes which impact EF development. For many of the environmental and biological factors the direction of causality remains unclear. Either EFs cause these factors to develop or EFs are the result of these factors. If researchers can address this limitation by conducting studies to identify the direction of causality, then they can create methods to negate the impact of these risk factors.

Chapter 3

Executive Function Interventions in Early Childhood

Introduction

Behavior, cognition, and the brain are all malleable. Bad behavioral habits can be lost through conscious effort, new cognitive strategies can be learned, and the brain can change during development and learning through neural plasticity. Because of these abilities, EFs can be changed throughout life. In fact, researchers are finding new strategies to improve EF skills. Greater long-term benefits on academic and life outcomes make intervening on EFs earlier in childhood a priority. Interventions can affect EF development in different ways. One method addresses risk factors like parenting and obesity in order to minimize the effects these have on children's EFs. Other interventions focus on the EF subsets working memory and inhibition, with mixed success. Finally, researchers developed a number of well-known interventions implemented in schools with the intention to improve school readiness or EFs.

Interventions Addressing Risk Factors

A few early childhood interventions target risk factors associated with poor EFs. Studies measuring the outcomes of these interventions demonstrate mixed results on the improvement of EF skills. The programs develop more positive home and classroom environments or encourage physical activity in children. The goals of the interventions were not to directly impact EF development; nevertheless, they may indirectly influence EFs by diminishing negative risk factors.

Home and Classroom Environments Interventions

Interventions address home and classroom environments through parental and teacher training. Programs with parents led to positive outcomes on EF-related risk

factors and behaviors, however further measurements are needed to determine the effect on EFs. By helping foster parents improve the children's attachment security, cortisol levels in the children were normalized (Dozier, Peloso, Lewis, Laurenceau, & Levine, 2008). Since attachment security is positively associated with EFs and dysregulated cortisol levels are negatively associated with EFs, the intervention may improve children's abilities to self-regulate. In another example, over eight weeks training sessions with parents coincided with attention exercises for the children (Neville et al., 2013). As a result, children improved in language skills and social behavior (Neville et al., 2013). In addition, researchers found changed neural activity in response to attending stimuli (Neville et al., 2013). While EFs were not measured in either of these studies, improvements in attachment security, cortisol levels, language skills, and social behavior may impact EF performance.

With either mixed parent and teacher programs or only teacher programs, two interventions found positive effects on children's behavior and school readiness. Parent and teacher training workshops increased the amount of positive parenting, decreased the use of harsh disciplining from parents and teachers, and encouraged stronger interactions between parents and teachers (Webster-Stratton, Reid, & Hammond, 2001). The main outcome of this intervention was a decrease in children's conduct behavioral problems (Webster-Stratton et al., 2001). An additional intervention used an online program to work on teacher development in preschool classrooms. The quality of teaching and classroom environment benefitted from the intervention (Landry, Anthony, Swank, & Monseque-Bailey, 2009). In addition,

children in the intervention classrooms scored higher on school readiness tests (Landry et al., 2009).

While these parent and teacher interventions did not measure EFs, there were positive improvements on risk factors for EF deficits and related behaviors. More research needs to be done to determine how these parent and teacher trainings affect children's EFs.

Exercise Interventions

With evidence showing the negative association between obesity and EFs, some interventions use exercise as a means to promote physical fitness and cognitive development. Studies in older children identify neural and behavioral changes as positive outcomes of interventions incorporating physical activity (Davis et al., 2011; Kamijo et al., 2011). Aerobic exercises for 13 or 36 weeks with average weight and overweight children ages seven to eleven resulted in improvements in working memory and general EF skills (Davis et al., 2011; Kamijo et al., 2011). Overweight children participating in the exercise program demonstrated increased activity in the prefrontal cortex and decreased activity in the posterior parietal cortex during EF tasks in fMRI scans (Davis et al., 2011). These results suggest that the children shifted towards greater use of more mature cognitive control regions of the brain. Six year olds who participated in a PE class that maximized exercising time had significant improved performances on the working memory portion of the Cambridge Neuropsychological Test Automated Battery compared to the children in the normal PE classes (Fisher et al., 2011). The results from these interventions indicate that exercise may improve cognitive functioning in young children.

