frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 18 June 2025
DOI 10.3389/feduc.2025.1573107

OPEN ACCESS

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RECEIVED 08 February 2025
ACCEPTED 28 May 2025
PUBLISHED 18 June 2025

CITATION
Kitil MJ, Diamond A, Guhn M and Schonert-Reichl KA (2025) Longitudinal relations of executive functions to academic achievement and wellbeing in adolescence. *Front. Educ.* 10:1573107.
doi: 10.3389/feduc.2025.1573107

Longitudinal relations of executive functions to academic achievement and wellbeing in adolescence

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Introduction: Executive functions (EFs) are essential for cognitive, social, and emotional competence and have important implications for developmental outcomes across the lifespan. Limited research has explored how EFs relate to academic achievement and well-being specifically in adolescence over time. This study investigated relations of EFs to grade point average (GPA) and well-being (life satisfaction, depressive symptoms) from early to late adolescence.

Methods: Data were collected using multiple methods from 65 students in 4th and 5th grades and then again in 11th and 12th grades.

Results: Results revealed that EFs and depressive symptoms in early adolescence predicted GPA eight years later. EFs and life satisfaction were also correlated in late adolescence.

Discussion: Given the malleability of EFs, these findings suggest early interventions to enhance EFs may improve academic achievement in high school.

KEYWORDS

executive functions, academic achievement, wellbeing, depressive symptoms, life satisfaction, social and emotional learning

1 Introduction

Executive functions (EFs) are a family of top-down mental processes needed for goal-oriented behavior, which are engaged during reasoning and problem-solving, focusing and paying attention, controlling one's impulses, and adapting to new information (Diamond, 2013; Cristofori et al., 2019). EFs are also critical for developmental outcomes that include academic achievement and psychological wellbeing (Diamond, 2013; Zelazo et al., 2016). EFs comprise three core interrelated components: working memory (the ability to hold information in mind and manipulate it), inhibitory control (the ability to suppress prepotent responses), and cognitive flexibility (the ability to flexibly switch perspectives or between tasks) (Diamond, 2013; Miyake et al., 2000). Although much research has focused on specific components in isolation, when one EF component is targeted, the other two are often engaged in service of the component that is targeted (e.g., cognitive flexibility always requires working memory and inhibitory control) (Diamond, 2013). Considerable overlap also exists between EFs and self-regulation, which involves emotion regulation and requires EFs to do so (Eisenberg et al., 2010).

Research conducted with children and adolescents show that EFs have remarkable continuity over time and can predict important outcomes reliably. In adolescence, EFs are linked to academic achievement (Mischel et al., 1989); in adulthood they predict financial prudence, higher earnings, and relationship satisfaction (Allemand et al., 2019; Fergusson et al., 2013; Moffitt et al., 2011). EF deficits have been linked to psychopathology such as attention-deficit/hyperactivity disorder (ADHD) in adolescents (Krieger and Amador-Campos, 2018). They also predict substance use, criminal offence, and adverse health outcomes in adolescents and adults (Miller et al., 2011; Moffitt et al., 2011). With regard to age, adolescents exhibit improvements in EFs as they develop over time (e.g., Davidson et al., 2006; Porter et al., 2024). In terms of gender, research indicates that differences in EFs can vary by age and by specific EF subcomponents among adolescents, with some findings suggesting that girls tend to reach EF maturity earlier than boys (Malagoli and Usai, 2018). Research also shows that EFs can be trained (Diamond and Ling, 2019; Takacs and Kassai, 2019), which can lead to improvements across a variety of developmental domains (Blair and Raver, 2014). Yet, limited research has explored how EFs relate to academic achievement and wellbeing specifically in adolescence over time. Use of longitudinal designs enable researchers to track the same group of individuals across multiple time points, allowing for the observation of developmental trajectories. This approach also facilitates the establishment of temporal precedence, which is essential for drawing causal inferences (Robinson et al., 2005). As such, the overall aim of this study was to investigate the longitudinal relations of early adolescent EFs to grade point average (GPA) and wellbeing (life satisfaction, depressive symptoms) in late adolescence.

1.1 EFs and academic achievement

A substantial body of research has found EFs to be predictive of academic achievement (Pascual et al., 2019). As cognitive processes that underlie thoughts and behaviors, EFs are crucial for learning, homework completion, and proper classroom conduct (Zelazo et al., 2016). EFs have also been found to contribute to GPA beyond the effects of IQ in adolescents (Duckworth and Seligman, 2005). Moreover, research examining gender differences have found girls to outperform boys on GPA due to better EFs (Duckworth and Seligman, 2006). Most longitudinal research on EFs and academic achievement has focused on standardized test scores or the completion of qualifying exams (Ahmed et al., 2019; Deer et al., 2020; Jacob and Parkinson, 2015). Recent research, however, has found high school GPA to be a strong and consistent predictor of college graduation (Allensworth and Clark, 2020), although gender differences favoring females in college grade achievement have also been observed (Fischer et al., 2013). Most of the investigations of EFs and academic achievement have been cross-sectional in nature (Best et al., 2011; Zorza et al., 2016). Among those examining the relation longitudinally (Duckworth and Seligman, 2005; Valiente et al., 2013), the longest timeframe involving adolescents examined the link between sixth grade students' EFs and their GPA 4 years (Samuels et al., 2016) and 6 years later (Samuels et al., 2019).

Most research examining the link between EFs and academic achievement have involved teacher reports [e.g., the Behavior Rating Inventory of Executive Function (BRIEF)] (Gioia et al., 2015) as in the research by Samuels et al. (2016). Teacher reports, however, may be confounded with GPA as usually the same individuals carry out both assessments. Furthermore, prior longitudinal research using task-based EF assessments have often utilized tasks less sensitive to individual differences (Ahmed et al., 2019; Diamond, 2013). Little research currently exists examining the predictability of EFs over time, with measurements specifically carried out in early adolescence. To detect individual differences, particularly challenging EF measures are often needed, such as task-switching paradigms (which challenge all three core EFs) as used in the present study (Davidson et al., 2006). Therefore, to address this gap in the literature, the aim of the present study was to examine the predictability of early adolescents' performance on EF tasks using task-switching paradigms on GPA 8 years later.

1.2 Wellbeing

Increasing focus has been placed on the wellbeing of adolescents during the past decade (Ross et al., 2020) as changes that occur during the adolescent period can have long-term impacts on wellbeing and other related outcomes over the life course (Allemand et al., 2024). Although numerous definitions for adolescent wellbeing have emerged in recent years, one broad conceptualization involves a definition that includes, "adolescents thrive and are able to achieve their full potential" (Ross et al., 2020, p. 473), accompanied by five interrelated areas that encompass subjective and objective constructs. These facets include good physical and mental health, cognitive and emotional resources and competencies, and the fulfillment of one's potential.

Although research investigations into the various indices of wellbeing have grown substantially over the past two decades, relatively few studies have explored the relation of life satisfaction and depressive symptoms to EFs, each of which fall into the wellbeing domains. Better EFs have been linked to the ability to recognize and stop rumination, make adjustments to one's mindset to manage stress, and maintain a sense of optimism in life (Short et al., 2016). In the present study, we explored the relation of EFs to the two wellbeing indicators, life satisfaction and depressive symptoms.

