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Research Article

Executive functions in Thai adolescents: Development of an inventory measure, its factors, and norms

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Abstract

Objective: Thai researchers developed a new self-report measure of executive functions for adolescents based on Diamond's framework (the Behavioral Inventory Measure of Executive Functions [BIMEFs]). How it was developed, its psychometric properties, and norms by sex and age are reported here. **Method:** An independent panel of experts evaluated the content validity of BIMEFs. Reliability was checked using Cronbach's alpha with a sample of 45 secondary students. 1,865 students, ages 12 – 18 years (65% female) from across Thailand participated in the normative study. **Results:** The BIMEFs consists of 42 items that assess inhibitory control (IC), working memory (WM), and cognitive flexibility (CF), including eight subcomponents. For all items, the index of item-objective congruence was >0.5 and Cronbach's alpha was >0.7. Confirmatory factor analysis (CFA) showed the adjusted goodness of fit index to be 0.9. The strongest sex difference was for IC. Students of 13 years scored lower on EFs overall, IC, WM, CF, and all subcomponents than older students. Self-control, verbal working memory, and being able to change perspectives showed the most pronounced differences by age. **Conclusion:** The BIMEFs, which is designed to be culturally-appropriate for Thailand and cross-culturally generally, is the first EF questionnaire based on Diamond's framework. It shows good psychometric properties and sensitivity to age and sex differences. It indicates that IC development, at least in Thailand, plateaus earlier than WM and CF and that CF shows a more protracted development during adolescence than IC or WM.

Keywords: Executive functions; Inhibitory control; Selective attention; Working memory; Cognitive flexibility; Inventory measure; Adolescents

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Statement of Research Significance

Research Question (s) or Topic(s): We report the development of a new behavioral inventory measure of executive functions for Thai adolescents, its psychometric properties, norms by sex and age, and differences by sex and age. **Main Findings:** This 42-item questionnaire assesses inhibitory control, working memory, cognitive flexibility, and their eight subcomponents. It has good psychometric properties. Female scored higher on inhibitory control and all its subcomponents than males. The largest age differences in executive functions were between 13 – 16 years and the least between 15 – 18 years. Self-control and verbal working memory showed the sharpest early improvement. The cognitive flexibility subcomponent, being able to change perspectives, showed the most change in later years of all EF variables. **Study Contributions:** This first inventory based on Diamond's framework specifically designed to be culturally-appropriate for Thailand and cross-culturally. Our results closely align with findings from the West, suggesting cross-cultural universality in adolescents' EF development.

Introduction

Executive functions (EFs) are neurocognitive skills that govern the goal-directed control of thought, emotion, and action, modulating attention and controlling behavior to enable more adaptive, planned, and focused action (Diamond, 2013; Zelazo, 2015; Hendry et al., 2016; Cristofori et al., 2019). EFs are essential skills for doing well at school and in the workforce, promoting psychosocial well-being, and for overall quality of life (Alloway & Alloway, 2010; Cristofori et al., 2019; Haenjohn, 2017, 2019; Haenjohn & Namyen, 2023; Moffitt et al., 2011; Toh et al., 2020). EF dysfunction can lead to learning difficulties and behavioral problems (Hammud et al., 2023; McNeilly et al., 2021; Riggs et al.,

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2006; Yang et al., 2022). Researchers in developmental psychology, cognitive psychology, education, and neuroscience have increasingly focused on assessing EFs in children (Diamond, 2016; Miyake et al., 2000; Zelazo et al., 2016) and adolescence (Blakemore & Mills, 2014; Ferguson et al., 2021) that are the periods of marked development improvement in higher cognitive abilities (Larsen & Luna, 2018).

The concept of EFs composed of three core components (inhibitory control [IC], working memory [WM], and cognitive flexibility [CF]) as proposed by Diamond (Diamond, 2013; 2020; Diamond & Ling, 2019) has long been widely recognized and influential. Diamond defines IC as comprised of self-control (or response inhibition) plus interference control (which includes selective/focused attention and cognitive inhibition). Self-control is the capacity to resist strong pulls to respond a certain way or impulsively and instead give the more appropriate or considered response. Selective attention is the ability to ignore external distractions, whereas cognitive inhibition involves ignoring internal distractions (as one might see in mind-wandering or excessive rumination). WM involves mentally maintaining and manipulating information, such as mentally exploring ideas, linking one concept to another, reordering or updating information, reflecting on the past or future, performing mental calculations, or holding onto a question you want to ask while following an ongoing conversation. CF involves being able to view things from different perspectives, think innovatively, navigate unexpected obstacles, adapt to changes, and seamlessly shift between tasks (Diamond, 2013, 2020).

Diamond's conceptualization has often been operationalized and measured through task-based assessments typically conducted in laboratory settings. Performance-based EF tasks typically use specially designed tool kits or are computerized. Examples of such tests include the Wisconsin Card Sorting Test, often used to assess CF and other aspects of EFs (Miles et al., 2021; Barcelo et al., 1997; Monchi et al., 2001) and the Hearts and Flowers task, often used to assess IC and CF (Davidson et al, 2006; Wright & Diamond, 2014). Such methods provide direct measures of actual behavioral performance. However, these tasks assess performance on arbitrary tasks far removed from daily life. EF performance on such tests is confounded with speed of processing (since these are usually timed) and with anxiety associated with being tested. Further, the use of these tests is limited by the cost of the supplies and equipment needed and that they have normally been administered one-on-one limiting their scalability (although methods for administering them to groups are evolving, see, e.g., Meuwissen et al., 2017; Obradović et al., 2018; Rosas et al., 2022).

On the other hand, self-report measures, while limited by all the problems of subjective reporting, are often used as a part of neuropsychological assessments because of a number of factors: (a) they have more ecological validity than laboratory tests because they ask about behavior in everyday life (Barkley & Fischer, 2011; Corneille & Gawronski, 2024), (b) they are easy to administer, often not requiring professional training to administer, (c) they are time-efficient, often requiring just a few minutes, and (d) they are suitable for large-scale or community-based research that requires large-scale and/or geographically-dispersed data collection (Hornsveld et al., 2020). When they are provided for free, they are cost-effective as they do not require expensive equipment. The development of free or low-cost EF self-report or observational scales represents an important option that can facilitate broader population-level screening. Such tools can serve as preliminary indicators of EF-related concerns and might identify individuals who could benefit from further evaluation through professional clinical assessment.

There is presently no EF questionnaire based on Diamond's framework, so the development of a scalable and accessible EF assessment instrument based on her framework seemed of importance for both research and applied settings. There is also no measure designed by Thai researchers for assessing EFs in Thailand. Western measures do not translate perfectly to Thai culture. For example, an item in the highly-respected and widely-used Behavior Rating Inventory of Executive Function (BRIEF) is: "My eyes fill with tears quickly over little things" (Gioia et al., 2003). Such an item may not be culturally appropriate for Thai adolescents, as traditional Thai cultural norms place a strong emphasis on emotional restraint. Displays of sadness, such as crying, are generally discouraged, particularly among males. The present study sought to fill those two gaps, creating a measure based on Diamond's framework appropriate for the Thai context. The measure is intended to be appropriate cross-culturally so items reflecting culturally-specific norms, such as emotional suppression or unquestioning obedience, were excluded, such as "I can always control my thoughts and feelings to avoid conflict" or "I always follow instructions from teachers without question." The Behavioral Inventory Measure of Executive Functions (BIMEFs) was created as a collaboration between Thai researchers and Diamond. Unlike measures like the BRIEF, that are intended primarily for clinical use, the BIMEFs is intended for use by researchers, educators, and even parents. It fills a need not met by the BRIEF or other EF questionnaires in having an inexpensive, readily accessible instrument for these purposes. We administered the BIMEFs to 1,865 students (ages 12 – 18 years) all across Thailand, establishing nationwide norms for this measure at each of those ages and for boys and girls.

