Cognition, Emotion & Education
CEE

Executive Function and Learning Outcomes: A Systematic Review

Raziyeh Bahri Roudposhti[1*], Taqi Al Abdwani[2]
[1]Ferdowsi University of Mashhad, Iran, [2]Gulf College, Oman

Abstract Executive functions of the brain as a suite of cognitive skills implemented to perform cognitive processes, especially during education, have been of great interest in recent years. Considering this issue, there has been a bulk of investigations on the role of executive function on academic achievement at school and earlier times through childhood. In this systematic review paper, a history of existing literature on different studies on the relationship between executive function and its prominence in learning excellence and the ways to improve it effectively was compiled and debated. This study found noteworthy executive functions such as working memory manipulation, planning, task switching, attention shifting, inhibitory control, and cognitive flexibility experienced while engaging in different activities. Furthermore, the paper examined the debatable role of socioeconomic status and bilingualism in executive function. Finally, different intervention programs were reviewed and discussed to enhance the brain's executive functioning.

Keywords: *Executive function, Academic achievement, Intervention programs, Cognition, Attention*

1. Introduction

Executive function (EF) skills refer to a gamut of cognitive functions: Reasoning, planning, problem-solving, and life management. There are connections between and influences from activities across many different brain areas promoting these activities (Blair, 2017). EF is required for almost all of our daily activities to be performed adequately (Snyder et al., 2015). Working memory, inhibitory control, and cognitive flexibility are the "Executive Functions" (EFs) that allow us to make plans in advance time, prevent impulsive or tempting behaviors, keep focus, reason, solve problems, adapt flexibly to changing needs or priorities, and view the world from novel and distinct angles (Diamond & Ling, 2016). The growth and development of EF skills commence in early childhood and typically extend until early adulthood, as they become progressively effective and efficient (Zalzo & Carlson, 2020). Children's development of EF profoundly affects their behavioral, cognitive, social, and mental skills. Recognizing the formation of these processes during development enables a thorough assessment of EF in this demographic (McKenna et al., 2017).

https://doi.org/10.22034/cee.2024.191024

***Corresponding Author:**
Raziyeh Bahri Roudposhti
rzhbahri@yahoo.com

Received: November 2023
Revised: January 2024
Accepted: February 2024
Published: February 2024

Recent years have seen an upsurge in the investigation of early childhood EF. The basic premise of many of these studies is that the development of EF is an outcome of several domain-general component processes (e.g., shifting, inhibitory control, and updating of working memory). This point of view has shaped our knowledge of the connections between EF and other facets of development, the environment's effect on EF's development, and the best methods to help children who struggle with it. Nonetheless, there are conceptual and empirical arguments against this interpretation of EF. It is more precise to describe the development of the EF as the formation of control-using abilities by particular goals. One study proposes that children do not just automatically adopt an inhibitory process they can use in various contexts. On the contrary, they acquire the ability to use control in specific ways to achieve particular goals, like not hitting a playmate who steals one of their toys. These abilities might be affected by a variety of factors, such as recognizing what it is like to be hit by someone and being aware of the hurt that others may cause, adhering to ethical values about refraining from injuring others, being aware of socially acceptable alternatives to hitting, having the social skills necessary to retrieve a toy without hitting, thinking that hitting could result in reprimands, and more (Doeble, 2020).

EF skills have also received much attention among the various factors contributing to the socioeconomic status (SES)- achievement gap, owing to their significance in facilitating the development of academic skills (Waters et al., 2021). Since academic achievement and EFs have a strong connection, providing specialized EF training might assist students in learning and acting with greater efficiency.

Nevertheless, the history of cognitive approaches in EF training intervention to attain academic achievement has taken a peculiar turn despite the proliferation of research on EF in the clinical population. Many interventions are available for young children and adolescents, but a comprehensive study on the effectiveness of these training programs still needs to be done. The objective of the current review is 1) to review the existing literature on EFs within the last decade, 2) to tie together all forms of eclectic EF training, along with the impact these interventions have on various cognitive processes, including bilingualism and reading/math comprehension and finally 3) to discuss the effectiveness of these interventions.

2. Development of Executive Function in Children

A brief overview of the evolution of EF skills from the viewpoint of developmental social-cognitive neuroscience was provided by Zelazo and Carlson (2020), who also remarked on the significance of experience on the normal and atypical development of the brain systems that underpin these skills. Considering this research, EF abilities are a basis for academic achievement and vital for learning arithmetic and solving math problems. Further research showed that EF skills can be acquired via scaffolded training and that the efficacy of interventions can be increased by training both hot (more emotional) and cool (more cognitive) EF skills, reducing disruptive bottom-up influences like stress, and including a reflective, metacognitive element that fosters far transfer of learned skills. The study had significant applications for children in danger of not finishing school. It also raised the possibility that interventions that target EF skills in the context of math education may help decrease socio-economic gaps in school success.