1.2.1 EFs and life satisfaction

Life satisfaction is defined as the degree to which individuals evaluate the overall quality of their lives as a whole in a positive way (Diener and Ryan, 2009). As the key factor within subjective wellbeing (De Neve et al., 2020), life satisfaction was chosen in this study because it is less influenced by temporary affective states that may reflect more recent life events. Although a paucity of research exists on the relations of adolescent life satisfaction to later outcomes, life satisfaction as measured in adults has been found to predict important outcomes, such as higher income 7 years later (De Neve and Oswald, 2012) and physical health and mortality two decades later (Willroth et al., 2020). Strong EFs have been suggested to be an underlying mechanism for some of these relations (Luerssen and Ayduk, 2017). Most research on adolescent life satisfaction, however, has been cross-sectional in nature, with associations to academic achievement and psychosocial factors, such as self-compassion and peer relationships (Alsarrani et al., 2022; Bluth et al., 2017; Ng et al., 2015). Few studies have examined the potential role of EFs in influencing life satisfaction (e.g., Wasif and McAuley, 2024).

Although empirical investigations examining the relation between EFs and life satisfaction have only begun to emerge, mechanisms have been proposed for the link between EFs and life satisfaction. These include (a) cognitive reappraisal as an emotion regulation strategy (Toh and Yang, 2022) and (b) stronger social relations and greater career success (Moffitt et al., 2011), both of which may be considered pathways through which EFs can foster higher life satisfaction. Prior investigations examining the link between EFs and life satisfaction in adolescents have primarily been cross-sectional in nature (Wasif and McAuley, 2024), with most studies utilizing the construct of self-control (Achkar et al., 2019; Ronen et al., 2016; Wiese et al., 2018). Given the paucity of research investigating this link in adolescence, the aim of the present study was to explore the relations of early adolescent EFs to life satisfaction in late adolescence.

1.2.2 EFs and depressive symptoms

Depressive symptomatology involves having feelings of fatigue, poor appetite and sleep quality, lack of focus, lack of interest in activities that were once pleasurable, and, for adolescents, irritability (American Psychiatric Association, 2013). Although the global prevalence rate for clinical depression in adolescents is low (8%), 37% of adolescents globally were found to report multiple depressive symptoms from 2011 to 2020 (Shorey et al., 2022). Similarly, 40% of US youth reported persistent feelings of sadness and hopelessness in 2023 (Centers for Disease Control and Prevention, 2024). Rates of depression among youth are also increasing; a cohort study of 1.7 million individuals between the ages of 5–22 found that the incidence and prevalence of depression increased by ~60% from 2017 to 2021 (Xiang et al., 2024). Depressive symptomatology in adolescence has been found to be predictive of poor psychosocial outcomes, such as peer rejection and family conflict in later adolescence (Musliner et al., 2016), lower income levels, lack of educational attainment (Yaroslavsky et al., 2013), and poor physical health in adulthood (Park et al., 2023). Many of these outcomes can be attributed to underlying EF deficits (e.g., Evans et al., 2016; Jankowski et al., 2018).

Substantial evidence links poor EFs to depression and depressive symptoms in adolescents (Goodall et al., 2018; Yang et al., 2022). Research suggests that adolescents with EF deficits tend to employ more maladaptive strategies (e.g., rumination) and fewer adaptive strategies (e.g., cognitive reappraisal), which may underlie depressive symptomatology (Wante et al., 2017). Bidirectional influences also may be present as sadness and depression predict poorer EF performance (Halse et al., 2022) and poorer information processing and memory (Goodall et al., 2018). Adults with depressive symptoms appear to have challenges disengaging from and reappraising negative information, required for emotion regulation (Joormann and Tanovic, 2015). Much of the research linking EFs to depressive symptoms in adolescents has been cross-sectional (Goodall et al., 2018; Mullin et al., 2018), however, and the findings from studies that have examined the link longitudinally suggest the overall associations are unclear (Fenesy and Lee, 2022; Halse et al., 2022; Morales-Muñoz et al., 2021; Han et al., 2016). To elucidate these relations, an aim of the present study was to explore the longitudinal link by examining the associations of early adolescent EFs to depressive symptoms in late adolescence.

1.2.2.1 EFs, academic achievement, and depressive symptoms

In addition to a large body of research linking EFs to both depressive symptoms and academic achievement, there is also substantial evidence that depressive symptoms independently predict poorer academic outcomes. Longitudinal studies have found that depressive symptoms predict GPA in high school students (McArdle et al., 2014), standardized test scores in a large cohort of adolescents aged 11–18 (López-López et al., 2021), and parent-reported academic outcomes in children aged 9–12 (Voltas et al., 2014). A meta-analysis also supported this relationship, identifying small to moderate effect sizes between depressive symptoms and academic achievement (Riglin et al., 2014). Despite the well-established links between EFs and academic achievement on the one hand, and between depressive symptoms and academic outcomes on the other, few studies have examined these predictors in the same model. For example, McLeod et al. (2012) found that depressive symptoms no longer predicted GPA once attention problems were controlled for in a large longitudinal sample. Recent findings from McCurdy et al. (2023) indicate that depressive symptoms predict certain academic outcomes (e.g., spelling) but not others (e.g., math), above and beyond the effects of attentional difficulties. Given the limited evidence, one aim of the present study was to examine whether depressive symptoms in early adolescence uniquely predict GPA in late adolescence, above and beyond the contribution of EFs.

1.3 Hypotheses

To contribute to a broader understanding of EFs and their implications for adolescent development, the present study examined both longitudinal and concurrent associations between EFs and key developmental outcomes in a sample of early adolescents (4th and 5th graders) who were followed into late adolescence (11th and 12th grade). The first aim was to investigate the relations between EFs and academic achievement, as measured by GPA, both cross-sectionally and longitudinally. Given that EFs are cognitive processes essential for goal-directed behavior, academic learning, task completion, and sustained classroom engagement (Zelazo et al., 2016), it was hypothesized that adolescents with stronger EFs would demonstrate higher GPAs, both cross-sectionally and longitudinally. The second aim was to explore the relations between EFs and indicators of wellbeing—specifically, life satisfaction and depressive symptoms—both cross-sectionally and longitudinally. Because stronger EFs have been associated with the ability to interrupt ruminative thinking, flexibly adjust to stress, and sustain a positive outlook on life (Short et al., 2016), it was hypothesized that adolescents with stronger EFs would report higher life satisfaction and lower levels of depressive symptoms, both cross-sectionally and longitudinally. The third aim was to investigate whether depressive symptoms in early adolescence would predict GPA in late adolescence, above and beyond the contributions of EFs. Although prior research has shown that depressive symptoms are associated with poorer academic performance (e.g., López-López et al., 2021), some findings suggest that this relationship may not hold after accounting for cognitive factors, such as attention problems (McLeod et al., 2012). Given the limited and inconclusive evidence, this aim sought to examine whether depressive symptoms in early adolescence would contribute to the prediction of GPA in late adolescence, after accounting for EFs. This aim was exploratory and did not include a directional hypothesis.

2 Methods

2.1 Participants

Participants for the present study were drawn from a larger study examining the long-term effectiveness of a social and emotional learning program. Data were taken from two time points, referred to as Time 1 (T1) and Time 2 (T2). The original T1 sample comprised 100 early adolescents (42% female) from four 4th and 5th grade classrooms located in public elementary schools in a large suburban school district in British Columbia, Canada. Sixty-five of the early adolescents (48% female) who participated at T1 also participated at T2 when they were in 11th and 12th grades.