Conceptual framework

The schematic representation of EFs is shown in Figure 1. EFs have three separate core components: IC, WM, and CF. These core components are further divided into sub-components. IC includes both interference control (which includes cognitive inhibition and selective attention) and response inhibition (which includes self-control and discipline). WM includes both verbal and visual–spatial working memory. CF includes being able to see things from different perspectives, being able to seamlessly switch between tasks, and being able to think outside the box. These EF core components help to facilitate higher EFs, such as reasoning, problem solving, and planning (Diamond, 2013).

Methods

The research was carried out in two phases. Phase I involved constructing a behavioral index of EFs appropriate for Thai adolescents. Phase II focused on collecting data using the newly constructed EF measure. The study was approved by the Ethical Committee of Burapha University and participants in both phases were treated according to standard ethical guidelines.

Phase I

Stage 1 of Phase 1: Constructing the preliminary BIMEFs for Thai adolescents and examining its internal consistency

Participants in Stage 1 of Phase 1: Participants here were an independent panel of five experts with expertise in neuroscience, psychology, child and adolescent psychiatry, statistics and measurement.

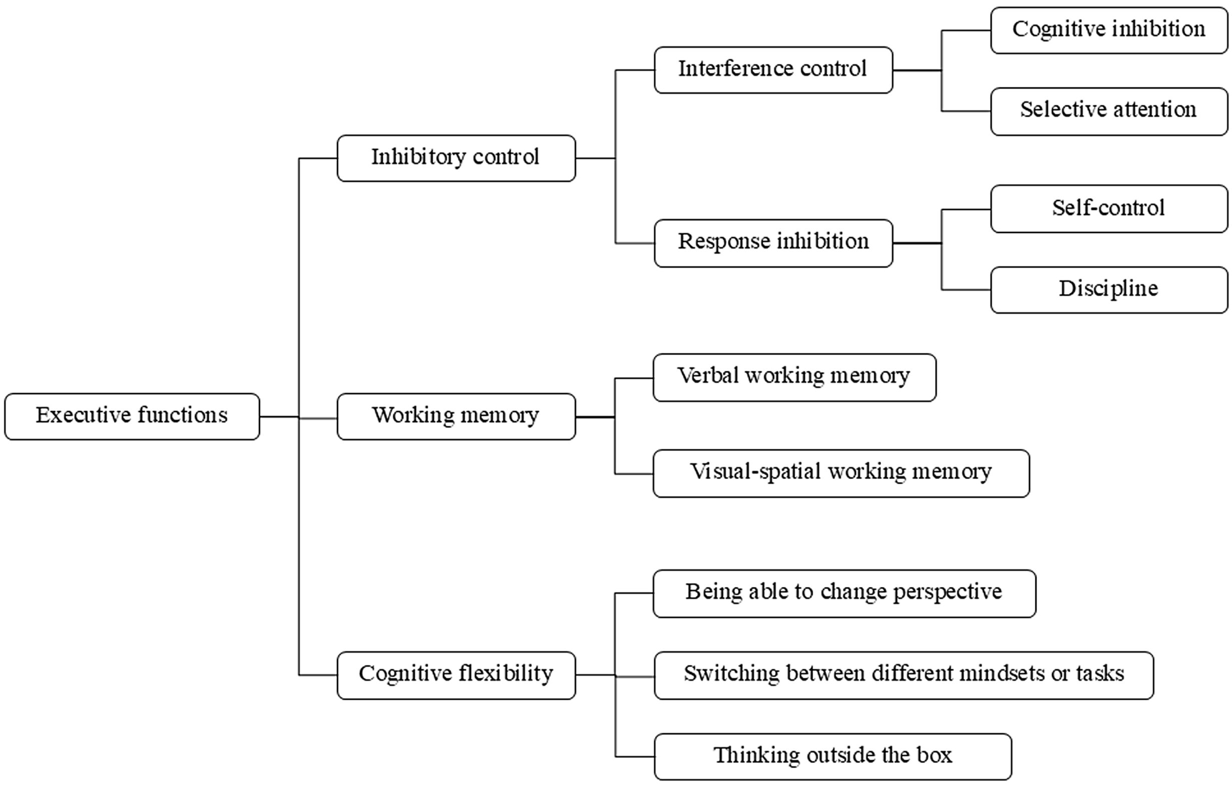

Figure 1. Conceptual framework of EFs.

Procedure for Stage 1 of Phase 1: To develop the BIMEFs, operational definitions, behavioral indicators and items were iteratively refined to align with Diamond's framework (Diamond, 2013). The interdisciplinary research team comprised of experts from various fields, including psychology, neuroscience, behavior science, and the science of education, collaboratively synthesized relevant concepts and engaged in extensive discussions to determine the operational definitions and indicators. After developing the operational definitions and indicators, the materials were submitted to Diamond, the originator of the conceptual framework, for an initial content validity review. Based on Diamond's feedback, the research team held follow-up meetings to revise the items accordingly. The revised version was then resubmitted for her further review. This iterative process continued until no further modifications were recommended. Subsequently, the 75-item instrument was translated into Thai by an expert with strong proficiency in both the relevant subject matter and the Thai language. The resulting BIMEFs is an online self-assessment questionnaire administered via Google Forms. Supplementary Table 1 in the Appendix provides the operational definitions, behavioral indicators, and the 75 items included in the BIMEFs.

Then the independent panel of five experts evaluated the BIMEFs for content validity.

Results for Stage 1 of Phase 1: The independent panel indicated that all items demonstrated a satisfactory index of item-objective congruence (IOC) values (≥ 0.50). This suggests that each item demonstrated appropriate alignment with its corresponding construct, ensuring that the scale adequately represented the theoretical dimensions and fulfilled the measurement objectives. Items with IOC values below 0.50 were either removed or revised prior to re-evaluation.

Stage 2 of phase 1: examining the internal consistency of BIMEFs

Participants in Stage 2 of Phase 1: Participants here were 45 students (64% Female), ages 12 – 18 years, who were studying in Chonburi province, Thailand. Inclusion criteria included normal vision or corrected-to-normal vision with eyeglasses, ability to communicate in Thai, as confirmed by teachers; and voluntary consent to participate.

Procedure for Stage 2 of Phase 1: The initial version of BIMEFs consisted of 75 items. The number of items per subcomponents of IC was: Cognitive Inhibition (CI: 8 items), Selective Attention (SA: 8 items), Self-Control (SC: 8 items), and Discipline (DP: 8 items), for WM: Verbal WM (VWM:11 items) and Visual–Spatial WM (VSM:10 items), and for CF: Being Able to Change Perspectives (BCP: 6 items), Switching Between Different Mindsets or Tasks (SDM: 8 items), and Thinking Outside the Box (TOB: 8 items).

Respondents selected the item that best reflected their behavior using a four-point Likert scale: 1 = never, 2 = sometimes, 3 = frequently, and 4 = always. There were both positive and negative items to try to minimize response biases. By including a mix of positive and negative items, we hoped that respondents would consider the questions and not mindlessly always endorse the high or low rating. Scores for negative items were reversed in the data analyses. Thus, higher scores indicated better EFs.

Internal consistency reliability was assessed using Cronbach's alpha coefficients. A threshold of ≥ 0.70 was established as acceptable. For any component with Cronbach's alpha <0.70, the appropriateness of the item was re-examined, and item removal or revision was considered to enhance reliability of the measure. Item discrimination analysis using the total-item correlation (TIC) method was used to assess discrimination power. The criterion for

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acceptable discrimination was set at a correlation coefficient of ≥ 0.20.