Additionally, the case of EF has been reinforced by the richness and diversity that the developmental period offered. Children's development of EF profoundly affects their behavioral, cognitive, social, and emotional capacities. Understanding the construction of these processes during development allows the efficient assessment of EF in this demographic. The aim of the meta-analysis done by McKenna et al. (2017) was to expand knowledge about the structure of children's EF. This meta-analysis was carried out, incorporating studies that used functional magnetic resonance imaging (fMRI) to assess children (ages 6 to 18) on tasks related to inhibition, shifting, and working memory updating. The neural activation shared by tasks was connected just to inhibition, shifting, or updating—tasks frequently thought of as basic executive processes, and it was contrasted with the activation shared by all executive tasks. The findings confirmed that inhibition, shifting, and updating are partially distinct but partially overlapping brain processes in children older than six.

Furthermore, there was a range of overlap between the shared neural activity across all tasks (linked to a hypothesized "unitary" component of EF) and the activation associated with each distinct executive

process. These results lent credibility to the idea that children of this age can benefit from applying one of the most prominent structural models of executive functioning in adults. The results also recommended that this population's particular executive processes and unitary EF must be carefully investigated and measured.

Along with the other investigations, a systematic developmental paradigm that recognized the integrative nature of children's EF was called for. The paradigm results revealed that a structural model of EF, which proposed several distinct processes and one provided underlying mechanism, could be used during development. Nevertheless, based on recent behavioral results, inhibition appeared unlikely to be separated from the common process. Furthermore, updating and switching seemed distinct when thinking about adolescents and children. However, it was possible for these processes to be converged in children. Therefore, a new systematic developmental model might be required considering the complexity of development and the shifting structural climate of EF throughout childhood (Brydges et al., 2014; Howard et al., 2015; Lerner & Lonigan, 2014). Careful measurements of both common and process-specific components should be fostered by the EF model (McKenna et al., 2017).

3. Socioeconomic Status: The Financial State of the Family Changes EF

Given their importance in fostering the development of academic skills (Nouraey et al., 2023; Sadeghi Ordoubadi et al., 2023), EF skills have drawn much attention among the several factors influencing the SES-achievement gap. While recent research indicates that global EF components affect SES-achievement links, investigating the precise roles played by individual EF components in the connection between SES and achievement has received less attention. The NICHD Study of Early Child Care and Youth Development data was examined to determine the direct and indirect connections between preschool EF skills, first-grade math and reading achievement, and SES indicators. Working memory and parent education were revealed to be the most distinct and predictive factors of both achievement domains using path analysis. Additionally, only working memory regulates the connection between parent education and children's math achievement after adjusting for baseline academic skills, verbal aptitude, and other child- and family-level factors. These results thoroughly examined the precise mechanisms by which children's socioeconomic disadvantage affects their growth in school and serve as a first step in developing more exact goals for programs and policies meant to close the achievement gap (Waters et al., 2021).

Evidence suggests that compound measures of EF, which can be obtained by averaging children's performance across different EF tasks or creating a latent EF variable, were employed in most studies. These analytical techniques help evaluate the general connections between EF and kids' performance results. Still, they cannot evaluate possible special impacts. The relevance of assessing their effects independently is emphasized by evidence of differential predictions among essential EF skills to children's accomplishments (Ahmed et al., 2019; Nguyen & Duncan, 2019). A single sign may predict EF, achievement, or both. However, previous studies have only used compound measures of SES. According to Davis-Kean et al. (2019), parent education and family income have specific impacts on children's development and should be modeled individually to compensate for their respective contributions to children's achievement and EF. Merely a small number of these studies integrated control variables into their analysis, like demographic traits or additional cognitive components (Jacob & Parkinson, 2015).

To further probe into culture as a contributing factor in SES development, while it frequently comes to light that children of immigrants from East Asia function better academically than children born in North America, little is known about the social-cognitive variables contributing to this discrepancy. It is possible that variations in academic achievements between East Asian and North American cultures could be caused by variations in EF, given the significant role of EF for academic achievement and evidence that EF matures more quickly in East Asian cultures than in North American cultures. This possibility was investigated by reviewing data revealing cultural variations in EF development, but it was found that the fundamental ideas and findings were limited in several important ways. To overcome these limitations, a framework was provided by Cho et al. (2023) that connected EF, culture, and academic achievement. This framework was based on novel theoretical concepts regarding the nature

of EF and how it relates to social context. Initially, the framework outlined a theoretically feasible mechanism by which interactions with others impacted children's EF, a crucial barrier in defining social factors that affect children's cognitive growth. It accomplished this by replacing the more traditional componential model of EF with a control skills characterization of EF. The main drawback of the componential view of EF was that contrary to popular practice-based interpretations of the causes of cross-cultural differences in children's EF, there was minimal empirical evidence for the far-transfer impacts of training core EF components (e.g., working memory, inhibitory control, and shifting; Kassai et al., 2019; Shepard et al., 2023).