At T1, early adolescents' ages ranged from 9.00 to 11.16 years (M = 10.19, SD = 0.55). The average annual income for the neighborhoods in which the elementary schools were located was similar to the median annual income for Canada in 2006 ($53,800 CAD) (Statistics Canada, 2006). Regarding family composition of the 65 adolescents at T1, 88% reported living in two-parent homes, 5% in single-parent homes, and 8% in dual custody arrangements. This is comparable to the family composition for the original sample of 100 students. Early adolescents provided a diverse range of responses with regard to first language learned at home at T1; the most commonly reported were English (75%), various Chinese dialects (7.7%), Spanish (4.6%), Korean (3.1%), and Romanian (3.1%). The range of language backgrounds reflects the ethnic and cultural diversity of the city where this research was conducted.

At T2, adolescents' ages ranged from 16.54 to 18.74 years (M = 17.54, SD = 0.58). T2 gender was asked differently from T1 with the question, "Which gender best describes you?" There was no change in reported T2 gender (48% female) as compared to T1. Family composition changed slightly at T2: 82% of adolescents reported living in two-parent homes, 16% in single-parent homes, and 2% in dual custody arrangements. One student chose not to respond to this question at T2. The average annual income for the neighborhoods in which the high schools were located was similar to the median annual income for Canada in 2015, when the data were collected ($80,940) (Statistics Canada, 2015).

2.1.1 Recruitment

Ethics approval was obtained from the university's institutional ethics board and ethics board of the participating school district for data collection at T1 and T2. At T1, 98% of parent/guardians of recruited early adolescents provided consent, and 98% of these adolescents gave their own assent. As a token of appreciation, all participating classrooms received a pizza party at the end of the study. At T2, the research team collaborated with school district administrators to support participant recruitment. The district provided a list of students who had participated at T1, along with the high schools they were currently attending. Of the original 100 adolescents, 28 had moved out of the school district and two had stopped attending classes, leaving a potential sample of 70 students. The research team then met with principals from 10 high schools to discuss the study. Each principal facilitated introductions between the research team and students, either in small groups or individually. During these meetings, the research team explained the study procedures and participation requirements. Students were informed that they would receive a $20 gift card for their participation. Five students declined to participate, resulting in a final T2 sample of 65 students. The study's 35% attrition rate aligns with findings from a meta-analysis of 143 longitudinal cohort studies, where the average retention rate was 73.5% (SD = 20.1%) (Teague et al., 2018).

2.2 Procedures

At T1, research assistants administered all measures to participating students. After consent / assent procedures, student self-report paper-based surveys were administered as a group to participating students in their classrooms. EF tasks were administered individually in a quiet room located elsewhere in the school during the same week. In addition to the pizza parties, all students in participating classrooms were compensated with a small thank you gift (e.g., eraser or pencil).

At T2, research assistants administered measures individually in a quiet room at each school. After consent /assent procedures, adolescents completed a self-report computerized survey at their own pace. Research assistants then administered the EF tasks. Upon study completion, adolescents were compensated with $20 gift cards to Starbucks, Subway, or iTunes. One year later, school district administrators facilitated the request for academic transcripts (available for 62 students); the remaining three students likely transferred to a different school district.

2.3 Measures

2.3.1 Demographics

Participants completed a self-report questionnaire at T1 and T2 inquiring about their gender, grade level, date of birth, family composition, and first language learned at home.

2.3.2 Executive functions

Participants completed two objective measures of EFs at T1 and T2: the Hearts and Flowers task (Davidson et al., 2006) and the Flanker/Reverse Flanker task (Munro et al., 2006). Both measures have been validated for ages 4 through adulthood, assess all three components of core EFs (inhibitory control, working memory, and cognitive flexibility), and have been widely used (e.g., Gambarini et al., 2023; Liu et al., 2023; Silvestri et al., 2023). The Presentation program by Neurobehavioral Systems (Berkeley, CA) was used for task administration on laptop computers and recorded responses using keys on the keyboard's left and right sides. The structure of both tasks was identical, with three blocks total, and practice trials preceding the first two blocks.

2.3.2.1 Hearts and flowers

In this task, a red heart or flower appeared on the left or the right side of the screen. In the congruent block, one rule applied: "Press on the *same side* as the heart." In the incongruent block, one rule applied: "Press on the *side opposite* of the flower." In the mixed block, incongruent and congruent trials were randomly intermixed, placing demands on all three core EFs.

2.3.2.2 Flanker/reverse flanker

In this task, the stimuli were small fish presented alone or in a horizontal row of five fish. For each of the three blocks, the target stimulus was determined by color. In the classic Flanker block (Block 1), the stimuli were blue, the target stimulus was in the middle, and one rule applied, "Press in the same direction that the *middle* fish is facing," ignoring any flankers (distractors) appearing on its left and right side. For congruent trials, all flankers faced the same direction. For incongruent trials, the flankers faced the opposite direction. In the Reverse Flanker block (Block 2), the stimuli were pink, the target stimulus were the outside fish, and one rule applied, "Press in the same direction that the *outside* fish are facing," ignoring the middle fish. In the mixed block (Block 3), Flanker and Reverse Flanker trials were intermixed, and two rules applied. Students had to flexibly apply the rules that corresponded to the color of the fish (i.e., "blue means focus on the middle; pink means focus on the outside"). During each trial, stimuli were presented for 1,500 ms.

For both tasks, participants were instructed to respond as quickly and accurately as possible.

2.3.2.3 Scoring of EF tasks

The percent of correct responses (accuracy) in the mixed block for each of the two EF tasks was used as a combined measure of the three core EFs. Responses were correct if students pressed the button on the keyboard (1) according to the specified rule, (2) at least 200 ms after the stimulus had appeared (<200 ms was considered too fast to be in response to the stimulus), and (3) before the stimulus disappeared. Practice trials were excluded from analyses. In the present study, accuracy was chosen over mean reaction time (RT) due to insufficient power to examine both. Prior research conducted with the *Hearts and Flowers* task has found accuracy to be the more informative score for children and samples with lower accuracy scores (Diamond et al., 2007), while RT is best for samples whose accuracy scores have reached ceiling level performance and no longer provide sufficient variability (Ursache and Raver, 2014). Scores for the mixed blocks was chosen because it has been shown to be the most challenging block due to the cognitive demand of switching response sets and holding more rules in mind than in the single-task blocks.

2.3.3 Academic achievement

Students' grade point average (GPA) for Grades 9 to 12 was calculated for core academic subjects (language arts, math, science, and social studies). Although subject-specific grades were available, we focused solely on GPA as a measure of academic achievement, given our interest in its broader implications for developmental outcomes across the life course. Grades were obtained from school transcripts, which were acquired after all students had completed the 12th grade. Study inclusion required a minimum of 3 years' worth of grades. All letter grades were converted to percentages (e.g., C = 64%) in accordance with the letter grade-percentage equivalence chart presented on the back of the transcripts.