Results for Stage 2 of Phase 1: The internal consistency reliability for Cronbach's alpha for CI was 0.80, for SA: 0.86, for SC: 0.90, for DP: 0.84, for VWM: 0.95, for VSM: 0.90, for BCP: 0.94, for SDM: 0.83, and for TOB: 0.82. TIC revealed all items demonstrated satisfactory discrimination power. Corrected TIC coefficients were >0.20 for all items, indicating that each item was positively, and moderately to strongly, correlated with the total score of its respective EF subcomponent. Discrimination power was also examined using TIC with Pearson's correlation coefficient to evaluate the extent to which each item effectively distinguished between individuals with higher and lower levels of each construct. Based on the results obtained, the number of items was reduced to 45 due to low and negative corrected item-total correlation (CITC) values, indicating a lack of internal consistency. The unidimensionality analysis revealed that each dimension exhibited multidimensional characteristics, clearly separating into positive and negative item dimensions. However, both dimensions were positively correlated (i.e., responses to negative and positive items were in the same direction). This suggests that the negatively-phrased items were less appropriate, at least for this adolescent population. Rather than re-phrasing items worded in the negative into positive terms, preserving the unique information the negatively-worded items asked about, all negatively-worded items were omitted; only positively-worded items were retained. In retrospect, we would have done this differently. The subsequent CFA results indicated that the 45-item model demonstrated a good fit within each component of the BIMEFs, as evidenced by acceptable fit indices: chi-square (4295, 933) = 4.60, adjusted goodness of fit index = 0.897, RMSEA = 0.044, CFI = 0.983, and SRMR = 0.043. These findings provide robust empirical support for the BIMEFs as a contextually appropriate instrument for assessing EFs among Thai adolescents. The research team then created a user manual for the BIMEFs.

Phase II: collecting data using the newly constructed EF measure

Participants in phase II

Participants here were 1,865 students (65% female), ages 12 – 18 years (% female: 62, 61, 66, 56, 70, 72, 63 respectively), who were studying in schools under the Office of the Basic Education Commission in Thailand. To reflect a national perspective, a nationwide sampling strategy was employed. A multi-stage random sampling technique was employed to ensure national representativeness. In the first stage, schools were selected from different regions of Thailand using simple random sampling. In the second stage, schools were further stratified by size (small, medium, and large) and selected using stratified random sampling. In the third stage, students from each selected school were randomly selected using simple random sampling. Inclusion criteria included normal vision or corrected-to-normal vision with eyeglasses, ability to communicate in Thai, as confirmed by teachers; and voluntary consent to participate. We did not exclude any participant based on any neurodevelopmental, psychiatric, or neurological disorders.

Procedure for phase II

In addition to administering the BIMEFs, general demographic information was collected from respondents also via Google Forms, including sex, grade level, and other relevant personal data such as whether they had ever been diagnosed with any mental health condition, such as attention-deficit/hyperactivity disorder or autism spectrum disorder, and whether they were currently taking any medications that might affect cognition.

The 45 items in the BIMEFs were distributed across nine subcomponents thusly: IC subcomponents (Cognitive Inhibition (CI: 3 items), Selective Attention (SA: 5 items), Self-Control (SC: 5 items), and Discipline (DP: 3 items)), WM subcomponents (Verbal WM (VWM:7 items) and Visual–Spatial WM (VSM:7 items)), and CF subcomponents (Being Able to Change Perspectives (BCP: 6 items), Switching Between Different Mindsets or Tasks (SDM: 6 items), and Thinking Outside the Box (TOB: 3 items)), as shown in Table 1.

Data analyses

CFA was conducted on the final set of 45 items for each subcomponent, EF component, and overall EFs to ensure the measurement model appropriately represented the theoretical structure underlying the EF framework. In evaluating model fit for CFA, several goodness-of-fit indices were used. Chi-square statistic (χ^2) assesses overall model fit; however, it is sensitive to sample size and may indicate poor fit even with minor discrepancies. Therefore, additional indices were used: the comparative fit index (CFI, with values >0.90 indicating acceptable fit and values >0.95 representing excellent fit), root mean square error of approximation (RMSEA, which evaluates the degree of approximation in the population, with values <0.08 suggesting acceptable fit and values <0.05 indicating good fit), and standardized root mean square residual (SRMR, which reflects the average discrepancy between observed and predicted correlations, with values <0.08 indicating a good fit). Together, these indices provided a comprehensive assessment of the adequacy of the hypothesized model.

The interpretation of norm-referenced scores was based on normalized *T*-scores. *T*-scores are z scores times 10 with 50 added to the product of that, thus ensuring that no score is negative. The BIMEFs was scored as follows: First, the total score for each EF subcomponent was divided by the number of items for that subcomponent, then normalized *T*-scores were calculated for each EF subcomponent. Second, to arrive at the *T*-score for each EF component (IC, WM, and CF), the *T*-scores for each of its subcomponents was summed and then divided by the number of subcomponents. Third, the *T*-score for EFs overall was arrived at by summing the *T*-scores for IC, WM, and CF. (Since the number of BIMEFs items per subcomponent differed, summing across all individual items would have given disproportionate weight to subcomponents with more BIMEFs items.)

Since no sex by age interactions were significant, sex is not included in the analyses of age differences and age is not included in the analyses of sex differences reported here, thus results for univariate analyses only are presented here. To analyze sex differences, analysis of variance was used. To analyze differences by age and grade level, linear regression was used, conducted by DA. Pairwise comparisons were conducted between each age and each school grade. Given the number of analyses conducted, we only considered p-values of $< .001$ to be statistically significant.

Results for phase II

The results for the CFA from 1,865 high school students are presented in the Figure 2, the three-factor model demonstrated acceptable fit indices, supporting the adequacy of the proposed

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Table 1. Results of the item analysis, including discriminative power, measurement of consistency of each component, loading of components, loading squared of components, and residual of items, were obtained for BIMEFs in Thai adolescents. These results were obtained through EFA and CFA