Second, the proposed model differentiated between the roles performed by social and cultural effects on EF. Social impacts were defined as the characteristics and conduct of caregivers, such as parents and instructors, and they immediately impacted children's capacity for self-control. In contrast, cultural influences related to the larger framework of standards and beliefs surrounding caregiver-child relationships facilitated the relationship between social factors and children's EF. Given this, the model might consider data indicating that, based on the child's cultural background, the same class of parental attitudes and behaviors—authoritarian parenting—might have distinct connections with different outcomes (Pinquart & Kauser, 2018). Although it was hypothetical, it had not been directly examined if culture affected the relationship between parental behaviors and children's EF as predicted by the model. Indeed, because there is a shared expectation in collectivist cultures that children ought to live up to family expectations, some researchers have proposed that Asian-American parents find it easier to teach their kids values related to academic achievement and a strong work ethic (Hsin & Xie, 2014). For a culture to be understood in proper cultural contexts, it is determined that culture is an ensemble of values and beliefs that children and caregivers share (Cheung & Lim, 2022; Huang & Gove, 2015). The model had merit in that it enabled an understanding of how social influences affect children's EF and incorporated findings regarding potential cultural differences in the psychological interpretation of specific socialization practices. This was made possible by the model's two distinct entities: Social influences as a variable affecting children's EF and culture as the moderating factor between social influences and children's EF (Cho et al., 2023).

4. The Role of EF on Math/Reading Comprehension

In the context of a different urban student population, Gerst et al. (2017) investigated the relationships between the two methods of measuring EF—cognitive vs. behavioral rating concerning reading comprehension and math calculations in fourth and fifth-grade students. The working memory, planning, inhibition, and shifting measures showed only moderate connections to each other, while there were more significant connections with academics. Even in pertinent covariates (age, language, and educational program), EF scores were associated with both academic outcomes. Across all test types, working memory was particularly crucial for reading comprehension. In particular, working memory evaluations based on behavior and cognitive assessments from all EF processes—especially inhibition and planning—were significant for math. They found evidence supporting the significance of these EF components for reading comprehension. To be more precise, (a) updating assists readers in understanding what they are reading by keeping relevant data active in working memory; (b) inhibition helps readers understand what they are reading by suppressing the activation of irrelevant text information and avoiding irrelevant information from escaping into memory; and (c) shifting allows readers to understand what they are reading by integrating conceptual and phonological knowledge while reading and by flexibly distributing attention to text features and reading strategies. Second, it was shown that, despite the data confirming EFs' critical involvement in reading comprehension, EFs have not been explicitly included in most renowned process models of reading comprehension.

Later, Follmer (2018) conducted a meta-analytic study to evaluate the connection between reading comprehension and EF. The research results supported a moderately beneficial connection between reading comprehension and EF. Moderator analyses revealed that while correlations between reading comprehension and EF differed according to the type of EF examined in the studies, they did not vary systematically by age range, type of reading comprehension measure used, or whether the study was published as an article or a dissertation. Before this study, Jacob and Parkinson (2015) also performed a systematic review in which they evaluated the relationship between EF and math and reading

achievement amongst students, and the evidence confirmed a causal relationship between the two. The review, which employed meta-analytic techniques, concluded that no firm evidence exists of a causal relationship between EF and achievement. Still, it finds a moderate unconditional association between the two independent of EF construct, age, or measurement type. There was no difference in the relationship between EF and math or reading achievement when they utilized an overall assessment of EF instead of just its subcomponents. When the associations were examined individually for each subcomponent, it was found that working memory and attention shifting were not as significantly correlated with EF and math achievement as attention control and inhibition were.

5. Bilingualism: An Unverified Contributing Factor in EF

Research concerning how bilingualism benefits children's cognitive development—particularly EF—was reviewed by Bialystok (2015). The goal of reviewing studies that indicated bilingual benefits in a variety of tasks was to pinpoint the mechanism or EF component that may be in charge of this bilingual advantage. She pointed out that when it came to examinations analyzing their knowledge of abstract language structure, bilingual children performed better than monolingual ones in most cases. Nevertheless, the findings had unexpected implications since it turned out that these metalinguistic benefits were mainly constrained to tasks including conflict and the need for control to handle it. Consequently, the apparent bilingual advantage in metalinguistic ability was attributed more to cognitive ability than to language processing.

The findings of the review by Bialystok (2015) suggested the possibility that being bilingual affects one's degree of attention to the surroundings. The infant is made aware of the distinctions between the systems by introducing two sets of sounds, cadences, structures, speakers, and facial expressions in two languages. Unlike similarity, contrasts offer novelty, which demands more attention and may require advanced processing. Therefore, bilingual infants might just be more aware of subtle environmental changes. If so, these techniques enhance attentional processing while contributing to constructing a more complex representational structure encompassing two languages. Once two representational structures are developed, the EF is used to sustain attention to the target language.

In light of the previously stated, Campfield (2021) also stated that bilingual children's superior cognitive task performance might be attributed to their enhanced EF proficiency, particularly compared to their monolingual peers. It is speculated that this results from the depth and breadth of their language surroundings. Academic achievement, general well-being, and happiness constitute some of the key strategies that are used in many international studies on EF. The primary focus is on studies of the bidirectional relationship of EF and L2, as well as causality, with the notion that individual childhood characteristics help individuals become better L2 learners, and that early exposure to L2 affects EF in a lasting way.