2.3.4 Life satisfaction

Life satisfaction at T1 and T2 was assessed using the Satisfaction with Life Scale for Children (SWLS-C) (Gadermann et al., 2010). This five-item self-report measure includes items such as, "In most ways my life is close to the way I would want it to be." Items were scored on a five-point Likert scale (1 = *disagree a lot* to 5 = *agree a lot*). The mean scores were taken, with higher scores reflecting greater levels of life satisfaction. This scale has been found to be valid for assessing life satisfaction in fourth to seventh grade students (Gadermann et al., 2010), with comparable Cronbach's alphas to those found in the present study, 0.75 for T1 and 0.88 for T2. Guhn et al. (2018) also found the SWLS-C to have satisfactory measurement invariance for grade and gender in a large sample of early adolescents.

2.3.5 Depressive symptoms

Depressive symptoms at T1 and T2 were assessed using the Seattle Personality Questionnaire for Children (SPQC) (Kusche et al., 1988), which is composed of four constructs: (a) behavioral problems, (b) anxious symptoms, (c) somatization, and (d) depressive symptoms. For the present study, only the 10-item depressive symptoms subscale was used. Items included: "Do you feel unhappy a lot of the time?" and "Do you feel sorry for yourself?" Items were scored on a four-point Likert scale (1 = *not at all* to 4 = *always*). Mean scores were taken, with higher scores reflecting higher levels of depressive symptoms. Prior research supports the reliability of the depressive symptoms subscale, with a Cronbach's alpha of 0.78 (Kusche et al., 1988). The present study also found the subscale to have adequate internal reliability with a Cronbach's alpha of 0.68 at T1 and 0.84 at T2.

2.4 Study inclusion

Final inclusion in the present study required that participants have complete data for the outcome variables. As a result, eight adolescents were excluded due to missing data for EFs ($n = 3$), life satisfaction ($n = 1$), or missing transcripts ($n = 4$).

2.5 Data analyses

Prior to conducting analyses, data were examined to ensure assumptions for correlational analyses and hierarchical linear regression were met. Tests for normality revealed the influence of an outlier with a *T2 Flanker/Reverse Flanker* score that exceeded acceptability: Histograms revealed the value was 3 SDs from the next lowest score (Cook's Distance >1; skewness = 5.27; kurtosis = 33.74). To ensure the assumptions for normality were met, this outlier was removed, resulting in a final sample size of 56. A p-value of 0.01 was adopted for all analyses due to the exploratory nature of the study. Pratt Indices, which provide a measure of relative importance of model variables, were calculated for models achieving significance, with higher values reflecting greater relative importance (Pratt, 1987; Thomas et al., 1998). Data analyses were performed using SPSS v. 24.

One-way ANOVAs were conducted for baseline measures comparing adolescents: (1) who participated to those who were lost at T2; (2) who had complete data at T1 and T2 to those with missing data at T2; and (3) who participated in the intervention at T1 to those who did not participate. Analyses revealed no significant mean differences for these three comparisons.

3 Results

3.1 Descriptive statistics and correlations

The means and SDs of all T1 and T2 variables are presented in Table 1. Scores on EFs improved from T1 to T2, and mean scores for *SWLS* decreased from T1 to T2.

Zero-order correlations revealed statistically significant relations in the expected direction, yielding medium to large effect sizes (see Table 1): (1) Age was positively correlated with *T2 Hearts* and *Flowers* scores, $r(56) = 0.35$, $p < 0.01$; (2) *T1 SWLS* was negatively correlated with *T1 depressive symptoms*, $r(56) = -0.46$, $p < 0.001$; (3) *T1 depressive symptoms* were negatively correlated with *T2 GPA*, $r(56) = -0.47$, $p < 0.001$; (4) *T2 Flanker/Reverse Flanker* scores were positively correlated with *T2 SWLS*, $r(56) = 0.41$, $p < 0.01$; and (5) *T2 SWLS* was negatively correlated with *T2 depressive symptoms*, $r(56) = -0.62$, $p < 0.001$.

3.2 Main analyses

Hierarchical linear regressions were conducted for each outcome variable with *gender* and *age* being entered into Step 1 of each model.

To address the first aim, a hierarchical regression was conducted to examine the extent to which *T1 and T2* EFs predicted *T2 GPA*, beyond the effects of gender and age. The overall model was significant, $F(6, 49) = 5.41$, $p < 0.001$, with *T1 and T2 EFs* collectively accounting for an additional 24% of the variance in GPA beyond gender and age. Further, gender significantly predicted *T2 GPA* ($\beta = 0.31$, $p = 0.009$), with females earning higher GPAs than males, even after controlling for EF performance. Of the four EF predictors, *T1 Hearts and Flowers* ($\beta = 0.36$, $p = 0.004$) and *T2 Flanker/Reverse Flanker* ($\beta = 0.37$, $p = 0.004$) uniquely predicted *T2 GPA* (see Table 2). That is, adolescents who performed more accurately on the task-switching blocks for *T1 Hearts and Flowers* and *T2 Flanker/Reverse Flanker* earned higher GPAs in Grades 11 and 12. Pratt Indices were calculated to evaluate the relative importance of predictors in the full model. Using a cut-off score of 0.08 (Thomas et al., 1998), four predictors emerged as relatively important: *T2 Flanker/Reverse Flanker* (31%), *T1 Hearts and Flowers* (30%), gender (22%), and age (14%). Effect sizes for these predictors ranged from medium to large (Cohen, 1988). The remaining EF variables accounted for less than 2% of the variance in GPA.

To investigate the second aim, regression analyses predicting *T2 SWLS* and *T2 depressive symptoms* were not significant (see Table 3). However, previously reported correlational analyses revealed a medium to large association between *T2 Flanker/Reverse Flanker* and *T2 SWLS*, $r(56) = 0.41$, $p < 0.01$. Small effect sizes were also observed for the relations between *T2 Flanker/Reverse Flanker* and *T2 depressive symptoms*, $r(56) = -0.32$, $p = 0.015$, and between *T1 depressive symptoms* and *T2 depressive symptoms*, $r(56) = 0.28$, $p = 0.038$. Both of these correlations approached statistical significance.

To examine the third aim, a hierarchical regression was conducted to test whether *T1 depressive symptoms* predicted *T2 GPA* above and beyond EFs, gender, and age. The overall model was significant, $F(7, 48) = 6.09$, $p < 0.001$. The addition of *T1 depressive symptoms* in Step 3 did not significantly improve the model, although the increase in explained variance approached statistical significance, $\Delta F(1, 48) = 6.52$, $p = 0.014$. The addition of *T1 depressive symptoms* explained an additional 7% of the variance in GPA. In the full model, gender ($\beta = 0.29$, $p = 0.011$), *T1 Hearts and Flowers* ($\beta = 0.25$, $p = 0.045$), *T2 Flanker / Reverse Flanker* ($\beta = 0.30$, $p = 0.017$), and *T1 depressive symptoms* ($\beta = -0.30$, $p = 0.014$) also approached statistical significance (see Table 4). Notably, the inclusion of *T1 depressive symptoms* reduced the significance of the previously predictive variables (*T1 Hearts and Flowers, T2 Flanker/Reverse Flanker*, and gender) suggesting that the unique contributions of these predictors to GPA may be attenuated when depressive symptoms are taken into account. Pratt Indices were again used to assess relative importance. Using a 0.07 threshold, *T1 depressive* symptoms (30%), *T2 Flanker/Reverse* Flanker (21%), *T1 Hearts and Flowers* (18%), and gender (17%) were identified as relatively important contributors to

TABLE 1 Zero-order correlations between T1 and T2 variables.