Item number	Items	Discriminative power		Internal consistency (Cronbach α)	EFA	CFA		
		CITC	SMC		Loading	Loading	Loading^2	Residual
Cognitive inhibition								
1	4. I can stop distracting thoughts while having a conversation with others.	0.560	0.319	0.731	0.812	0.615	0.378	0.622
2	5. Even though thoughts about other things might pop up while working on a report, I can stop those thoughts.	0.581	0.339		0.826	0.638	0.407	0.593
3	7. I can focus on the present.	0.522	0.273		0.782	0.715	0.511	0.489
Selective attention								
4	9. When biking or driving, I am able to focus on the road and not be distracted.	0.404	0.179	0.706	0.621	0.520	0.270	0.730
5	11. Even though there is a disruptive question or comment while I am presenting my classwork, I can continue and smoothly present my classwork.	0.510	0.283		0.728	0.647	0.419	0.581
6	12. I can focus on what someone is saying to me even when the environment is very noisy.	0.527	0.291		0.740	0.648	0.420	0.581
7	14. I can continue to concentrate on reading a book even when a TV program comes on.	0.377	0.168		0.589	0.418	0.175	0.825
8	15. I focus on the workload that I am working on without letting noise in the room bother me.	0.512	0.268		0.721	0.607	0.368	0.631
Self-control								
9	17. If someone says or does something that hurts me, I am able to resist doing something unkind to that person.	0.402	0.164	0.728	0.599	0.538	0.289	0.711
10	19. I do not interrupt while others are speaking.	0.524	0.296		0.732	0.592	0.350	0.650
11	20. I patiently wait to buy the products I want until they are available at a lower price.	0.446	0.202		0.650	0.527	0.278	0.722
12	21. I think and ponder before speaking or acting.	0.524	0.283		0.728	0.623	0.388	0.612
13	22. I do not try to butt ahead in line.	0.561	0.325		0.760	0.660	0.436	0.564
Discipline								
14	25. Even though something might be a lot harder and take a lot longer than I expected, I keep at it until it is finished.	0.612	0.418	0.736	0.849	0.704	0.496	0.504
15	26. If I am determined to do something, then I have to accomplish it.	0.625	0.429		0.858	0.700	0.490	0.510
16	31. I do what I am supposed to do, even if I don't want to.	0.453	0.206		0.718	0.581	0.338	0.662
Verbal working memory								
17	33. I am able to mentally put information I hear in the correct and sequential order.	0.653	0.430	0.869	0.756	0.714	0.510	0.490
18	35. I can mentally calculate whether I have enough money to purchase all the items I might want to buy.	0.563	0.333		0.675	0.612	0.375	0.625
19	37. I am good at relating what I am learning now to other things I learned earlier.	0.640	0.452		0.748	0.658	0.433	0.567
20	39. If I have a question or comment, I can follow the ongoing conversation or lecture and still remember what I was going to say when the time comes to say or ask it.	0.550	0.306		0.663	0.627	0.393	0.607
21	41. I am good at seeing the connections between something new I learn or hear and other things I already knew.	0.681	0.505		0.783	0.702	0.493	0.508
22	42. I can compare and contrast new situations with old ones for decision-making.	0.715	0.541		0.810	0.748	0.560	0.441
23	43. I consider the pros and cons of each alternative to select the best way to solve the problem.	0.710	0.532		0.805	0.761	0.579	0.421
Visual–spatial working memory								
24	44. I am able to mentally sort or re-order items by size without needing to see them again or write anything down.	0.551	0.322	0.804	0.692	0.673	0.453	0.546
25	45. I am able to memorize the route/directions after the first trip.	0.528	0.317		0.671	0.500	0.250	0.750
26	46. I can mentally calculate the distance to know which route is longer or shorter.	0.598	0.399		0.737	0.594	0.353	0.647
27	47. If I need to do several errands, I can mentally calculate the most efficient route.	0.577	0.375		0.719	0.692	0.479	0.521
28	49. Even if two shapes are quite close in size, I can tell which is larger without having to physically put them next to one another.	0.517	0.292		0.657	0.591	0.349	0.651
29	50. If I follow someone along a route to get somewhere I haven't been before, I can find my way back without difficulty.	0.522	0.304		0.661	0.506	0.256	0.744
30	51. When working on a jigsaw puzzle, I can tell whether a piece will fit in a certain place or not before actually placing it there.	0.466	0.229		0.607	0.534	0.285	0.715
Being able to change perspectives								
31	54. I am able to switch from seeing something as an unwelcome problem to seeing it as a welcome challenge.	0.546	0.302	0.853	0.676	0.671	0.450	0.549
32	55. Amidst the bad, I can still see the good things that are hidden.	0.655	0.439		0.774	0.681	0.464	0.536
33	56. I always find a way to succeed despite obstacles.	0.653	0.431		0.772	0.689	0.475	0.525
34	57. I am able to change my mindset to focus on the present and to enjoy every problem I face.	0.648	0.421		0.766	0.717	0.514	0.486

(*Continued*)

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Table 1. (*Continued*)

Item number	Items	Discriminative power		Internal consistency (Cronbach α)	EFA	CFA		
		CITC	SMC		Loading	Loading	Loading^2	Residual
35	58. I am able to see opportunities hidden in life's crises.	0.678	0.479		0.793	0.706	0.498	0.501
36	59. I can turn obstacles into opportunities for self-improvement.	0.650	0.442		0.771	0.692	0.479	0.521
Switching between different mindsets or tasks								
37	61. I am able to switch my focus among having a conversation with my friends, summarizing report contents, and arranging figures for presentation.	0.513	0.279	0.746	0.697	0.597	0.356	0.644
38	63. I am able to switch my thoughts between focusing on color to focusing on shapes or numbers.	0.484	0.268		0.672	0.701	0.491	0.509
39	64. I am able to talk on the phone while doing other activities.	0.479	0.256		0.665	0.636	0.404	0.595
40	65. I can read books and watch TV at the same time.	0.440	0.210		0.612	0.275	0.076	0.924
41	66. I can have a conversation with different people on a variety of topics at the same time.	0.561	0.318		0.735	0.565	0.319	0.681
42	67. I can mentally calculate while holding a conversation with friends.	0.437	0.213		0.611	0.408	0.166	0.833
Thinking outside the box								
43	71. I can find solutions to problems that others cannot see.	0.487	0.268	0.612	0.815	0.668	0.446	0.553
44	72. I am able the find a better method for solving problems, although the old method worked.	0.459	0.253		0.798	0.717	0.514	0.486
45	73. I tend to have different ideas from others about clothing, designing, etc.	0.328	0.109		0.641	0.407	0.166	0.835

model. It shows good psychometric properties and sensitivity to age and sex differences.

However, omitting all the negatively-worded items had left only 3 items assessing the TOB subcomponent and their internal consistency was weak; including TOB weakened the results for CF. Thus, items assessing the TOB subcomponent were dropped, leaving a total of 42 items in the BIMEFs, which is what the analyses of national norms and results by sex, age, and grade level are based on.

The results for national norms are presented in Table 2, providing a standardized reference for interpreting individual scores.

Analyses of BIMEFs responses from Thai adolescents by sex and age.

Female adolescents tended to report that they have better EFs overall than did male adolescents, but that did not quite reach statistical significance (see Table 3). For IC, however, the sex difference is clear and consistent. Females scored higher on IC (CI, SA, SC, and DP), and on all 4 subcomponents of IC, than did males. There was no sex difference for WM overall because the sex differences go in opposite directions for its two subcomponents. Females tended to report better VWM than males, while males tended to report better VSM than females (though the latter was only significant at $p < .045$). There was no sex difference for CF or any of its subcomponents.

We recruited the students from 7th to 12th grades of middle and high schools, ranging in age from 12 to 18 years old. Each grade includes a few children of a younger age (e.g., 20% of the students in Grade 7 in our study were 12 years old, the rest were 13 years old; similarly, 22% of the students in Grade 8 in our study were 13 years old, the rest were 14 years old, etc.) thus there were only a small number of students aged 12 years in our study. Therefore, the analyses by age were conducted starting from age 13, where the results were more reliable. For analyses of male–female differences (see Table 3) and of differences by grade level in school (see supplementary online table) all participants, including the 12-year-olds are included, and the means on each EF variable for children of 12 years are provided in Table 4, though readers are cautioned that given the small N for that age, the results for 12-year-olds should not be taken as robust indicators of the population mean.

Results revealed a significant main effect of age on overall EFs (see Table 4). Indeed, *all* EF variables showed a significant main effect for age using BIMEFs (indicating that older children reported having better EFs than younger children). The final column in Table 4 presents results of pairwise comparisons between the different ages for EFs overall and each EF component and sub-component that were significant at $p < .001$ or showed a trend (i.e., were significant at $p < .03$). These pairwise comparisons show that students aged 13 years scored lower than students of any other age (from 14 through 18 years) on overall EFs, the EF components of IC and WM, and all of their subcomponents. For CF and its subcomponents (BCP and SDM), 13-year-olds reported significantly worse performance than students of 15, 16, 17, or 18 years, but only showed a trend to be worse than 14-year-olds (see Table 4).

For EFs overall, 14-year-olds scored lower than 18-year-olds and tended to score lower than 17-year-olds; from age 15 on there were no significant pairwise differences between ages. This indicates that, while self-reported EFs at age 13 were lower than for all other ages (even age 14), after that there was little self-reported difference in EFs overall in this sample.

For IC and its four subcomponents, there were no significant pairwise differences between students of 14 – 18 years, except for SC, where 18-year-olds scored significantly better than 14-year-olds. As the graphs in Table 4 illustrate, IC and its subcomponents tended to plateau after 14 years of age, especially the IC subcomponents that reflect attentional interference control (CI and SA). The age differences in SA were smaller than for the other IC subcomponents (CI, SC, and DP).