To put it into examination, Sullivan et al. (2014) performed many EF tasks on two groups of participants at the university level. A nonverbal Go/No-Go task was one of the tasks. Two groups of students participated in year-long courses: One for Introduction to Psychology and the other for Introduction to Spanish. There were no differences between the students in the two groups following the first testing session; however, the ERP figures for the Spanish students were higher following the second testing session. Consequently, the waveforms of L2 learners varied from those of students attending a first session, even though there were no changes between learners at the behavioral level. An earlier investigation (Moreno et al., 2014) generated similar results, exhibiting waveform variations between monolingual and bilingual participants and demonstrating that the electrophysiology of bilinguals was consistent with superior performance. In fact, after just one week of intensive language instruction, some studies have shown improvements in cognitive functioning (Bak et al., 2016). These studies, therefore, confirm that (a) variations in cognitive processes can be witnessed even in the absence of behavioral data (behavioral differences); (b) even a slight amount of experience in L2 learning may lead to these variations; and (c) these variations occur in both child and adult learners who's been exposed in a limited time to instructional settings.

On the other hand, some investigations suggest no distinctions between mono and bilingual participants, even though neuroimaging results show differences in brain activation and behavioral studies reveal

higher bilingual performance. In a relatively large sample of around 4,524, 9–10-year-olds across the country, Dick et al. (2019) showed that there is barely any proof of a bilingual advantage for key EF skills, including inhibitory control, attention, and task switching, or cognitive flexibility. They additionally confirmed the limitations in English vocabulary previously documented in bilinguals. However, when individual differences in socioeconomic class or IQ are taken into consideration, the discrepancies in the English vocabulary are significantly reduced. Despite the widely recognized benefits of obtaining a second language in childhood, there is not much evidence that it contributes to the development of EF.

Moreover, as noted by Paap et al. (2015), after 2011, over eighty percent of tests for bilingual benefits included null results, and the vast majority of those that reported a significant bilingual advantage usually featured small sample sizes. The use of more robust baselines or evaluations of the significant interaction might avert group differences in specific published studies demonstrating significant bilingual advantages. Certain beneficial findings might have resulted from inconsistencies regarding demographic variables, while other findings might have only produced noteworthy variances when the analysis of covariance was deceptively applied to "correct" these variables. Direct replications are not often used, but when they are, the findings of important studies are irreplicable. Furthermore, substantial performance differences may reflect task-specific strategies rather than domain-free EF abilities, as most studies examining bilingual benefits use measurements and tasks lacking recorded convergent validity. Only a small amount of information has been obtained from brain imaging studies to assess the bilingual advantage hypothesis, mainly due to the neural differences not matching the behavioral differences and often undetermined neural measures regarding whether much bigger magnitudes should result in higher or lower performance. The combined impact of typical research procedures and confirmation biases has either led to the belief in a phenomenon that does not exist or overestimated the frequency and effect size of an actual event that is most likely to occur relatively seldom and in restricted and undetermined circumstances.

6. Intervention Programs: A Path to Enhance EF

Since academic achievement and EFs have a strong connection, it has been suggested that implementing specialized EF training could help students learn and behave in a goal-directed manner in the classroom. However, there is inconsistent proof of training programs' long-term and transferable effects (Simons et al., 2016). A CanDiD framework was established by Kamkar et al. (2017) to reconsider EF and its connections to education. Branded as CanDiD, the framework highlighted the significance of Development and Individual Differences (DiD) as well as the Contextual and Dynamic components of EF (CanD). A trio of presumptions constituted its foundation. EF is dynamic and sensitive to environmental factors to start. Insofar as development limited the newly formed dynamics and contextual factors operating EF, development was more than practice. Third, EF depended primarily on individual differences. These presumptions had special consequences for considering the connection between EF and the classroom and were based on cognitive and neurophysiological investigations of EF and its development.

Notably, most cognitive and neurophysiological theories neglect the fact that EF is dynamic by nature. A broad spectrum of intrinsic (i.e., external to the child) and extrinsic (i.e., internal to the child) factors can affect interference suppression, working memory, and cognitive flexibility, which may end up in a consistent and systematic change in these processes' efficiency over a brief amount of time. The nature and complexity of this variability are vital to the function of cortical networks, even those that are supposedly linked to EF. This variability occurs dynamically over short periods (Hutchison & Morton, 2015; Medaglia et al., 2015; Nomi et al., 2016). One of the intrinsic factors generating dynamic distinctions in EF's efficacy is the body's innate circadian rhythm. An ancient 24-hour cycle of arousal, the circadian rhythm is regulated by a neuroendocrine circadian clock. The circadian rhythm is endogenous or self-regulating, although it is habituated to the outside environment by light and temperature, among other factors. EF is affected by circadian rhythm-linked daily fluctuations in arousal (Zou et al., 2022). These effects seem exclusive to cognitive processes demanding effort, like EF. In fact, the most appropriate periods for an individual's circadian cycle are when implicit or effortless forms of memory retrieval work best. In contrast, explicit or tedious forms function best

during non-optimal times. Together, these data suggest that endogenous processes dynamically alter thinking styles throughout a 24-hour period, with effortful and automatic thought processes dominating during "optimal" and "non-optimal" circadian times, respectively (Kamkar et al., 2017).