For future studies on interventions for exercise and EFs, researchers should identify possible differences between the effects of sports and running (Best, 2010). Sports and games necessitate the practicing of EFs in order to keep in mind the goal of the game. In contrast, running strictly has a physiological effect without practicing cognitive processes. Differentiating between these two types of exercise would illustrate whether EFs benefit from exercise because of additional EF practice or physiological changes. Either way, small benefits and changes to EF skills, related behaviors, and neural circuits make exercise an important component of an EF intervention.

Conclusion

These interventions targeting children's environments or exercise may have an indirect effect on EFs by addressing the risks often associated with poor EFs. These studies found positive effects on behaviors which may be related to optimal EF functioning. Yet, with many of the interventions for parents and teachers, EFs were not measured. As a result, it is unclear whether or not targeting home and classroom environments affected EF performance. For exercise interventions, future studies need to identify which component of the program— games practicing EFs or physiological changes— influence EF performance. These interventions demonstrate effective methods in targeting EF risk factors, and possibly influencing EF abilities. Of these two types of intervention programs, the ones addressing the home and classroom environments may have a larger impact because they provide safe and supportive places for children to continue practicing their EFs.

Interventions on Individual Subsets of Executive Functions

For older children, particularly those diagnosed with attention-deficit/hyperactivity disorder (ADHD), a number of interventions target either working memory or inhibitory control. These programs are founded on the theory that these two subsets of EFs share a common neural circuitry, and thus, the benefits from training one skill will transfer to the other skill.

After training subjects on a set of cognitive tasks, researchers analyze the results to find evidence supporting two types of transfer effects. The near-transfer effect refers to greater performance on non-trained tasks measuring the same cognitive process as the trained task. The far-transfer effect refers to improvement on non-trained tasks measuring related cognitive processes to the one trained. For example, in some of these programs, individuals trained on a working memory task (Liu, Zhu, Ziegler, & Shi, 2015). Then, during the post-tests, individuals completed tasks testing similar working memory skills, to measure near-transfer, and to tasks testing inhibitory control or math, to measure far-transfer. Working memory and inhibitory control intervention studies provide feedback on the optimal method for improving these cognitive skills and add to the understanding of the EF structure.

Working Memory

Cogmed, a computerized program used to improve working memory, is directed towards schools and children with ADHD (Shipstead, Hicks, & Engle, 2012). A number of studies investigate the efficacy of this program. In children between the ages four and twelve with and without ADHD, studies found evidence for a near-transfer effect, such that training improved performance on non-trained

tasks for visuospatial and verbal working memory (Holmes et al., 2009; Holmes & Gathercole, 2014; Klingberg et al., 2005; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009).

The effect of the training on far-transfer was mixed. Older children with ADHD improved on the Stroop task, which measures inhibition, while typical preschoolers did not (Klingberg et al., 2005; Thorell et al., 2009). Children around the age of ten who underwent the program had improved performance on mathematics months after the program ended (Holmes et al., 2009; Holmes & Gathercole, 2014). Although, one of these studies limited the training to children initially beginning at a low academic level and used controls which may not account for confounding variables (Holmes & Gathercole, 2014). As a result, it remains unclear if the intervention would be for children with other academic standings. It also remains unclear whether other effects were not accounted for due to the use of flawed controls. Nonetheless, positive results suggest the possibility for far-transfer, but researchers need to conduct further studies.

Other limitations also could have impacted the studies. These studies either consisted of a homogenous SES population or did not control for SES. Moreover, the training programs were short, often less than 25 sessions (Holmes et al., 2009; Holmes & Gathercole, 2014; Klingberg et al., 2005; Thorell et al., 2009). If the studies were longer in duration, the effect on related cognitive processes may be stronger. Despite these limitations, the results suggest that training in working memory leads to improved performance on related working memory tasks, but has limited success on related executive tasks.

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A study training preschoolers with two working memory tasks and not Cogmed, found improved working memory on the backward word span task, without transfer to inhibitory control or cognitive flexibility (Blakey & Carroll, 2015). The effect on working memory persisted for three months after the ending of training, and at this time math ability was greater for the trained group (Blakey & Carroll, 2015). These results support findings from the Cogmed studies, in which working memory training has near-transfer effects, but limited far-transfer effects.