WM and its subcomponents showed rather continuous improvement from 13 – 18 years. Students of 14 years tended to report poorer WM than students of 16 or 18 years. The self-reported VWM of students of 14 years was worse than 16- and 18-year-olds, and tended to be worse than 17-year-olds. VSM tended to be worse among 14-year-olds than among 18-year-olds and seemed to plateau at 15 years. Younger students tended to report being poorer on VWM than VSM, so the slope for VWM as steeper than for VSM for ages 13 – 16.

Unlike EFs overall and IC, for CF there was only a tendency for 14-year-olds to score better than 13-year-olds, and improvements

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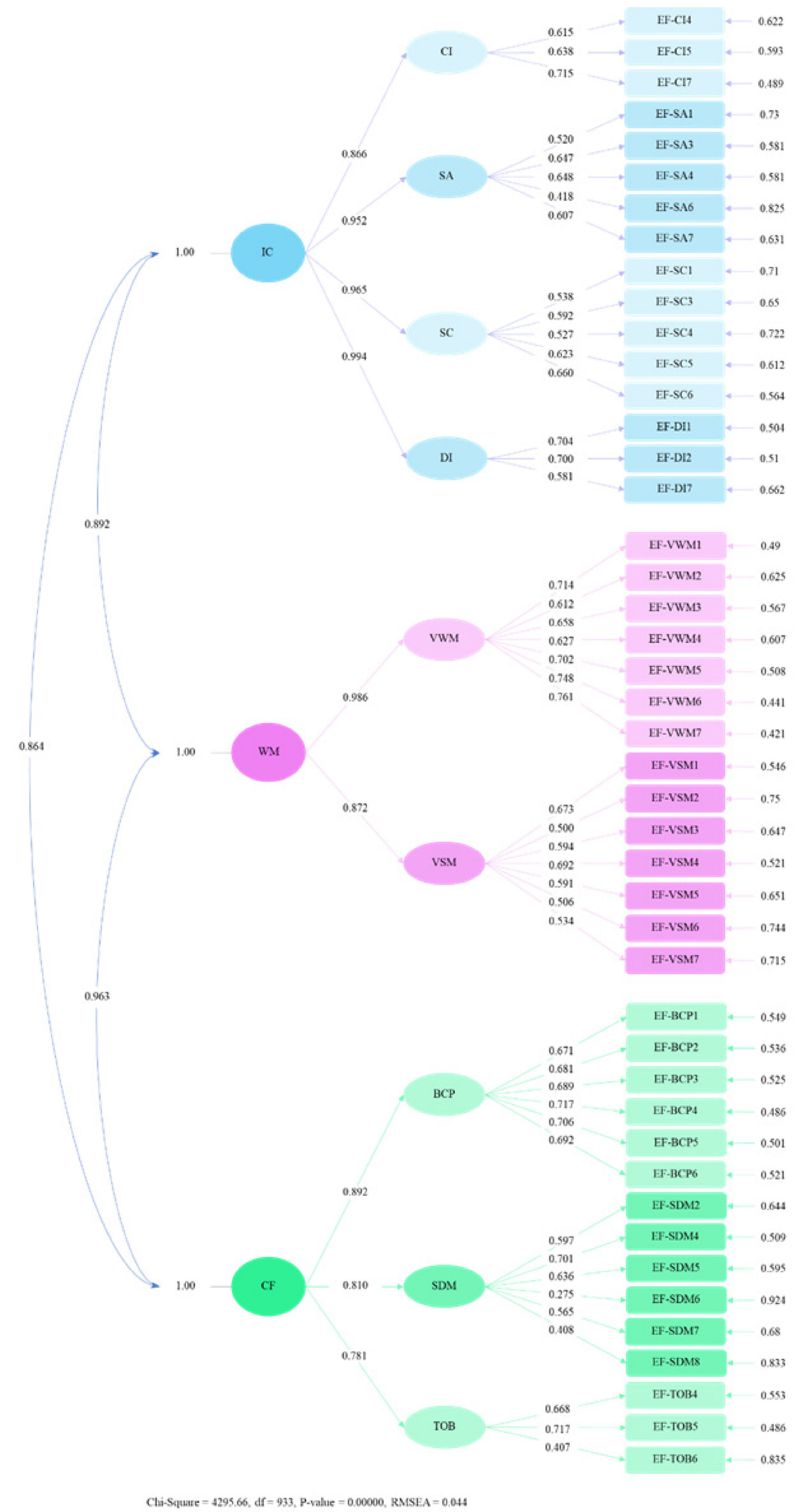

Figure 2. The finding of confirmatory factor analysis of the BIMEFs in Thai adolescents.

after 14 years were still evident at 16 and 17 years and especially at 18 years, suggesting that while self-reported IC improved sharply between 13 and 14 years and little thereafter, CF showed a more protracted development (see the graphs in Table 4). The CF subcomponent of BCP had the steepest slope from 14-18 years of all EF variables, and together with VWM showed the most pairwise differences between 14-year-olds and older children. Students age 14 were significantly worse at BCP than 16- or 18-year-olds and showed a trend to be worse than 17-year-olds. This is the only EF variable where 15-year-olds showed evidence of performing worse

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Table 2. The interpretation criteria of the BIMEFs according to the country norm-referenced criteria (standardized *T*-scores) for Thai adolescents

Component	Number of Items	Mean	Quintiles				
			Lowest Level	Low Level	Moder-ate Level	High Level	Highest Level
Executive Functions (EFs) overall	**42**	**150**	**<132**	**132 – 145**	**146 – 156**	**157 – 170**	**>170**
Inhibitory control (IC)	**16**	**50**	**<44**	**44 – 48**	**49 – 52**	**53 – 57**	**>57**
Working memory (WM)	**14**	**50**	**<43**	**43 – 47**	**48 – 52**	**53 – 58**	**>58**
Cognitive flexibility (CF)	**12**	**50**	**<43**	**43 – 48**	**49 – 52**	**52 – 57**	**>57**

Table 3. Results of the analysis of variance comparing the EF performance of male and female Thai adolescents

EF Variable	Mean *(sd)*		ANOVA Results for Sex Differences			
	Males (*N* = 653)	Females (*N* = 1,212)	*F*-test	R^2	*p*-value	Direction of Difference
Overall Executive Functions (EFs)	148.14 *(26.51)*	151.00 *(21.78)*	6.27	0.003	*p* = *.01*	*M* < *F* (trend)
Inhibitory Control (IC)	48.59 *(9.21)*	50.76 *(7.89)*	28.30	0.02	*p* < *.001*	*M* < *F*
Working Memory (WM)	49.82 *(10.19)*	50.10 *(8.51)*	0.39	0.03	*p* = .54	NS
Cognitive Flexibility (CF)	49.72 *(9.22)*	50.15 *(8.18)*	1.04	0.001	*p* = *.31*	NS
Cognitive inhibition (CI)	48.79 *(10.39)*	50.65 *(9.73)*	14.88	0.01	*p* < *.001*	*M* < F
Selective attention (SA)	48.89 *(10.65)*	50.60 *(9.58)*	12.39	0.01	*p* < *.001*	*M* < F
Self-control (SC)	48.07 *(11.16)*	51.04 *(9.15)*	38.31	0.001	*p* < *.001*	*M* < F
Discipline (DP)	48.63 *(10.61)*	50.74 *(9.58)*	19.02	0.01	*p* < *.001*	*M* < F
Verbal working memory (VWM)	49.01 *(11.01)*	50.53 *(9.37)*	9.91	0.01	*p* = *.002*	*M* < F (trend)
Visual–spatial working memory (VSM)	50.63 *(10.73)*	49.66 *(9.57)*	4.04	0.002	*p* = *.045*	*M* > F (weak trend)
Being able to change perspectives (BCP)	49.56 *(10.37)*	50.24 *(9.79)*	1.98	0.001	*p* = .16	NS
Switching between different mindsets or tasks (SDM)	49.89 *(10.28)*	50.06 *(9.85)*	0.12	0.0001	*p* = .73	NS

Legend: sd = standard deviation, NS = not significant. Degrees of freedom for all rows are 1 for the numerator and 1,862 for the denominator.

than older children; they scored worse than 18-year-olds and tended to score worse than 17-year-olds. SDM seemed to plateau at 15 years. There was so much individual variation in scores on the BIMEFs, however, that neither age nor sex accounted for more than 3% of the variance for any EF component or subcomponent.