The main goal of EF training is to boost the capacity to achieve real-world goals like academic success or far transfer. While numerous training courses for EFs have successfully enhanced EFs, far transfer is more challenging to achieve (Sala & Gobet, 2020). In a study published in 2021, Gunzenhauser and Nückles investigated the relationship between academic achievement and EF training. They started by sorting out potential causes of transfer issues. They proposed that learning-related behaviors and cognitions are the two distinct mechanisms that Fs may facilitate academic achievement. According to Duckworth et al. (2019), students may be able to exhibit these targeted learning-related actions without significantly focusing on their EF skills if they have already developed strong preference habits (such as finishing their homework every day after lunch).

On the contrary, it is believed that any EF intervention to improve performance ought to target the particular EF skill essential for the academic achievement that is being targeted in real life. For example, bull and Lee (2014) attempted to correlate EFs with particular curriculum topics in mathematics. In this regard, they proposed that learning to cope with fractions would require a solid grounding in inhibitory control since students would need to suppress the notion that larger numbers imply larger quantities. They also rely on the learner's prior knowledge. A detailed examination of reading comprehension can show how previous information impacts executive functioning. According to Richter and Maier (2017), reading comprehension can be viewed as a two-step model that consists of a strategic, intentional processing mode and a passive, automated monitoring process. As a result, there may be two possible results from prior knowledge regarding the significance of EFs to effective learning.

On the one hand, effective use of EFs might demand a certain amount of prior knowledge. For example, readers should be able to eliminate irrelevant or misleading concepts and activate relevant, expedient ideas in their long-term memory to address comprehension problems when reading a text. However, a wealth of well-structured prior knowledge may lessen the strain on EFs during the learning process, as robust knowledge schemas will enable the reader to understand a significant amount of the text through automatic processing.

Furthermore, a standardized intervention can only target several particular task types. Interestingly, the training effects may cease once the intervention ends (Blair et al., 2018). Incorporating continuous scaffolding of EF applications into the teaching setting is a possibility of moving beyond a one-time boost and dealing with real-life demands in every school subject. Educators should receive training on conducting an adequate (i.e., not overly time-consuming) cognitive task analysis. This would enable them to stay focused on the demands placed on students' EFs when creating instructions and assignments (e.g., whether a task necessitates working memory manipulation, task switching, or multistep plans; Gunzenhauser & Nückles, 2021).

Upon recognizing the requirement for EF, a teacher can also decide to approach these details as redundant extraneous cognitive load and attempt to minimize them (Diamond & Ling, 2019). It can be done by offering word problems without complicated and enticing situational backgrounds) or employ it as an avenue for students to practice coping mechanisms for inhibitory control difficulties (e.g., by warning about the potential trap of being misled by irrelevant details; Eitel et al., 2019). Classroom-based training on handling demands on EFs in academic tasks is unlikely to systematically increase the difficulty or complexity of demands on specific EF components, compared with particular systematic EF training (Gunzenhauser & Nückles, 2021). Therefore, while it may contribute to the real-world objective of assisting students in using their EF skills for better learning and achieving academic success, it might not lead to steady improvements in cognitive tasks developed to measure certain EF components.

According to previous studies, there is a correlation between academic achievement and a family's low SES, as reflected by the children's poor academic scores. This discrepancy extends throughout the lives of children and starts in preschool. EFs are believed to be integral to the SES-achievement gap; hence, prioritizing EF development at an early age is essential to minimizing the detrimental consequences of

poverty. In line with the notion that higher EFs may foster school preparation and decrease school failure, a teacher-led program titled "Put your EF glasses on" was employed in a quasi-experimental study to increase children's EFs. Through strong teacher-student interactions, EF-supporting activities (such as games), and a positive learning atmosphere, the program aimed to increase children's EFs. This quasi-experimental pilot study allocated Teachers and students into experimental and control groups. While teachers in the control group practiced teaching as normal, teachers in the experimental group performed the program (getting materials and coaching to assist with implementation). All teachers answered the BRIEF-P, a questionnaire about everyday problems with executive functioning in preschoolers, both before and after the training session. They evaluated the impact of the classroom curriculum on EF problem scores in children from middle-class to upper-class backgrounds. The results of the study showed that compared to middle-to-high-SES children, all low-SES children had considerably greater baseline ratings for EF issues (total problem score, working memory, inhibition, and planning and organizing). Children from lower socioeconomic backgrounds exhibited progress in the program. In particular, there was no program effect on the regulation of emotions and inhibition, but EF components (total problem score, working memory, shifting, and planning and organizing) stayed consistent over time in the low-SES group in the experimental group. Children from low-SES families encountered more EF issues in the control group, expanding the gap between them and children from middle-to-high-SES families. The program had little effect on children from middle-to-high-SES families. The findings highlighted the potential benefits of a teacher-mediated classroom program for EF development, especially among toddlers at sociodemographic risk (Kellens et al., 2023).