Variable	*M (SD)*	Min	Max	1	2	3	4	5	6	7	8	9	10
1. T1 Gender	–	–	–	–									
2. T1 Age	10.19 (0.55)	9.28	11.16	−0.092	–								
3. T1 HF	0.82 (0.12)	0.42	1.00	0.009	0.166	–							
4. T1 FF	0.91 (0.08)	0.65	1.00	0.152	0.073	0.198	–						
5. T1 SWLS	4.16 (0.71)	1.80	5.00	0.069	−0.143	0.125	0.000	–					
6. T1 Dep Sym	2.05 (0.48)	1.18	3.27	−0.091	−0.226	−0.287	0.060	−0.463**	–				
7. T2 HF	0.92 (0.08)	0.63	1.00	−0.155	0.346*	0.264	0.069	−0.093	0.025	–			
8. T2 FF	0.96 (0.03)	0.84	1.00	0.045	0.081	−0.071	0.184	0.074	−0.109	0.339	–		
9. T2 GPA	75.02 (11.04)	56.00	97.27	0.274	0.264	0.333	−0.033	0.105	−0.471**	0.249	0.335	–	
10. T2 SWLS	3.64 (0.93)	1.40	5.00	0.157	0.014	0.047	0.149	0.162	−0.199	0.079	0.412*	0.225	–
11. T2 Dep Sym	1.95 (0.53)	1.00	3.18	0.015	−0.021	0.116	0.144	−0.112	0.279	−0.101	−0.323	−0.176	−0.616**

N = 65. Gender is coded 1 = Male, 2 = Female; correlations involving gender are point-biserial; all others are Pearsons's r. HF = Hearts & Flowers; FF = Flanker/Reverse Flanker; percent correct on the mixed block for T1 and T2 EFs. SWLS = Satisfaction with Life Scale; Dep Sym = Depressive Symptoms; GPA = Grade Point Average for core academic subjects from Grades 9 to 12.
$^*p < 0.01$. $^{**}p < 0.001$.

TABLE 2 Hierarchical Multiple Regression Analysis Predicting GPA from T1 and T2 EFs.

Step	Predictors	*B*	*SE*	*β*	*t* value	*p*-value	Pratt *d*
1	Gender	6.86*	2.50	0.31*	2.74	0.009	0.22
	Age	4.29	2.39	0.21	1.80	0.079	0.14
2	T1 HF	33.55*	11.14	0.36*	3.01	0.004	0.30
	T1 FF	−33.80	16.70	−0.24	−2.02	0.048	0.019
	T2 HF	2.85	18.85	0.02	0.15	0.88	0.013
	T2 FF	125.12*	41.99	0.37*	2.98	0.004	0.31

$F(6, 49)$ on overall regression analysis was 5.41, $p < 0.001$, $\Delta F = 4.86$, $p < 0.01$, Model 1 $R^2 = 0.16$, Model 2 $R^2 = 0.40$, $\Delta R^2 = 0.24$. Gender is coded 1 = Male, 2 = Female; Age is in years; HF = Hearts & Flowers; FF = Flanker/Reverse Flanker; percent correct on the mixed block for T1 and T2 EFs. *$p < 0.01$. **$p < 0.001$.

TABLE 3 Hierarchical multiple regression analysis predicting T2 wellbeing from T1 and T2 EFs, accounting for T1 wellbeing.

Step	Predictors	T2 SWLS					T2 Depressive Symptoms				
		B	*SE*	β	*t*-value	*p*-value	*B*	*SE*	β	*t*-value	*p*-value
1	Gender	0.21	0.24	0.12	0.87	0.38	0.03	0.14	0.03	0.19	0.85
	Age	0.02	0.24	0.01	0.09	0.93	0.06	0.14	0.06	0.46	0.65
2	T1 SWLS	0.15	0.18	0.11	0.84	0.41					
	T1 Dep Sym						0.34	0.16	0.31	2.14	0.04
3	T1 HF	0.51	1.11	0.07	0.46	0.65	0.75	0.66	0.17	1.14	0.26
	T1 FF	0.56	1.63	0.05	0.34	0.74	0.98	0.95	0.14	1.04	0.31
	T2 HF	−0.69	1.86	−0.06	−0.37	0.71	−0.59	1.08	−0.09	−0.55	0.59
	T2 FF	11.92	4.14	0.41	2.88	0.006*	−4.65	2.39	−0.28	−1.94	0.06

$F(7, 48)$ on overall regression analysis for SWLS was 1.85, $p = 0.10$, $\Delta F = 2.47$, $p = 0.057$, $R^2 = 0.21$, $\Delta R^2 = 0.16$. $F(7, 48)$ on overall regression analysis for depressive symptoms was 1.98, $p = 0.078$, $\Delta F = 2.20$, $p = 0.083$, $R^2 = 0.22$, $\Delta R^2 = 0.14$. Gender is coded 1 = Male, 2 = Female; Age is in years; HF = Hearts & Flowers; FF = Flanker/Reverse Flanker; percent correct on the mixed block for T1 and T2 EFs; SWLS = Satisfaction with Life Scale; Dep Sym = Depressive Symptoms. *$p < 0.01$. ** $p < 0.001$.

GPA. Effect sizes for these predictors ranged from medium to large (Cohen, 1988), while the remaining EF variables and age explained less than 2% of the variance in GPA.

4 Discussion

Our first prediction was that EFs would be significantly related to academic achievement, both cross-sectionally and longitudinally. The findings from the present study support this hypothesis and, to the best of our knowledge, this is the first study to examine that relation in a sample of adolescents across 8 years. This study extends prior research which found cross-sectional relationships between EFs as assessed by objective performance-based measures (e.g., the Trail Making Test) and GPA (Zorza et al., 2016) in early adolescence with effect sizes comparable to those reported here. Our finding here also corroborates prior reports of longitudinal relationships in adolescents between teacher reports of students' EFs (using the BRIEF) and GPA across 4 years (Samuels et al., 2016) and 6 years (Samuels et al., 2019), also with effect sizes similar to those reported here. The present study extends prior research by using objective performance-based task-switching measures that required all three core EFs simultaneously and thus provide a measure of overall EFs. The task-switching paradigms used here put significantly greater demands on working memory (especially in the Flanker/Reverse Flanker task) than do most task-switching paradigms. Ahmed et al. (2019) found their working memory task to be the only measure in their battery of EF measures sensitive enough to detect longitudinal relations with academic achievement from the age of 54 months to 15 years. The heavy demands on working memory in the task-switching blocks of the EF paradigms used in the present study may be key as recent research conducted by Li et al. (2024) in an adolescent sample found that working memory at T1 was more predictive of critical thinking at T2 than thinking dispositions at T1. This underscores the role of working memory in higher-order EFs (such as reasoning and problem solving) that are necessary for school success. The present findings contribute further evidence that EFs (in particular, situations taxing all three core EFs simultaneously) are important predictors of academic achievement. This makes sense given that EFs underlie students' ability to pay attention, stay on task, relate new learning to old, mentally relate ideas and information, problem solve, reason, plan, see something from different perspectives, manage emotions, and engage in self-regulated learning (Diamond, 2013; Zelazo et al., 2016).