Inhibitory Control

A few interventions attempt to train inhibitory control in children. Two of the studies mentioned above trained inhibitory control jointly with working memory, finding minimal improvements in inhibitory control (Blakey & Carroll, 2015; Thorell et al., 2009). In training kindergarteners on a tablet game similar to a typical Go/No-Go task, Liu et al. (2015) found improved performance on the training game, but not on related inhibition tasks or working memory tasks. The lack of strong positive findings suggests a challenge in training inhibitory control which has not been addressed or an inability to train this subset of EFs.

Conclusion

A few reasons possibly explain the lack of near or far transfer in inhibitory control interventions alongside more successful working memory interventions. For continued growth in a cognitive skill, a task needs to continuously challenge individuals to push them beyond their current level (Thorell et al., 2009). Working memory tasks can do this by increasing the number of items held in mind, but increasing the challenge in inhibition tasks is more difficult. Furthermore, in a

working memory task, this cognitive process is continuously required to maintain and manipulate information. Inhibition is required for brief periods to inhibit a response during tasks. As a consequence, over a span of minutes, working memory is regularly used, but inhibition is needed for only small spurts of time. This limitation on time spent using inhibition restricts the practice of this skill, and thus could explain the resulting minimal effects of training. While inhibition training was not as successful, working memory trainings had near-transfer effects and possible far-transfer effects to math and inhibition. Further studies need to explore these relationships.

Interventions for Improving School Readiness and Executive Functions

Researchers have developed a number of interventions with the aim to promote school readiness or EFs. Through trainings with teachers or by directly working with children, these interventions generally have a positive effect on the students. Many of the studies investigating the effectiveness of these interventions are conducted with a low-income population. As a result, the generalizability of some of the findings is limited. Another problem involves the lack of follow-up studies, which are necessary to identify long-term benefits of an intervention. Despite these limitations, the following interventions have promising results on improving children's school readiness and EFs.

Providing Alternative Thinking Strategies

Providing Alternative Thinking Strategies (PATHS) is a school based program aiding in social-emotional development in order to reduce behavioral problems (Kusché & Greenberg, 1994). Through training sessions and weekly help

from coaches, second and third grade teachers taught a PATHS lesson three times a week for a school year (Riggs, Greenberg, Kusché, & Pentz, 2006). Results indicated a positive effect of the intervention on the ability to verbalize emotions, the main goal of the program (Greenberg, Kusche, Cook, & Quamma, 1995). With regard to effects on EFs and behavior, the PATHS program positively influenced inhibitory control and verbal fluency development (Riggs et al., 2006). These in turn moderated the effect of the intervention on externalizing and internalizing behaviors (Riggs et al., 2006).

The measurements used by this study limit the interpretation of the results. Inhibitory control was measured only by the Stroop task (Riggs et al., 2006). Meanwhile, the teachers, who were not blind to the treatment, subjectively reported observed behaviors (Riggs et al., 2006). More measures of inhibition and less objective measures for behavior would strengthen the findings.

The results from PATHS are promising for intervening on child development, especially in the social-emotional skills and EFs. The improvement on verbal fluency may help in EF performance by providing more mature language skills to verbalize and work through problems. Therefore, future studies on PATHS need to find correlations between the intervention and other EFs. In addition, follow up studies will identify any long lasting benefits. The PATHS program demonstrates how a social-emotional intervention can impact EFs. In addition, these results demonstrate that social-emotional interventions should include EF development activities to use the moderating effect EFs have on behavior.

Research-Based Developmentally Informed (REDI)

Bierman et al. (2008) incorporated PATHS into a school readiness program called Research-Based Developmentally Informed (REDI). Implemented in Head Start preschool classrooms, REDI added the social-emotional program to a reading program with the goal to improve literacy and self-regulation (Bierman et al., 2008). The intervention led to small positive effects on two EF measures, the Dimensional Change Card Sort and task orientation, as well as improved behavior for those children starting with poor behavior (Bierman et al., 2008). These improvements partially mediated the effect of the program on literacy and social-emotional progress (Bierman et al., 2008).