Considering the fact that usually, a great deal of practice on abstract lab-based activities is acquired, these interventions result in gains on these practiced tasks. Interventions, however, rarely result in outcomes like academic achievement and hardly increase performance in activities that are not practiced. According to modern theories of EF development, social, historical, cultural, and personal environments influence how EFs develop and are used. Abstract exercises designed for the lab should not be anticipated to provide broad advantages outside the lab since they fail to reflect the real-world circumstances in which EFs are required accurately. Niebaum and Munakata (2023) suggested a viewpoint for comprehending individual differences in performance on EF assessments that focuses on contextual influences on EFs. Rather than explicitly teaching EFs, they extended this contextual approach to training engagement with the EF. Initially, task content that is related to the intended objective should be included in interventions. Second, rather than explicitly teaching EFs, interventions should encourage their participation through contextual relevance and reinforcement, as this may have a bigger effect on real-world results. Given the number of resources devoted to strengthening EFs, they hypothesized that interventions focused on encouraging children's engagement with EFs have a greater chance to influence real-world outcomes than those aimed at increasing EF capacities, even though such individualized interventions do not address systemic factors that significantly influence outcomes like academic achievement.

7. Concluding Remarks

Notwithstanding a wealth of literature on academic achievement and its contributing factors, this systematic review stands apart in that it concentrates on various studies with different viewpoints on EFs over the past ten years. To give an exhaustive overview of the subject, this study also took into account and adopted a range of samples and research investigations conducted in various countries. This review emphasized the EFs and allowed for an assessment of the diversity of the variables associated with academic achievement. Contrary to the preschool or secondary education stages, the primary education stage obtained less research interest; the university level received the most research. Although the use of numerical grades dropped, the number of measures of academic achievement based on competencies has grown in the studies. This is because numerical grades are believed to be a more precise measure of learning (Pascual et al., 2019).

A growing number of research investigations are employing neuroimaging methods, such as ERPs (Event-Related Potential) and EEG, to assess the impacts of various contributing factors, such as SES and various interventions, on multiple components of the brain's EF system. However, they still fail to be thorough enough to address all variables linked to the EF. Furthermore, the growth of EF is an

incremental procedure that could be bothersome to participants for being under assessment and also challenging to track over the years. The fact that it was attainable to confirm that EFs, rather than the degree of intelligence, have been the most investigated variable about academic achievement over the past ten years and that both at present have the same predictive potential is an important result. The review's findings corroborate the multifaceted nature of EFs and show that working memory is the most studied and accurate predictor of these functions. It has been found that most of the executive components are more strongly correlated with mathematical performance than with language in the case of bilingualism. The papers reviewed endorse the idea that EFs can be broken down into distinct components (working memory, inhibition, cognitive flexibility, and planning) that are specifically associated with specific learning styles, even though there is always controversy over classifying EFs as a domain-general cognitive variable.

As the last word, this review has seen a major limitation across the studies as it was revealed that the outcome of executive functioning enhancement is primarily measured in academic achievement in the form of numerical scores received by the students. Despite being the most accurate, these scores would not indeed be a great representative of the student's EF skills. Therefore, finding an alternative path to measure academic achievement could be better due to greater EF.

Disclosure Statement

The authors claim no conflict of interest.

Funding

The research did not receive any specific grants from funding agencies.

References

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology*, *111*(3), 446–458. https://doi.org/10.1037/EDU0000296

Bak, T. H., Long, M. R., Vega-Mendoza, M., & Sorace, A. (2016). Novelty, challenge, and practice: The impact of intensive language learning on attentional functions. *PLOS ONE*, *11*(4), e0153485. https://doi.org/10.1371/JOURNAL.PONE.0153485

Bialystok, E. (2015). Bilingualism and the development of executive function: The role of attention. *Child Development Perspectives*, *9*(2), 117–121. https://doi.org/10.1111/CDEP.12116

Blair, C. (2017). Educating executive function. *Wiley Interdisciplinary Reviews. Cognitive Science*, *8*(1–2), e1403. https://doi.org/10.1002/WCS.1403

Blair, C., McKinnon, R. D., & Daneri, M. P. (2018). Effect of the tools of the mind kindergarten program on children's social and emotional development. *Early Childhood Research Quarterly*, *43*, 52–61. https://doi.org/10.1016/J.ECRESQ.2018.01.002

Blankenship, T. L., Slough, M. A., Calkins, S. D., Deater-Deckard, K., Kim-Spoon, J., & Bell, M. A. (2019). Attention and executive functioning in infancy: Links to childhood executive function and reading achievement. *Developmental Science*, *22*(6), 1–9. https://doi.org/10.1111/desc.12824

Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014). The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis. *Intelligence*, *47*, 34–43. https://doi.org/10.1016/J.INTELL.2014.08.010

Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives*, *8*(1), 36–41. https://doi.org/10.1111/CDEP.12059

Campfield, D. E. (2021). Cognition and second language experience: How are executive function and second language acquisition related? In J. Rokita-Jaśkow, & A. Wolanin (Eds.), *Facing diversity in child foreign language education* (pp. 17-37). Springer. https://doi.org/10.1007/978-3-030-66022-2_2

Cheung, H. S., & Lim, E. (2022). A scoping review of Singapore parenting: Culture-general and culture-specific functions of parenting styles and practices. *Infant and Child Development*, *31*(4), e2312. https://doi.org/10.1002/ICD.2312

