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Patterns of individual differences in executive functions for preschoolers from low-income backgrounds: Associations with pre-academic skills

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A R T I C L E I N F O

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A B S T R A C T

Primarily studying executive functions of children from low-income backgrounds in comparison to more affluent peers can promote a deficit perspective that they are uniformly lacking in skills. We used latent profile analysis to investigate patterns of heterogeneity in executive functions in a sample of 232 preschoolers (M_{age} = 52.15 months, SD_{age} = 6.70 months; 50 % female; 34 % Latine, 31 % White, 10 % Asian, 7 % Black, 14 % Multiracial, and 4 % other) from low-income backgrounds in the Midwestern United States. Five executive functions (working memory, inhibitory control, cognitive flexibility, complex planning, and behavioral self-regulation) were used as indicators. We found evidence of four latent profiles including three profiles with consistently below average, above average, and high executive functions. A fourth discordant profile had high executive functions but below average behavioral self-regulation. We also estimated relations among executive function profiles and concurrent numeracy, vocabulary, and geometry; patterns of relations differed by pre-academic skill.

Educational relevance and implications: Primarily studying executive functions of children from low-income backgrounds in comparison to more affluent peers can promote a deficit perspective that they are uniformly lacking in skills. Using a statistical method that allowed us to explore sub-groups of children based on their executive function skills, we found evidence of four distinct sub-groups in a sample of preschoolers from low-income backgrounds. One sub-group scored high in executive functions but lower in incorporating them into gross motor behavior, which may be particularly important for early math. Results disrupt deficit perspectives and point to future areas of research for designing targeted and differentiated instruction.

1. Introduction

Preschoolers' individual differences in executive functions are robustly associated with many important outcomes, including pre-academic skills that provide a foundation for learning when they enter formal schooling (Blair & Raver, 2015). Children from families with low incomes perform lower, on average, on direct measures of executive functions than peers from more affluent backgrounds (Raver et al., 2013). However, group comparisons by income level fail to represent the variability in executive functions in children from low-income backgrounds and can promote a deficit narrative that they are uniformly lacking in skills, further contributing to their marginalization (Miller-Cotto et al., 2022). Mapping within-group variability in executive functions and relations with pre-academic skills is necessary for guiding differentiated and targeted support of executive functions in preschool. In this study, we consider individual differences in a population often treated as a monolith by employing person-centered analyses to identify patterns of heterogeneity and relative strengths in a sample of preschoolers from low-income backgrounds and their associations with foundational pre-academic skills.

1.1. Preschool executive functions

Executive functioning skills are higher order processes that support effortful control of attention, thoughts, and actions in pursuit of a goal (Carlson et al., 2013; Doebel, 2020). Although various theoretical accounts exist to explain the structure and development of executive functions, most researchers agree that they emerge early in life with

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rapid development in the preschool years (Garon et al., 2008) and that the construct is multifaceted (Diamond, 2013; Miyake et al., 2000). Core executive functions include the skills of working memory, inhibitory control, and cognitive flexibility. Working memory allows children to hold and manipulate relevant information in short-term memory, such as remembering multi-step instructions or a mathematics story problem that has been read aloud. Inhibitory control allows children to inhibit prepotent responses, such as ignoring distracting stimuli. Cognitive flexibility allows children to flexibly switch attention, such as a transitioning from one classroom activity to another (Diamond, 2013; Miyake et al., 2000).

Children's executive function skills are often measured through direct assessments, which tightly control conditions during novel experimental tasks (McCoy, 2019). These tasks are designed to assess specific executive function skills (e.g., working memory), with relatively high levels of precision (Gershon et al., 2010). However, given the inherent relations between skills, tasks may measure multiple executive functions simultaneously (Miller-Cotto et al., 2022).

Theoretical frameworks suggest that simpler executive function skills form the building blocks for more complex and contextualized executive function skills (Diamond, 2013; Jones et al., 2016). For example, Diamond (2013) posits that higher-level executive functions, including planning and problem solving, draw upon and require the coordination of the simpler skills of working memory, inhibitory control, and cognitive flexibility. Jones et al.'s (2016) framework also identifies complex, proximal executive function skills that are hierarchically more sophisticated than the core executive functions that comprise them. Planning is one of these complex skills and requires the use of the simpler executive functions to organize thoughts and behaviors to achieve goals through multi-step processes (Allain et al., 2005). A common direct measure of planning is the Tower of Hanoi task (Carlson et al., 2004), in which children must strategize to move game pieces while following a set of rules. Performance on directly assessed simple executive function tasks, particularly those assessing inhibitory control and working memory, is related to performance on the Tower of Hanoi task (Senn et al., 2004).