Correlational analyses in the present study revealed that EFs improved from early to late adolescence, with older adolescents outperforming younger peers on the Hearts and Flowers task in late adolescence. This finding aligns with research showing that EFs improve both as children transition into adolescence and throughout the adolescent period (e.g., Davidson et al., 2006; Luna, 2009; Luna and Sweeney, 2001; Porter et al., 2024). Notably, the scores for this task in late adolescence did not emerge as a significant or unique predictor in any of the regression analyses in the current study, suggesting that although there were age effects, there may have been insufficient

TABLE 4 Hierarchical multiple regression analysis predicting GPA from T1 depressive symptoms, accounting for T1 and T2 EFs.

Step	Predictors	*B*	*SE*	β	*t*-value	*p*-value	Pratt *d*
1	Gender	6.27	2.38	0.29	2.63	0.011	0.17
	Age	2.71	2.35	0.13	1.16	0.254	0.07
2	T1 HF	23.27	11.30	0.25	2.06	0.045	0.18
	T1 FF	−25.63	16.15	−0.18	−1.59	0.119	0.01
	T2 HF	14.24	18.42	0.10	0.77	0.443	0.05
	T2 FF	100.92	40.92	0.30	2.47	0.017	0.21
3	T1 Dep Sym	−7.01	2.75	−0.30	−2.55	0.014	0.30

$F(7,48)$ on overall regression analysis was 6.09, $p < 0.001$, $\Delta F = 6.52$, $p = 0.014$, $R^2 = 0.47$, $\Delta R^2 = 0.07$. Gender is coded 1 = Male, 2 = Female; Age is in years; HF = Hearts & Flowers; FF = Flanker / Reverse Flanker; percent correct on the mixed block for T1 and T2 EFs. Dep Sym = Depressive Symptoms. *$p < 0.01$. **$p < 0.001$.

variability for the scores to be a significant predictor of GPA. The regression analyses examining the effects of gender on GPA found that females earned higher GPAs than males, even after controlling for EFs. This suggests that the gender effects on GPA may not be due to differences in EF abilities. This contrasts with some prior research showing that girls with better self-control tend to earn better grades (Duckworth and Seligman, 2006) and that boys with stronger working memory perform better academically (Dubuc et al., 2020). Yet other research suggests that in general, there are no effects of gender on EF performance in adolescents (Alarcon et al., 2018) or that the effects of gender on EFs vary as a function of age (Malagoli and Usai, 2018). The overall effect of gender on academic achievement is consistent with prior research (Voyer and Voyer, 2014), however, and the present findings suggest that other factors, such as motivation (Bugler et al., 2013) or engagement in learning activities (Lei et al., 2018) may underlie these gender differences. In all, the findings from the present study add to the evidence that EFs and gender are significant predictors of GPA, a key developmental outcome.

Our second prediction was that adolescents with better EFs would have greater life satisfaction and fewer depressive symptoms, cross-sectionally and longitudinally. The findings from the current study do not support the hypothesis for the longitudinal relations between EFs and either life satisfaction or depressive symptoms, or the cross-sectional relations between EFs and depressive symptoms. Correlational analyses, however, do support the hypothesis that better EFs are associated with greater life satisfaction in the 11th and 12th grades, with a medium to large effect size. Research suggests that satisfaction with one's life is strongly related to having a happy mood and one's EFs are better when one is happy (e.g., Hirt et al., 2008; Yang et al., 2013). This corroborates findings from cross-sectional research conducted with adolescents during the transition to high school using the BRIEF self-report measure, which found similar effect sizes (Wasif and McAuley, 2024). Our study also revealed larger effect sizes than those reported in previous research linking self-control to life satisfaction (e.g., Achkar et al., 2019; Ronen et al., 2016; Wiese et al., 2018). This suggests that EFs overall—or specifically cognitive flexibility and working memory, which were most heavily engaged in the task-switching blocks of our study—may have a stronger relationship with life satisfaction than self-control. Notably, self-control is primarily associated with the EF of inhibitory control, specifically, response inhibition. Relatedly, Moffitt et al. (2011) also found that inhibitory control between the ages of 3–11 years predicted a host of life outcomes 32 years later. The larger effect sizes found here with the task-switching paradigms, compared to those previously reported for self-control, are consistent with the generally weak correlations between objective performance-based measures of EFs and subjective questionnaire-based measures (e.g., parent or teacher reports). This pattern has been observed both for EFs overall (e.g., Malanchini et al., 2019; McAuley et al., 2010; Schneider et al., 2024; Toplak et al., 2013) and of self-control specifically (Duckworth and Kern, 2011). The null finding for the association between EFs and life satisfaction longitudinally is open to speculation. There may be many reasons why the two were found to be unrelated. Just as life satisfaction in late adolescence was found to be unrelated to its earlier measurement, recent life events may have a stronger influence on adolescents' current affect and perceived life satisfaction than measures of EFs or life satisfaction taken 8 years prior.

Moreover, the present study also found that mean scores for life satisfaction decreased from T1 to T2, which are in line with prior findings using nationally representative data from samples in 43 countries examining trajectories of life satisfaction across adolescence (Daly, 2022; Orben et al., 2022). Research suggests that an increased prevalence of psychological disorders and distress during adolescence (Silva et al., 2020) could very well produce a decline in life satisfaction (Lombardo et al., 2018). Older adolescents may also experience an increase in academic-related pressure arising from anxiety about getting into college and what they will do after high school that could contribute to a decrease in life satisfaction (Moksnes et al., 2016; Oathout, 2023).

Although no statistical significance was found longitudinally or cross-sectionally for the relation of EFs to depressive symptoms, there was a trend toward statistical significance for the correlation between depressive symptoms and EFs in the 11th and 12th grades. That is consistent with a substantial body of evidence on the concurrent associations of EFs to depressive symptoms in adolescence (Goodall et al., 2018; Halse et al., 2022; Han et al., 2016; Yang et al., 2022) and all stages of life (Crandall et al., 2018; Dotson et al., 2020). As for the longitudinal relations between EFs and depressive symptoms, previous research has revealed largely mixed findings. A number of studies have failed to find support for poorer EFs predicting later depressive symptoms in adolescence (Fenesy and Lee, 2022; Han et al., 2016; Morales-Muñoz et al., 2021). However, deficits in the EF of attentional control (e.g., sustained attention in Morales-Muñoz et al., 2021, and inattention in Fenesy and Lee (2022), have been shown to predict later depressive affect over shorter time periods (e.g., 2 years in early adolescence, though not earlier) (Halse et al., 2022). Other research suggests that EFs and depression may share a common genetic etiology rather than a causal relationship (Friedman et al., 2018) or that the relation is bidirectional (e.g., Halse et al., 2022). Further research is needed to elucidate the longitudinal relations between EFs and depressive symptoms, particularly with samples of adolescents who previously did not exhibit symptoms of depression (Yang et al., 2022).

Correlational analyses in the present study revealed that depressive symptoms in early adolescence were negatively correlated with GPA 8 years later. This finding aligns with prior longitudinal research conducted with a large cohort of adolescents measured across a similar timeframe using a repeated measures design (López-López et al., 2021). Although only approaching statistical significance, depressive symptoms in early adolescence was also found to be positively related to depressive symptoms in late adolescence in the present study. These findings are supported by prior research suggesting that depressive symptoms are often stable over time (e.g., Verboom et al., 2014) due to the nature of the reinforcing feedback loops that are often present in depressive symptomatology. Such symptoms may include sustained or further loss of cognitive, social, and/or environmental resources (Wittenborn et al., 2016) that may further impact outcomes such as academic achievement.