Cho, I., Hosseini-Kamkar, N., Song, H. J., & Morton, J. B. (2023). Culture, executive functions, and academic achievement. *Frontiers in Psychology*, *14*, 1100537. https://doi.org/10.3389/fpsyg.2023.1100537

Davis-Kean, P. E., Tang, S., & Waters, N. E. (2019). Parent education attainment and parenting. In M. H. Bornstein (Ed.), *Handbook of parenting: Biology and ecology of parenting* (3rd ed., pp. 400–420). Routledge/Taylor & Francis Group. https://doi.org/10.4324/9780429401459-12

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Diamond, A., & Ling, D. S. (2019). Review of the evidence on, and fundamental questions about, efforts to improve executive functions, including working memory. In J. M. Novick, M. F. Bunting, M. R. Dougherty, & R. W. Engle (Eds.), *Cognitive and working memory training* (pp. 143–431). Oxford University Press. https://doi.org/10.1093/OSO/9780199974467.003.0008

Doebel, S. (2020). Rethinking executive function and its development. *Perspectives on Psychological Science*, *15*(4), 942–956. https://doi.org/10.1177/1745691620904771

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., & Gross, J. J. (2019). Self-control and academic achievement. *Annual Review of Psychology*, *70*, 373-399. https://doi.org/10.1146/ANNUREV-PSYCH-010418-103230

Eitel, A., Bender, L., & Renkl, A. (2019). Are seductive details seductive only when you think they are relevant? An experimental test of the moderating role of perceived relevance. *Applied Cognitive Psychology*, *33*(1), 20–30. https://doi.org/10.1002/ACP.3479

Follmer, D. J. (2018). Executive function and reading comprehension: A meta-analytic review. *Educational Psychologist*, *53*(1), 42–60. https://doi.org/10.1080/00461520.2017.1309295

Gerst, E. H., Cirino, P. T., Fletcher, J. M., & Yoshida, H. (2017). Cognitive and behavioral rating measures of executive function as predictors of academic outcomes in children. *Child Neuropsychology*, *23*(4), 381–407. https://doi.org/10.1080/09297049.2015.1120860

Gunzenhauser, C., & Nückles, M. (2021). Training executive functions to improve academic achievement: Tackling avenues to far transfer. *Frontiers in Psychology*, *12*, 624008. https://doi.org/10.3389/fpsyg.2021.624008

Howard, S. J., Okely, A. D., & Ellis, Y. G. (2015). Evaluation of a differentiation model of preschoolers' executive functions. *Frontiers in Psychology*, *6*, 123033. https://doi.org/10.3389/FPSYG.2015.00285/BIBTEX

Hsin, A., & Xie, Y. (2014). Explaining Asian Americans' academic advantage over whites. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8416–8421. https://doi.org/10.1073/PNAS.1406402111

Huang, G. H. C., & Gove, M. (2015). Confucianism, Chinese families, and academic achievement: Exploring how Confucianism and Asian descendant parenting practices influence children's academic achievement. In M. Khine (Ed.), *Science education in East Asia: Pedagogical innovations and research-informed practices* (pp. 41–66). Springer. https://doi.org/10.1007/978-3-319-16390-1_3

Hutchison, R. M., & Morton, J. B. (2015). Tracking the brain's functional coupling dynamics over development. *Journal of Neuroscience*, *35*(17), 6849–6859. https://doi.org/10.1523/JNEUROSCI.4638-14.2015

Jacob, R., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research*, *85*(4), 512–552. https://doi.org/10.3102/0034654314561338

Kamkar, N. H., & Morton, J. B. (2017). CanDiD: A framework for linking executive function and education. *Frontiers in Psychology*, *8*, 1187. https://doi.org/10.3389/fpsyg.2017.01187

Kassai, R., Futo, J., Demetrovics, Z., & Takacs, Z. K. (2019). A meta-analysis of the experimental evidence on the near- and far-transfer effects among children's executive function skills. *Psychological Bulletin*, *145*(2), 165–188. https://doi.org/10.1037/BUL0000180

Kellens, S., Dieusaert, F., De Wilde, J., Spilt, J. L., & Baeyens, D. (2023). The impact of an interaction-based classroom program on executive function development in low-SES preschoolers: First support for effectiveness. *Frontiers in Education*, *8*, 1149977. https://doi.org/10.3389/feduc.2023.1149977

Lerner, M. D., & Lonigan, C. J. (2014). Executive function among preschool children: Unitary versus distinct abilities. *Journal of Psychopathology and Behavioral Assessment*, *36*(4), 626–639. https://doi.org/10.1007/S10862-014-9424-3/METRICS

McKenna, R., Rushe, T., & Woodcock, K. A. (2017). Informing the structure of executive function in children: A meta-analysis of functional neuroimaging data. *Frontiers in Human Neuroscience*, *11*, 154. https://doi.org/10.3389/fnhum.2017.00154