One year after completing the REDI program, researchers found continued positive effects on children's literacy abilities, engagement, social problem solving, and overall behavior (Bierman et al., 2014). Some of these outcomes differed in children attending high versus low quality kindergartens. For example, a decrease in aggressive behavior was more significant for children who went through the program and were in low quality kindergarten classrooms (Bierman et al., 2014). This finding suggests that follow-up studies should recognize possible effects kindergarten quality might have on long-term outcomes. Furthermore, if the quality of schooling following the program affects outcomes, interventions should consider how to continually work with children to ensure lasting effects.

When a home-visit training program for parents was added to the REDI program, there were improvements in children's literacy skills, self-direction, social competence, and teacher-reported academic performance beyond the effect of the

basic program (Bierman, Welsh, Heinrichs, Nix, & Mathis, 2015). In further analysis, this study found the level of parent engagement, as measured by home observations of the quality of parental use of provided home materials, affected children's outcomes (Bierman et al., 2015). Meanwhile, the number of home visits, indicative of the amount of training parents received, was irrelevant to child outcomes (Bierman et al., 2015). Therefore, parents who may not have time for extensive training programs may still provide benefits to their children if they are active and engaged in applying the tools taught in the program. This has implications for future interventions with parent programs because parental engagement over parental attendance should be encouraged to maximize the benefits of the program.

PATHS and REDI are low cost interventions that impacted social-emotional behaviors, led to small improvements in EFs, and promoted academic growth, especially in literacy. Further studies need to investigate the long-term benefits of PATHS and the effects of the program on more EF measures.

Tools of the Mind

One of the few interventions focused primarily on EFs, Tools of the Mind, uses 40 EF activities to promote development over the school year (Bodrova & Leong, 2007). The goal of the intervention is for preschoolers to construct their own knowledge as teachers encourage dramatic play and provide scaffolding for self-regulation skills (Barnett et al., 2008). These goals are achieved with minimal teacher training. Children in the program increased their performance on inhibition, working memory, and attentional control tasks (Blair & Raver, 2014; Diamond, Barnett, Thomas, & Munro, 2007). One year later, children who went through the program

had significantly higher reading and vocabulary scores compared to controls, while the effect of the program on math abilities was reduced (Blair & Raver, 2014). Attempts to replicate these findings in large samples were unsuccessful, and in fact found negative effects on outcomes (Farran & Wilson, 2014; Wilson & Farran, 2011). Researchers proposed possible explanations for these results. First, teachers face difficulties in including the complex curriculum within the time of a typical preschool day, possibly affecting the amount and quality of material taught (Farran & Wilson, 2014). Second, there may be a problem with the theoretical model of teacher-mediated activities leading to children development (Farran & Wilson, 2014).

Results from studies investigating Tools of the Mind are contradicting in the effect of the program on academic and EF outcomes. Further studies are needed to replicate the efficacy of this program.

Chicago School Readiness Project

The Chicago School Readiness Project (CSRP) focuses on teacher development in order to indirectly affect children's outcomes. Through workshops and weekly coaching support from mental health consultants, Head Start teachers enriched the classroom environment (Raver et al., 2008, 2009). The support allowed teachers to improve the quality of teacher-child relationships (Jones, Bub, & Raver, 2013). This in turn mediated the impact of the intervention on children's EFs, as measured by performance on a number of EF tasks (Jones et al., 2013; Raver et al., 2011). Then, as a consequence of higher EFs, children performed higher on academic and behavioral outcomes (Jones et al., 2013; Raver et al., 2011).

The outcomes of the intervention were dependent on teachers' attendance, such that teachers who attended more workshops and received more help from the mental health consultants ran classrooms more beneficial to children (Zhai et al., 2010; Zhai, Raver, & Li-Grining, 2011). In a follow up study, greater academic and behavioral achievements were found in children who went to a high quality kindergarten after completing CSRP (Zhai, Raver, & Jones, 2012). This finding supports the theory mentioned in PATHS, which stated interventions might have differential long-term effects depending on the quality of the following schools.

Studies on CSRP provide evidence for the success of an intervention improving children's EFs, academics, and behaviors through the support of teachers. This intervention is costly in resources and time, but the outcomes are positive. If costs were reduced and the outcomes remained the same, CSRP would be a promising intervention for widespread use in classrooms.