Our third aim was exploratory: to examine whether depressive symptoms in early adolescence would predict GPA above and beyond EFs. Our results revealed that even after accounting for EFs, early adolescent depressive symptoms remained a significant predictor of academic achievement. This finding contrasts with previous research indicating that depressive symptoms cease to predict academic outcomes once cognitive factors, such as attention problems, are taken into account (McLeod et al., 2012). In the regression model, Pratt Indices revealed that depressive symptoms contributed more variance than the other variables in the model, suggesting that early adolescent depressive symptoms have a greater impact on high school grades than EFs when considered together. Nonetheless, none of the individual predictors uniquely contributed to GPA. Notably, gender and EFs, which were significant in the earlier model predicting GPA, no longer showed unique contributions after depressive symptoms were added. This suggests that depressive symptoms may also attenuate the unique effects of EFs and gender on academic performance. Specifically, in the absence of depressive symptoms, girls appeared to perform better academically. Once depressive symptoms were included in the model, however, gender was no longer a significant predictor of GPA. This finding is consistent with research suggesting that adolescent girls experiencing depressive symptoms tend to earn lower GPAs (Verboom et al., 2014). Nevertheless, this gender difference was not found in another study (López-López et al., 2021), suggesting the need for future research to clarify the effects of gender on GPA among those with depressive symptoms. Furthermore, the loss of the unique predictive power of EFs further underscores the complexity of its relationship with depressive symptoms. Prior research has found depressive symptoms assessed at age 12 to predict latent variables of EFs (Common EF factor and Updating-Specific factor) at ages 17 and 23, in which the variance for working memory is parsed out between the two (Friedman et al., 2018). These findings are consistent with those of the present study. This alignment is expected, given that the EF tasks used in this study place a particularly high demand on working memory compared to similar tasks of its kind. As discussed previously, prior studies have also proposed a relationship between the two that is bidirectional (Halse et al., 2022) or have common genetic origins (Friedman et al., 2018), suggesting that these variables may not function independently in their influence on academic outcomes. Future research with larger samples, particularly with adolescents who do not have a prior history of depressive symptoms (Yang et al., 2022), is needed to clarify the distinct and overlapping contributions of EFs and depressive symptoms to academic achievement.

Lastly, analyses revealed that life satisfaction was significantly and inversely correlated with depressive symptoms in both early adolescence and late adolescence. These findings were expected and are in line with prior research showing similar relations in other samples of adolescents (e.g., Moksnes et al., 2016). Adolescents who are feeling depressed are less likely to be satisfied with their lives.

4.1 Strengths and limitations

There are a number of methodological strengths observed in the present study. First, this is the first study to our knowledge to examine the longitudinal relations of EFs to GPA in a sample of adolescents across 8 years. The longitudinal design also enabled us to examine whether depressive symptoms would contribute to academic outcomes, even after taking into account the effects of EFs. It is also the first study, to our knowledge, to examine the longitudinal relations of EFs to life satisfaction in adolescence. A second strength is the use of multiple methods and sources of data (i.e., including two different objective performance-based measures of EFs, self-report measures of life satisfaction and depressive symptoms, and administrative school records for GPA). Moreover, this is one of the few studies to use objective measures of EFs in the examinations of relations between EFs and GPA across the adolescent period, as teacher reports of students' EFs that have been used in numerous studies can be confounded with GPA (e.g., Samuels et al., 2016, 2019). Importantly, this study found that only the most challenging block of each EF task (the task-switching mixed block) yielded significant predictions and correlations, and most studies that have used performance-based tasks have not taxed EFs to the extent that the task-switching blocks did in this study.

The present study also has several limitations. First, while the longitudinal design allowed us to examine the long-term relationship between EFs, GPA, and wellbeing, it also introduced challenges. The eight-year gap between data collection points contributed to an attrition rate of 35%, reducing the sample from 100 to 65 participants. Although this rate is comparable to other longitudinal studies (Teague et al., 2018), future researchers should aim for lower attrition to enhance sample reliability. Second, key factors such as socioeconomic status (SES) were not available for analysis. Given that SES has been shown to be correlated with EFs across diverse age groups (e.g., Lawson et al., 2018), future studies should include it as a control variable. Third, we were not able to ascertain a latent or true measure of EFs, given that the employment of a latent class analysis (Kline, 2016) of EFs was not possible with the measures that were available in the present study. Scores from task-based measures are often confounded with measurement error and task-specific effects (i.e., the task impurity problem; e.g., visual tracking, motor control) that contribute to individual differences in observed EF scores (Miyake et al., 2000). Future research should consider including multiple measures across the multiple domains of EFs to be able to examine latent EFs in relation to academic achievement and wellbeing. Fourth, a substantial body of research has found EFs, specifically working memory, to overlap considerably with fluid intelligence (Engle et al., 1999; Kane et al., 2005), with many researchers in the field considering fluid intelligence to be a component of higher-order EFs (Diamond, 2013; Zelazo et al., 2016). Some evidence further suggests that working memory is the main driver behind general (*g*), fluid, and crystalized intelligence in children and adolescents (Tourva et al., 2016). Nonetheless, there is ongoing debate as to whether *g* is distinct from fluid intelligence, or whether it subsumes fluid and crystalized intelligence (Canivez et al., 2017; Duncan et al., 2012; Kent, 2017). Although measures of intelligence were not available for inclusion in the present study, future research should consider their inclusion to clarify the roles of *g*, fluid intelligence, and working memory in predicting GPA. Fifth, despite the longitudinal nature of our analyses, the study remains correlational. As such, we cannot establish a causal link between early adolescent EFs and later high school GPA and wellbeing. Causal inferences require well-designed experimental studies. Nonetheless, research consistently shows that EFs support higher-order cognitive functions, such as planning and reasoning, and predict academic achievement even after controlling for early achievement, SES, and home environment (Ahmed et al., 2019). Thus, it is highly plausible that EFs played a significant role in determining high school GPA in the current study.

4.2 Educational implications

The findings of the present study carry several important educational implications. Given the long-term predictive value of EFs for high school GPA, EFs may serve as a promising target for early intervention. Strengthening EFs during childhood and early adolescence is critical for shaping developmental trajectories and establishing positive feedback loops. Small differences in EFs early in life can widen over time, as children with stronger EFs benefit from cumulative advantages, while those with weaker EFs may experience increasing disadvantages, ultimately contributing to broader achievement gaps (Alexander et al., 2001; Diamond, 2012; O'Shaughnessy et al., 2003). Encouragingly, research has shown that EFs are malleable and can be enhanced through targeted training and intervention (Diamond, 2012; Diamond and Lee, 2011; Diamond and Ling, 2019; Takacs and Kassai, 2019), including those introduced during adolescence (e.g., Manjunath and Telles, 2001; Schmidt et al., 2015). Research also suggests that some approaches are more effective than others (see Diamond and Ling, 2019, for a review). For example, programs or interventions that engage EFs (Niebaum and Munakata, 2023), that implicitly foster EF development through daily activities (e.g., mindful awareness practices) (Schonert-Reichl et al., 2015), or that integrate the training of and challenging of EFs within regular classroom activities (e.g., Blair and Raver, 2014; Diamond et al., 2019), have been shown to yield improvements in both EFs and academic outcomes. These approaches tend to be more effective than traditional cognitive training methods, whether computerized or not (Diamond and Ling, 2019). Nevertheless, current evidence suggests that the benefits of EF training are often narrow in scope and context dependent. Improvements typically occur in the specific skills practiced and within the settings in which the training takes place, with limited transfer to untrained domains (Diamond and Lee, 2011; Diamond and Ling, 2019; Melby-Lervåg et al., 2016; Niebaum and Munakata, 2023; Simons et al., 2016). This highlights the need for more comprehensive and ecologically valid EF interventions in educational settings.