Medaglia, J. D., Satterthwaite, T. D., Moore, T. M., Ruparel, K., Gur, R. C., Gur, R. E., & Bassett, D. S. (2015). *Flexible traversal through diverse brain states underlies executive function in normative neurodevelopment*. *Quantitative Biology > Neurons and Cognition*. https://arxiv.org/abs/1510.08780v1

Moreno, S., Wodniecka, Z., Tays, W., Alain, C., & Bialystok, E. (2014). Inhibitory control in bilinguals and musicians: Event related potential (ERP) evidence for experience-specific effects. *PLOS ONE*, *9*(4), e94169. https://doi.org/10.1371/JOURNAL.PONE.0094169

Nguyen, T., & Duncan, G. J. (2019). Kindergarten components of executive function and third grade achievement: A national study. *Early Childhood Research Quarterly*, *46*, 49–61. https://doi.org/10.1016/J.ECRESQ.2018.05.006

Niebaum, J. C., & Munakata, Y. (2023). Why doesn't executive function training improve academic achievement? Rethinking individual differences, relevance, and engagement from a contextual framework. *Journal of Cognition and Development*, *24*(2), 241–259. https://doi.org/10.1080/15248372.2022.2160723

Nomi, J. S., Farrant, K., Damaraju, E., Rachakonda, S., Calhoun, V. D., & Uddin, L. Q. (2016). Dynamic functional network connectivity reveals unique and overlapping profiles of insula subdivisions. *Human Brain Mapping*, *37*(5), 1770–1787. https://doi.org/10.1002/HBM.23135

Nouraey, P., Bavali, M., & Behjat, F. (2023). A post-pandemic systematic review of e-learning: A cross-cultural study. *International Journal of Society, Culture & Language*, *11*(3), 97-114. https://doi.org/10.22034/ijscl.2023.1971247.2799

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex*, *69*, 265–278. https://doi.org/10.1016/j.cortex.2015.04.014

Pascual, A. C., Muñoz, N. M., & Robres, A. Q. (2019). The relationship between executive functions and academic performance in primary education: Review and meta-analysis. *Frontiers in Psychology*, *10*, 1582. https://doi.org/10.3389/fpsyg.2019.01582

Pinquart, M., & Kauser, R. (2018). Do the associations of parenting styles with behavior problems and academic achievement vary by culture? Results from a meta-analysis. *Cultural Diversity and Ethnic Minority Psychology*, *24*(1), 75–100. https://doi.org/10.1037/CDP0000149

Richter, T., & Maier, J. (2017). Comprehension of multiple documents with conflicting information: A two-step model of validation. *Educational Psychologist*, *52*(3), 148–166. https://doi.org/10.1080/00461520.2017.1322968

Sadeghi Ordoubadi, M., Tabatabaeian, M., & Farkhondehfal, E. (2023). Communication apprehension, privacy preferences and l2 willingness to communicate: Can they predict communication ability? *Journal of Business, Communication & Technology*, *2*(2), 39-53. https://doi.org/10.56632/bct.2023.2204

Sala, G., & Gobet, F. (2020). Working memory training in typically developing children: A multilevel meta-analysis. *Psychonomic Bulletin and Review*, *27*(3), 423–434. https://doi.org/10.3758/S13423-019-01681-Y/TABLES/3

Shepard, E., Sweeney, C., Thompson, L., Jacobs, S., Grimm, J., & Weyandt, L. L. (2023). Effectiveness of executive functioning training among heterogeneous adolescent samples: A systematic review. *Applied Neuropsychology: Child*, *12*(4), 327–343. https://doi.org/10.1080/21622965.2022.2106436

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. L. (2016). Do "brain-training" programs work? *Psychological Science in the Public Interest*, *17*(3), 103–186. https://doi.org/10.1177/1529100616661983

Snyder, H. R., Miyake, A., & Hankin, B. L. (2015). Advancing understanding of executive function impairments and psychopathology: Bridging the gap between clinical and cognitive approaches. *Frontiers in Psychology*, *6*, 328. https://doi.org/10.3389/fpsyg.2015.00328

Sullivan, M. D., Janus, M., Moreno, S., Astheimer, L., & Bialystok, E. (2014). Early stage second-language learning improves executive control: Evidence from ERP. *Brain and Language*, *139*, 84–98. https://doi.org/10.1016/J.BANDL.2014.10.004

Waters, N. E., Ahmed, S. F., Tang, S., Morrison, F. J., & Davis-Kean, P. E. (2021). Pathways from socioeconomic status to early academic achievement: The role of specific executive functions. *Early Childhood Research Quarterly*, *54*, 321–331. https://doi.org/10.1016/J.ECRESQ.2020.09.008

Zelazo, P. D., & Carlson, S. M. (2020). The neurodevelopment of executive function skills: Implications for academic achievement gaps. *Psychology & Neuroscience*, *13*(3), 273–298. https://doi.org/10.1037/pne0000208

Zou, H., Zhou, H., Yan, R., Yao, Z., & Lu, Q. (2022). Chronotype, circadian rhythm, and psychiatric disorders: Recent evidence and potential mechanisms. *Frontiers in Neuroscience*, *16*, 811771. https://doi.org/10.3389/FNINS.2022.811771/BIBTEX

Do NOT Delete this Page