We thought that Thai educators might want to see our results by grade level, so those results are presented in Supplementary Table 2. Those results, which include all students even the 12-year-olds, closely mirror the results by age. Like the regressions by age, the regressions by grade level were significant for EFs overall, all EF components, and all EF subcomponents. Scores for students in Grade 7 were lower for EFs overall, IC, WM, all four IC subcomponents, and both WM subcomponents than students in any other grade from 8 – 12 (just as 13-year-olds scored significantly worse than all older ages [14-18] on those same variables).

Unlike the results for IC differences by age, where no differences were found between ages 14-18 except on SC where 18-year-olds scored higher than 14-year-olds, IC tended to be better (according to self-reports) in Grade 10 than Grade 8 and in Grade 12 compared with Grade 9. And, not only was SC better in Grade 10 than Grade 8, DP tended to better in Grade 10 than Grade 8 and in Grade 11 compared with Grade 9.

WM also showed more improvements continuing past the youngest grade than it showed past the youngest age (perhaps because the youngest age in the age analyses [age 13] spanned Grades 7 and 8). WM tended to be better in Grade 10 than Grade 8 and in Grades 11 and 12 compared with Grade 9. VWM was better in Grade 10 than Grade 8 and tended to be better in Grades 11 and 12 compared with Grade 9. VSM showed a tendency to better in Grade 11 than Grade 9. These WM, VWM, and VSM results map well onto the differences by age observed.

On CF, 7th graders only tended to score worse than 8th graders, just as 13-year-olds only a tended to perform worse than 14-year-olds. Scores in Grade 8 tended to be lower than in Grade 10, and scores in Grade 9 tended to be lower than in Grades 11 and 12, consistent with the protracted development of CF seen over age. Unlike all other EF variables, SDM showed no difference in Grade 7 versus Grade 8 and although Grade 7 scores were significantly lower than in Grades 9, 10, and 12, they only tended to lower than in Grade 10. Just as BCP showed the clearest and strongest differences by age, the same was true for differences by grade level (see Supplementary Table 2).

Overall discussion

EFs are critical for school and career success. This study (a) developed a self-report measure, the BIMEFs, based on Diamond's model of EFs, to assess EFs among Thai adolescents, (b) established

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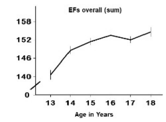
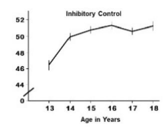
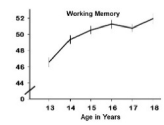
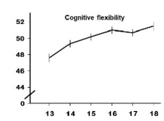
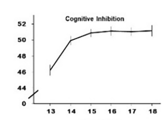
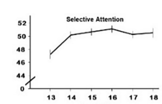
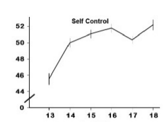
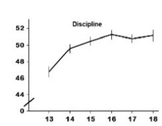
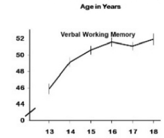
Table 4. Results of the linear regressions comparing the EF performance of Thai adolescents by age

	Mean *(sd)*							Regression Results for Differences by Age			
EF Variable	12 yrs (*N* = 58)	13 yrs (*N* = 282)	14 yrs (*N* = 305)	15 yrs (*N* = 324)	16 yrs (*N* = 319)	17 yrs (*N* = 365)	18 yrs (*N* = 212)	*F*-value	R^2	Graph of results by age	Direction of Difference
Overall Executive Functions (EFs)	144.46 *(25.44)*	140.24 *(26.39)*	148.49 *(23.36)*	151.60 *(21.76)*	153.53 *(22.61)*	152.35 *(21.34)*	154.86 *(23.39)*	14.78	0.04		13 v 14: *t* (585) = 4.02 13 v 15: *t* (604) = 5.81 13 v 16: *t* (599) = 6.65 13 v 17: *t* (645) = 6.45 14 v 16: *t* (622) = 2.74, p = .003 (trend) 14 v 17: *t* (668) = 2.23, p = .01 (trend) 14 v 18: *t* (515) = 3.05
Inhibitory Control (IC)	47.87 *(9.16)*	46.44 *(9.76)*	49.91 *(8.15)*	50.77 *(7.76)*	51.31 *(7.89)*	50.61 *(7.85)*	51.25 *(8.19)*	12.25	0.04		13 v 14: *t* (585) = 4.70 13 v 15: *t* (604) = 6.08 13 v 16: *t* (599) = 6.77 13 v 17: *t* (645) = 6.02 13 v 18: *t* (492) = 5.80
Working Memory (WM)	48.06 *(9.70)*	46.58 *(9.56)*	49.37 *(9.39)*	50.54 *(8.58)*	51.25 *(8.72)*	50.78 *(8.61)*	51.95 *(9.04)*	10.87	0.03		13 v 14: *t* (585) = 3.57 13 v 15: *t* (604) = 5.38 13 v 16: *t* (599) = 6.27 13 v 17: *t* (645) = 5.86 13 v 18: *t* (492) = 6.33 14 v 16: *t* (622) = 2.61, *p* = .005 (trend) 14 v 18: *t* (515) = 3.13
Cognitive Flexibility (CF)	48.53 *(9.02)*	47.23 *(9.16)*	49.21 *(8.26)*	50.30 *(8.34)*	50.96 *(8.23)*	50.97 *(7.99)*	51.66 *(8.88)*	10.12	0.03		13 v 14: *t* (585) = 2.76 13 v 15: *t* (604) = 4.32 13 v 16: *t* (599) = 5.26 14 v 16: *t* (622) = 2.65, p = .004 (trend) 13 v 17: *t* (645) = 5.54 14 v 17: *t* (668) = 2.79 13 v 18: *t* (492) = 5.39 14 v 18: *t* (515) = 3.21
Cognitive Inhibition (CI)	46.90 *(11.39)*	46.22 *(10.81)*	49.92 *(9.60)*	50.89 *(9.00)*	51.12 *(9.75)*	51.05 *(9.72)*	51.16 *(10.09)*	10.16	0.02		13 v 14: *t* (585) = 4.40 13 v 15: *t* (604) = 5.80 13 v 16: *t* (599) = 5.84 13 v 17: *t* (645) = 5.96 13 v 18: *t* (492) = 5.17
Selective Attention (SA)	49.40 *(11.33)*	47.25 *(11.32)*	50.16 *(9.54)*	50.65 *(9.33)*	51.10 *(9.38)*	50.26 *(9.74)*	50.51 *(10.20)*	4.66	0.01		13 v 14: *t* (585) = 3.38 13 v 15: *t* (604) = 4.05 13 v 16: *t* (599) = 4.56 13 v 17: *t* (645) = 3.63 13 v 18: *t* (492) = 3.31
Self-Control (SC)	46.20 *(11.00)*	45.53 *(11.22)*	49.98 *(9.89)*	51.05 *(9.31)*	51.77 *(9.21)*	50.34 *(9.32)*	52.16 *(9.48)*	15.47	0.04		13 v 14: *t* (585) = 5.11 13 v 15: *t* (604) = 6.63 13 v 16: *t* (599) = 7.48 13 v 17: *t* (645) = 5.96 13 v 18: *t* (492) = 6.95 14 v 18: *t* (515) = 3.13
Discipline (DP)	48.98 *(10.11)*	46.76 *(11.17)*	49.59 *(9.75)*	50.49 *(9.51)*	51.28 *(9.78)*	50.78 *(9.50)*	51.17 *(9.74)*	7.10	0.02		13 v 14: *t* (585) = 3.28 13 v 15: *t* (604) = 4.44 13 v 16: *t* (599) = 5.29 13 v 17: *t* (645) = 4.94 13 v 18: *t* (492) = 4.58
Verbal Working Memory (VWM)	47.81 *(10.07)*	45.89 *(10.67)*	49.16 *(10.09)*	50.64 *(9.50)*	51.62 *(9.49)*	51.12 *(9.31)*	51.95 *(9.94)*	12.97	0.03		13 v 14: *t* (585) = 3.82 13 v 15: *t* (604) = 5.80 13 v 16: *t* (599) = 6.97 13 v 17: *t* (645) = 6.65 13 v 18: *t* (492) = 6.44 14 v 16: *t* (622) = 3.14 14 v 17: *t* (668) = 2.62, *p* = .005 (trend) 14 v 18: *t* (515) = 3.11