The findings also suggest that adolescents experiencing depressive symptoms may benefit from targeted intervention approaches. Notably, some strategies shown to enhance EFs, such as mindfulness practices, have also been associated with reductions in depressive symptoms (Schonert-Reichl et al., 2015). Furthermore, research suggests that adolescents' approaches to learning and success may be linked with later mental health outcomes. For instance, school-based interventions that promote mastery-oriented goals, such as those emphasizing skill development and subject comprehension rather than peer comparison, may serve as effective strategies for mitigating depressive symptoms (Steare et al., 2024). A recent study also found that a growth mindset intervention was effective in reducing depressive symptoms among adolescent girls, but not boys (Heaman et al., 2024), highlighting the need for further investigation into the potential gender-specific effects of these interventions.

Furthermore, the findings from the current study suggest that focusing on strategies that improve adolescents' wellbeing (including reducing symptoms of depression) may also improve EFs. For example, research has found that adolescents who are more motivated to interact socially or have high-quality friendships tend to be happier, are protected against EF challenges and poorer life satisfaction, and have better EFs one to 2 years later (Alsarrani et al., 2022; Ben-Asher et al., 2023; Wasif and McAuley, 2024). Therefore, creating conditions and opportunities for adolescents to engage socially in meaningful ways may be one way to boost their happiness, reduce feelings of loneliness and isolation, and improve their EFs at the same time. Second, physical activity may be another way to promote wellbeing in adolescents. In line with research evidence (e.g., McMahon et al., 2017), the World Health Organization recommends that adolescents engage in an average of 60 min of moderate-to-vigorous physical activity per day for physical fitness (Bull et al., 2020). The threshold for achieving wellbeing may be lower, however. In response to the growth in sedentary behavior often attributed to increased recreational screen time, recent longitudinal research has found that adolescents who engaged in at least 60 min of light physical activity (e.g., casual walking) per day had depression scores 6 years later that were 20% lower than their peers who had been persistently sedentary (Kandola et al., 2020). An even larger difference (31%) was found for adolescents engaging in moderate-to-vigorous activity. This suggests that strategies to promote wellbeing that also protect against developing depressive symptoms can be simple, do not need much planning or focused time, and can be easily integrated into a daily routine, for example, by having standing classes or incorporating movement into them. Third, as mentioned previously, research has found that mindfulness-based practices, when done appropriately and practiced on a regular basis, can enable adolescents to reduce stress (Fulambarkar et al., 2023) as well as cultivate greater emotional awareness and emotional clarity (Frank et al., 2021).

Besides being good for one's wellbeing, being more physically active has been found to be related to better EFs in children, adolescents, and adults (Hillman et al., 2005; Prakash et al., 2015; Sibley and Etnier, 2003). Stress is also negatively correlated with EFs at all ages (Blair et al., 2011; Gothe et al., 2016; Shields et al., 2016). Mindfulness practices have been shown to improve EFs in children, adolescents, and adults (Ben-Soussan et al., 2015; Manjunath and Telles, 2001; Schonert-Reichl et al., 2015). All of these activities might be particularly important during adolescence, a period when elevated emotionality and increased susceptibility to contextual factors may compromise the functions of EFs (Nook et al., 2018; Somerville et al., 2010).

Lastly, other avenues to improve wellbeing, and simultaneously enhance EFs, involve engaging adolescents in enriching, real-world activities (Diamond and Ling, 2019). These activities should challenge EFs, be personally meaningful and relevant, and be guided by a supportive adult. Ideally, they are also fun, build camaraderie, and inspire self-confidence. In other words, they should be both cognitively challenging and social and emotionally nourishing. Examples include creative activities such as theater, musical ensembles, and communal dance; sports; and social service activities that allow adolescents to make a positive contribution to their community. Many of these activities show emerging research support for their potential to promote EFs, although much more research is needed.

5 Conclusion

In sum, the present study offers several contributions to the literature. The findings extend prior research through the examination of both cross-sectional and longitudinal relations of EFs and depressive symptoms to academic achievement in an adolescent sample. It also contributes to prior research by exploring the relations of both cross-sectional and longitudinal relations of EFs to indices of wellbeing. Adolescence represents an ideal window for prevention and intervention, as it is a transitional period characterized by significant biological, psychosocial, and cognitive changes (Pfeifer and Blakemore, 2012). Research in cognitive neuroscience demonstrates that the adolescent brain undergoes a period of increased neural plasticity, marked by significant development and restructuring of the prefrontal cortex and its connections to other brain regions (Galván, 2021). This is particularly relevant given that the prefrontal brain network underlies EFs (Niendam et al., 2012). Because of this neural malleability, adolescence provides a critical opportunity to introduce experiences and activities that support the development of EFs—one of the motivations for focusing on this age group in the current study. The finding that EFs significantly predict academic achievement further supports the value of equipping educators with ecologically valid strategies to foster EF development within classroom settings and broader school environments. The finding that depressive symptoms significantly predict worse academic outcomes also highlights the need for targeted approaches that promote mental health and wellbeing, many of which may also boost EFs and academic performance at the same time. Such integrated and innovative educational approaches not only promote cognitive growth, but also support the development of social and emotional skills, which may help to address the needs of the "whole child" (Immordino-Yang et al., 2019).

Data availability statement

The datasets presented in this article are not readily available because of the nature of this research, as participants did not agree for their data to be shared publicly. Requests to access the datasets should be directed to MJK, kitil@uic.edu.

Ethics statement

The studies involving humans were approved by the University of British Columbia Behavioral Research Ethics Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MK: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft. AD: Conceptualization, Methodology, Writing – review & editing. MG: Methodology, Writing – review & editing. KS-R: Conceptualization, Funding acquisition, Methodology, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported by a grant awarded to KSR from the Goldie Hawn Foundation and the Edith Lando Charitable Foundation. AD was partially supported by a Canada Research Chair Tier 1 (CRC #950–27472) from the Canada Excellence Research Chairs Program during all phases of this project. These funding sources had no involvement in study design, data collection and analysis, or writing of this manuscript.

Acknowledgments

We thank the former KSR social and emotional learning research lab members, Drs. Jenna Whitehead and Jacqueline Maloney, for their assistance with data collection. We are grateful to the student participants and their parents and to the teachers and administrators in the school district for their participation in this project.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. ChatGPT (GPT-4-turbo, May 2024 version), a generative AI model developed by OpenAI (https://openai.com/chatgpt), was used to support rephrasing of parts of the text and interpretation of selected statistical outputs. All content was critically reviewed and finalized by the authors.

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