Circle Time Games

Another intervention designed to support EFs is the Circle Time Games. The preschool intervention challenges EF skills through engaging musical games over 16 sessions (Tominey & McClelland, 2011). The sessions were led by a researcher who removed a small group of children from the classroom to run the games (Tominey & McClelland, 2011). The results from the study found no significant gains on EFs for the overall group, but those children with low initial scores had significant gains by the end of the intervention (Tominey & McClelland, 2011). On academic tests, children in the program performed higher on letter word identification, but not applied problems or vocabulary (Tominey & McClelland, 2011). Investigating the

results further, Tominey and McClelland (2013) found that children who initiated off-task behavior during the circle time sessions were more likely to be in the low regulatory group in the spring. This group, as well as imitators of off-task behavior, were more likely to be in Head Start, a low income program (Tominey & McClelland, 2013). This finding suggests a possible mechanism through which children of low SES experienced less gains in the program (Tominey & McClelland, 2011). Moreover, this additional analysis of behavior demonstrates how quantitative notes of children's behavior in interventions may add to a deeper understanding of the results.

Another study implemented the intervention in only Head Start programs (Schmitt, McClelland, Tominey, & Acock, 2015). There were significant effects on EF tasks like Head-Toes-Knees-Shoulders and Card Sorting, but not on teacher reports or academic measures (Schmitt et al., 2015). Future studies need to reconcile the contradicting results between the studies. In addition, follow up studies will demonstrate any long-lasting effects. Nonetheless, this intervention may impact children's EFs and academic outcomes.

Play-based Training

A more recent intervention used a 12 session play-based training in classrooms of a disadvantaged region of Italy (Traverso et al., 2015). Through stories presented to a small group of kindergarteners, trained psychologists encouraged group cooperation to overcome challenging activities (Traverso et al., 2015). These activities were part of stories and required the use of EFs to solve. On a battery of EF tasks, the children in the program outperformed the controls on most inhibition and

working memory tasks, as well as on one cognitive flexibility task (Traverso et al., 2015).

This study should be repeated in the United States to determine if the results could be replicated here. In addition, classroom teachers, rather than trained psychologists, should implement the intervention in order to determine the effectiveness of incorporating the program into a typical school day. If these two conditions result in positive outcomes, the play-based training could be an effective low-cost intervention used in classrooms.

Conclusion

These school-based interventions have a number of positive outcomes, but studies need to use more comprehensive measurements to determine the full impact of the programs. The use of multiple EF measures, blind observers for behavior assessments, follow-up measures, and tests for moderation will provide a greater understanding of the short-term and long-term effects of these interventions. Other considerations for future studies include the effect of schooling quality following the intervention. Findings from CSRP and PATHS demonstrate differential long-term effects of the intervention depending on the quality of school in the year following (Bierman et al., 2014; Zhai et al., 2012). Some findings indicated that children who were lowest achieving at the beginning, improved the most over the course of the program (Tominey & McClelland, 2011). This aspect should be considered in analyses and further investigated. While researchers need to conduct more studies on these interventions, the results are promising.

Conclusion

The various interventions related to EFs have different intentions, measures, and outcomes. With positive outcomes from many of the interventions, future studies need to focus on the effects interventions have on EFs. Parent and teacher interventions lead to improvement in behaviors that are risk factors for EF deficits, demonstrating the ability to change parenting through training. The next step will be to determine if these changes impact children's EFs. There were small benefits to EF skills with exercise interventions. Researchers need to continue investigating these types of interventions to determine whether more time practicing EFs or physiological changes explain the outcome. Interventions targeting working memory were successful for near-transfer of improvements, but not far-transfer. Inhibition was not significantly improved during training. These results suggest that targeting specific subsets of EFs is not the most beneficial approach to EF interventions.

PATHS, Tools of the Mind, CSRP, Circle Time Games, and the play-based training showed positive outcomes on behaviors and cognition, but did not consistently measure EFs. Tools of the Mind, Circle Time Games, and the play-based training were the only ones to target strictly EFs in their intervention. Moving forward, researchers need to identify which part of these interventions have the largest impact on EFs in order to focus the interventions. While these interventions target behaviors, researchers need to address or acknowledge factors like stress and genetics which may cause biological limitations to the improvement of EFs.