(*Continued*)

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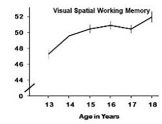
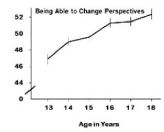
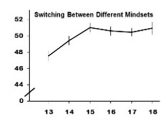
Table 4. (*Continued*)

EF Variable	Mean (*sd*) 12 yrs (*N* = 58)	13 yrs (*N* = 282)	14 yrs (*N* = 305)	15 yrs (*N* = 324)	16 yrs (*N* = 319)	17 yrs (*N* = 365)	18 yrs (*N* = 212)	Regression Results for Differences by Age *F*-value	R^2	Graph of results by age	Direction of Difference
Visual–Spatial Working Memory (VSM)	48.32 *(11.22)*	47.26 *(10.09)*	49.57 *(10.24)*	50.44 *(9.60)*	50.89 *(9.61)*	50.43 *(9.79)*	51.96 *(10.02)*	5.69	0.01		13 v 14: t (585) = 2.75 13 v 15: t (604) = 3.97 13 v 16: t (599) = 4.51 13 v 17: t (645) = 4.02 13 v 18: t (492) = 5.13 14 v 18: t (515) = 2.62, p = .005 (trend)
Being Able to Change Perspectives (BCP)	46.96 *(9.66)*	46.92 *(10.24)*	49.01 *(9.86)*	49.60 *(9.38)*	51.33 *(10.06)*	51.50 *(9.94)*	52.39 *(9.57)*	10.57	0.03		13 v 14: t (585) = 2.51, p = .003 (trend) 13 v 15: t (604) = 3.36 13 v 16: t (599) = 5.32 13 v 17: t (645) = 5.73 13 v 18: t (492) = 6.04 14 v 16: t (622) = 2.92, p = .002 (trend) 14 v 17: t (668) = 3.25 14 v 18: t (515) = 3.88 15 v 17: t (687) = 2.57, p = .005 (trend) 15 v 18: t (534) = 3.34
Switching Between Different Mindsets or Tasks (SDM)	50.10 *(11.06)*	47.53 *(10.03)*	49.42 *(9.54)*	50.99 *(10.11)*	50.59 *(9.92)*	50.44 *(9.36)*	50.93 *(10.85)*	4.20	0.01		13 v 14: t (585) = 2.34, p = .005 (trend) 13 v 15: t (604) = 4.22 13 v 16: t (599) = 3.75 13 v 17: t (645) = 3.80 13 v 18: t (492) = 3.60

Legend: sd = standard deviation. Degrees of freedom for all rows are 1 in the numerator and 1,805 in the denominator. All *F*-values are significant at $p < .001$. Only pairwise comparisons that were significant that $p < .001$ or indicated a trend (significant at $p < .03$ or less) are listed in the last column; unless otherwise noted the comparison was significant at $p < .001$. Note the very small number of 12-year-olds; for that reason they were not included in the regression analyses or graphs; the mean values provided for them here should not be taken as strong indicators of the population mean.

norms for interpreting performance of Thai adolescents on this measure, and (c) investigated EF differences by sex and grade level among Thai adolescents as revealed by the measure.

General comments about the BIMEFs

The final version of the BIMEFs has 42 items across eight subcomponents (four for IC, two for WM, and two for CF). It contains only positive items because in pretesting the BIMEFs positive and negative items were positively correlated, suggesting that Thai adolescents did not seem to be accurately understand the negative items. Our CFA results, which found three main components to EFs (inhibition, updating/WM, and shifting/CF), are in line with previous research (e.g., Miyake et al., 2000).

Correlation analyses showed stronger relationships between a few subcomponents of different EF components than between subcomponents of the same EF component (e.g., DP [a subcomponent of IC] correlated more highly with VWM [a subcomponent of WM] and with BCP [a subcomponent of CF]) than with other IC subcomponents). This pattern raised the possibility of a latent "general factor" underlying EFs. Results from higher-order CFA and bifactor modeling, however, indicated that, although a general EF factor accounted for a substantial proportion of the shared variance, domain-specific components (WM, IC, and CF) retain significant unique variance. This is consistent with the results of several other factor analyses of EFs (Demetriou et al., 2024; Lehto et al., 2003). These findings support the conclusion that the BIMEFs captures both a global EF construct and separable subdomains. Those subdomains may potentially be of clinical or developmental relevance. The authors readily acknowledge that the factor structure of EFs warrants further study.

Although both the BRIEF and BIMEFs assess IC, CF and WM, the BRIEF does not have some items found in the BIMEFs. For example, the following items in the BIMEFs have no corresponding items in the BRIEF: for SA: "*I focus on the workload that I am working on without letting noise in the room bother me,*" for VWM: "*I am able to mentally put information I hear in the correct and sequential order,*" and for VSM:"*I can mentally calculate the distance to know which route is longer or shorter.*" The BRIEF and other EF questionnaires also contain far less coverage of CF than does the BIMEFs.

The BRIEF and other EF questionnaires also contain components that most people would not consider to be EFs. Indeed, at least one of the authors of the BRIEF, Isquith, freely admits that the components, Organization of Materials, Initiate, and Emotional Regulation of the BRIEF are not part of EFs. Rather, these constructs reflect more behavioral outcomes of EFs. Further, to quote Isquith: "*Of interest, most of the other EF scales have copied the Initiate scale and Organization of Materials scale without considering whether or not they are actual executive functions. They just followed our lead . . . . EF affects emotion regulation and emotions affect EF*" (personal communication, March 10, 2018). Similarly, while the Comprehensive Executive Function Inventory (CEFI, Naglieri & Goldstein, 2013) includes scales for WM, IC, and CF, it also includes scales for organization, initiation, emotion regulation, self-monitoring, and for the higher-order EFs of planning and problem-solving. Our results are in line with other

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international assessment of EFs using questionnaire measures, such as the BRIEF-P (Gioia et al., 2003), BRIEF-SR (Guy et al., 2004), BRIEF-A (Roth et al., 2005) and BRIEF2 (Gioia et al., 2015) that EFs consist of both a global EF construct and separable subdomains.

Discussion of Results for Age and Sex Differences using the BIMEFs

Females tended to report better EFs than males. The largest sex differences in EFs were for IC. Female adolescents scored significantly higher on IC and on all four of its subcomponents than male adolescents. Females tended to show better VWM than males and males showed a weak tendency to show better VSM than females. There were no sex differences in CF or any of its subcomponents. There are no significant sex X age interactions.

These findings on sex differences in IC and WM are consistent with the literature. For example, Tetering et al. (2020) found that females aged 13 – 16 self-reported better SA and SC than did their male peers. Haenjohn (2017) also found that females of 11 – 13 years reported better EFs generally than their male peers, and better IC and its subcomponents than their male peers at 14 – 18 years age. In their meta-analysis and systematic review, Gaillard et al. (2021) found females (across ages) show better SC and DP than males, and that males show better VSM than females. In their meta-analysis, Voyer et al., 2017 found evidence of a small male advantage in VSM (consistent with our finding of a small male advantage there). They found that this sex difference first appears in the age group 13 – 17 years. In a separate meta-analysis and systematic review, Voyer et al. (2021) found evidence for a small female advantage in VWM, again consistent with our finding of a small female advantage there and with the first author's finding (Haenjohn, 2017) of better self-reported VWM among female adolescents versus males. We were not able to find any reports of a sex difference in CF or its subcomponents, consistent with our finding of no sex differences there.

For EFs overall, all three EF components, and all eight subcomponents scores were higher for older adolescents than younger ones, except that for many of these variables there was a small dip at 17 years (most marked for SC, and not evident for CI, BCP, or SDM). We have no explanation for the dip at 17 years and had not expected it. It deserves further study to see if it is just an accidental finding or reflects something more serious. By far the biggest and most consistent differences were between the self-reported performance of 13-year-olds and children of 14 – 18 years; 13-year-olds performed worse than all other ages on EFs overall, the EF components of IC and WM, and all of their subcomponents. IC seemed to plateau earliest (after age 14). Differences in self-reported EFs between those of ages 14 – 18 were minimal, with VWM and BCP being notable exceptions, suggesting that these two EF subcomponents continued to show significant developmental improvements at older ages than other EF subcomponents. Students of 13 and 14 years tended to report more similar performance on CF and its subcomponents than they did for IC or WM or their subcomponents, indicating perhaps less improvement in CF and its subcomponents between our two youngest ages than for other EF variables, with developmental improvements in CF and its subcomponents coming a bit later. BCP, together with VWM, showed the most pairwise differences between students of 14 – 18 years of any EF variable and BCP showed the steepest slope from 14 – 18 years. It was the only EF variable where significant improvement after age 15 was found as evidenced by pairwise comparisons between 15-year-olds and 17- and 18-year-olds. SC and VM showed the steepest slopes from 13 – 15 years of all EF variables.

These findings are consistent with the large literature using laboratory tasks where behavioral performance was directly assessed showing that older children and adolescents have better EFs than younger children and adolescents (e.g., Best & Miller, 2010; Folker et al., 2025; Larsen & Luna, 2018; Luna, 2009; Luna et al, 2004). Although many EF skills begin to develop during childhood, they still undergo refinement and further improvement during adolescence (Best & Miller, 2010; Diamond, 2013; Luna, 2009). Notably, Best, Miller, and Naglieri (2011) found that in a large representative national sample in the US that performance on three complex EF tasks improved until age 15 but not after, just as we found that in our large national Thai sample that EFs overall improved from age 13 to 15 but no pairwise differences between ages were after age 15. Similarly, studies have found that IC and its subcomponents improve over the age range in our study (e.g., Aïte et al., 2018; Constantinidis & Luna, 2019; Huizinga et al., 2006; Lamm et al., 2006), but that performance on many IC measures plateaus by the early teens (e.g., Igazság et al., 2019), just as we found it plateaued early in the present study. WM has also been found to improve over the age range studied here, although the evidence is clearer for this from neuroscience studies than from purely behavioral studies where performance tends to show marked improvements between 14 – 15 years and then plateau (Anderson et al., 2001; Conklin et al., 2007; Igazság et al., 2019; Kwon et al., 2002; Prencipe et al., 2011; Scherf et al., 2006). Consistent with our finding that self-reported VSM was better than self-reported VWM at 13 years, Conklin et al. (2007) found that performance in early adolescence was better on VSM tasks than on VWM ones. Much as we found here, performance on behavioral tasks indicates that cognitive flexibility tends to take the longest time to improve, often not plateauing until 18 – 19 years (Igazság et al., 2019; Klenberg et al., 2001; Piper et al., 2012). A further similarity between our findings and those of others using behavioral measures is the finding of significant individual differences in EFs of young people of the same age (e.g., Folker et al., 2025).

Limitations and future research

The present study lacked information about the children's home environment such as socioeconomic status (e.g., parents' levels of education, parents' occupations) or their levels of stress. As these factors have been shown to affect EFs, future research using the BIMEFs should consider collecting that information.

Our study included almost twice as many females as males although in Thai grade schools as well as high schools there are roughly equal numbers of male and female students. Since participation in our study was completely voluntary, the higher representation of females may reflect their greater willingness to fill out our rather long questionnaire. This raises a potential concern that the subset of males who participated might potentially differ in some systematic way from the males who did not.

The final version of the BIMEFs was refined from the initial 75 items down to 42 items through careful item selection and validation processes, but we did not conduct further item reduction analyses and did not construct, and then test out, positively worded versions of all 30 negatively-worded items that were omitted. We acknowledge these shortcomings and that inclusion of positive versions of the five negatively-worded items for TOB might have resulted in better internal consistency for TOB and that subcomponent then being retained in our analyses. We consider refinement of BIMEFs an important direction for future research to further optimize the scale's efficiency and accuracy while maintaining its psychometric robustness.

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We did not investigate whether the factor structure differed by age or sex, nor has the BIMEFs been tested with clinical populations to determine whether it effectively differentiates between patients and typically-developing children. Such work will be important to do in the future.

A comprehensive, realistic assessment of EFs in daily life should not be limited only to self-report measures, like the BIMEFs, as these measures are inherently subjective. Self-report measures correlate poorly with performance on behavioral tests, which probably reflects shortcomings in both approaches. Given that, it is worthwhile to administer both to get a fuller picture of any individual or population. We note, however, that in broad outline our results map on quite well to those from studies of EFs using behavioral tests with the same age group. We also note that while offering free tools is commendable in many respects, it raises an ethical concern about the potential misuse of such tools in a hasty or irresponsible manner without adequate clinical or psychometric training.

Conclusions

The BIMEFs represents a first in being 1) an EF questionnaire based on Diamond's framework, 2) an EF measure designed for adolescents in Thailand, and 3) an EF measure developed by Thai researchers. Western measures do not translate perfectly to Thai culture. For example, "My eyes fill with tears quickly over little things" is not culturally appropriate for Thai adolescents, as traditional Thai culture places a strong emphasis on emotional restraint. Created to hopefully be appropriate across many cultures, explicitly omitted in the BIMEFs are items reflecting culturally-specific norms, such as emotional suppression or unquestioning obedience.

The BIMEFs has been shown to be sensitive to age and sex differences. It showed that among adolescents in Thailand between the ages of 13 to 18 years, the biggest improvements in self-perceived EFs are between 13 – 16 years and the least are between 15 – 18 years of age. SC, VM, and BCP showed the largest improvements over age and BCP showed the most protracted, being the only variable to show significant differences between 15-year-olds and older adolescents. Since the results obtained here map on quite well to results obtained both with objective behavioral measures and with questionnaire measures in the US, Europe, and Australia, it suggests cross-cultural universality in the development of EFs. Efforts were made in the design of BIMEFs for it to be appropriate for use in other cultures besides Thailand. It can be used for research purposes to evaluate EFs among adolescents, to plan programs in schools or elsewhere to address EF challenges adolescents in that community report, or as a preliminary screening tool (or general screening tool) for the risk of EF impairment among adolescents, indicating those most likely to need to further undergo full standard clinical evaluations and diagnosis.

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Authors contribution. JH conceptualized the study and acquired the funding; JH, WS, and JN designed the study; JH, WS, and JN curated the data and materials; JH, WS, and SC collected the data; ST, SC, and JH participated in data analyses and interpretation; JH, JN, and SC participated in writing the manuscript. Canadian team: DA analyzed the Phase 2 data; AD played a major role in writing the Introduction, Methods Section, Results of Phase 2, and the Discussion, and in choosing the initial 75 BIMEFs items, but no role in Phase 1 factor analyses or culling of BIMEFs items. All authors have read and approved the manuscript.

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Consent to participate. Informed consent was obtained from all individual participants included in the study.

Consent for publication. Not applicable.

Availability of data and materials. All data generated or analyzed during this study are included in this published article.

Code availability. Not applicable.

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