Conclusion

Research on EF structure in early childhood is needed to clarify the most important concept of EFs. Without identifying the best model for the structure of EFs, measurements will be limited in their ability to fully capture EF behavior. This in turn affects all other studies exploring EFs in children. Beyond affecting measurements, establishing the EF structure informs the development of interventions. If EFs are composed of subsets, evidence suggests that working memory, but not inhibition, may be trained (Blakey & Carroll, 2015; Thorell et al., 2009). However, if EFs are a united process, an intervention should focus on activities that incorporate multiple EF skills. Furthermore, if hot and cool EFs are distinguishable, children will need to learn how to control thoughts and behavior in affective and abstract contexts.

Although a relatively cheap and child-friendly brain imaging technique, fNIRS is unlikely to be used as a common diagnostic tool. However, studies with fNIRS will illustrate the neural maturation process paralleling cognitive and behavioral changes of EFs. Knowing the neural regions associated with EFs may identify shared neural circuits with biological risk factors like obesity and stress, thus explaining how deficiencies or alterations in EFs or biological factors cause changes to the other. Insight from these studies and studies investigating the interactions between environmental and biological factors may lead to understanding the mechanism by which the environment shapes EFs. fNIRS studies may not have direct practical applications, but will influence education and research by enhancing the understanding of EF development and related factors.

Future studies on EFs should consider a few aspects. First off, until more standardized measures are implemented, a battery of tasks measuring EFs will allow for more comprehensive results. Cognitive performance lab tests on EF subsets and observational behavioral notes in the classroom capture a variety of EF skills, and are necessary for a well-rounded view of children's abilities. Secondly, studies should control familial income levels since this factor moderates children's EF performance (Ardila et al., 2005; Mezzacappa, 2004; Wanless et al., 2011). Thirdly, in intervention studies the treatment should be randomized by classroom. Children in an EF program may have effects that spillover into the classroom environment, such that improving children's EFs leads to a higher quality classroom environment compounding the positive effects of the program. Finally, researchers should consider recording behavioral data in the process of completing a lab task or during the intervention. If children use different strategies to complete a task, this may suggest a mechanism by which development happens. In interventions, children's outcomes may be affected by their behavior during the intervention (Tominey & McClelland, 2013).

A fundamental area researchers need to explore is the direction of causation in the relationship between EFs and academic success. If EFs influence academics, then by emphasizing and improving EF skills in early childhood education, there is potential for positive effects on academic success. Low-cost interventions improving EFs and school readiness could be widely implemented in preschools with numerous benefits. These interventions are especially important for children from low-income families who are more likely to have lower self-regulation and academic achievement (Hair, Hanson, Wolfe, & Pollak, 2015; Wanless et al., 2011). Since EFs may mediate

the relationship between income and academics, improving these skills in low SES populations may decrease the academic achievement gap that exists between SES groups (Raver et al., 2011).

A comprehensive EF intervention needs to work on children's EF skills directly through training activities and consider environmental and biological factors which may limit the effectiveness of the program. Firstly, if children's cortisol levels remain elevated due to the stress at home, the children will gain fewer benefits from the intervention since the cortisol affects their cognition. Therefore, an intervention should include a component that supports parents in minimizing stress at home. Secondly, interventions improving parent-child interactions illustrate an additional route to support EF development (Bierman et al., 2015; Neville et al., 2013; Webster-Stratton et al., 2001). By helping parents create an environment in which children are supported in practicing their EFs, greater benefits may be seen from the intervention. Thirdly, if children exposed to early high risk environments have the protective genotype Val/Val for COMT, they may improve more on EFs than children who have the Met/Met genotype. Understanding how genetics may affect children's basic cognitive skills will inform individual limitations on intervention effects and possibly open up an area of research directed towards identifying a way to promote positive effects in those without the protective genotype.

Studies demonstrate the long-term positive outcomes of attending preschool, but there is no evidence yet suggesting that EF trainings will have similar long-term effects (Campbell et al., 2002; Muennig et al., 2011; Schweinhart et al., 2005). If EF interventions lead to higher EFs in adulthood, the benefits would be extensive.

Beyond academic success, EF skills are associated with mental health, quality of life, job success, and public safety (Diamond, 2013). Even if EFs of children who participated in an intervention scored no differently from control children years after the program, the benefit of greater school readiness and early academic outcomes would have lasting benefits. By starting off with the EF skills that better prepare them for academics, children will be set on a higher trajectory through school and experience better life outcomes.

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