Jones et al. (2016) also identified "umbrella" skills that integrate multiple executive function skills across regulation-related domains, including behavioral self-regulation. McClelland and colleagues define this construct as the manifestation of working memory, inhibitory control, and cognitive flexibility in overt and observable behavior, often in everyday contexts (McClelland et al., 2007). Behavioral self-regulation is sometimes measured through caregiver rating scales or behavioral observations in everyday settings. However, direct assessments that measure children's ability to integrate executive functions into overt behavior have been developed and validated (e.g., the Head-Toes-Knees-Shoulders [HTKS] Task; Ponitz et al., 2009). McClelland et al. (2014) found that directly assessed cognitive flexibility and inhibitory control were most highly related to HTKS performance for preschoolers, while working memory was most highly related to HTKS performance for kindergarteners. These results support the notion that behavioral self-regulation, as measured by the HTKS, requires the coordination of multiple simple executive function skills in the early childhood period.

1.2. *Executive functions and pre-academic skills*

Directly assessed executive function skills are associated with a wide range of outcomes including pre-academic skills, developing in preschool, that provide a foundation for academic achievement upon entry to formal schooling. Children with higher levels of executive function, who can pay attention and persist through challenging tasks, may be better equipped to benefit from learning opportunities in the preschool classroom (McClelland et al., 2007). As the pre-academic skills of preschool numeracy (Devlin et al., 2022), vocabulary (Ramsook et al., 2020), and geometry (Clements & Sarama, 2014) are all associated with later academic learning and achievement, it is worthwhile to investigate how they relate to patterns of heterogeneity in executive function skills.

Early numeracy—children's understanding of numbers and their relations—is robustly associated with preschoolers' executive functions (Blair & Razza, 2007; McClelland et al., 2007; Purpura et al., 2017; Schmitt et al., 2017). Some researchers have estimated relative contributions of specific executive function skills and numeracy outcomes, but results have differed by study. For example, Espy et al. (2004) found that higher numeracy was associated with higher working memory and inhibitory control, but not cognitive flexibility, while Harvey and Miller (2017) found that higher numeracy was associated with inhibitory control, but not working memory or cognitive flexibility. Purpura et al. (2017) reported that all three of the simple executive function skills predicted numeracy, covarying for background variables, but relations depended on the numeracy task. Inhibitory control was related to numeracy across tasks, working memory was specifically related to more advanced numeracy skills requiring comparison and combination of numbers, and cognitive flexibility was related to abstract numeracy skills like numeral identification. Behavioral self-regulation (Devlin et al., 2024; McClelland et al., 2007; Schmitt et al., 2014) and complex planning (Clark et al., 2010) have also been linked to numeracy outcomes. Differences in results across studies likely reflect the various direct executive function measures, and the specific executive function skills included in the study.

Preschooler's knowledge of receptive vocabulary – the words that they can comprehend and respond to—is also associated with concurrent executive functioning skills (Carlson, 2005; Harvey & Miller, 2017; Weiland et al., 2014; White et al., 2017). As with numeracy, receptive vocabulary has been linked to each of the simple executive function skills individually (Harvey & Miller, 2017; Weiland et al., 2014). Planning (Carlson et al., 2004) and behavioral self-regulation (McClelland et al., 2007) are also associated with concurrent receptive vocabulary. Fewer studies have estimated early associations among executive functions and geometry, which includes shape identification and reasoning. However, Harvey and Miller (2017), found that working memory, but not inhibitory control or cognitive flexibility, was associated with concurrent geometry skills, covarying for the other skills and child age and language abilities. Taken together, results suggest that performance on directly assessed executive function skills are robustly associated with numeracy, vocabulary, and geometry. However, differing batteries between studies of directly assessed executive functions, which often exclude more complex and contextualized skills, have led to a lack of consensus on the contributions of specific executive functions to pre-academic skills.

1.3. *Executive functions in children from low-income backgrounds*

Some research presents that children from lower income backgrounds often have poorer performance on direct measures of executive functions than their peers from higher income backgrounds (Conway et al., 2018; Hackman et al., 2015; Lawson et al., 2018; Li et al., 2017; Raver et al., 2013). For example, Conway et al. (2018) found differences in working memory and cognitive flexibility at kindergarten-entry in a large, nationally representative sample, favoring children with higher family incomes. Such studies lay important groundwork for understanding the role of context in executive function development. However, although children from lower-income backgrounds perform lower on average, comparing children's performance on executive function assessments by family income-level can promote a deficit narrative that children from families with lower incomes are all lacking in skills, further contributing to their marginalization (Miller-Cotto et al., 2022). That is, group comparisons by income-level may fail to represent variability in executive functions for children from low-income backgrounds, as marked individual differences may be masked when the focus of analysis is on group differences. Studies focused solely on low-income samples have reported substantial variability in executive functions. For example, McClelland et al. (2021) found standard deviations equivalent to 38 %, 41 %, and 73 % of the mean scores on tasks assessing inhibitory control, cognitive flexibility, and behavioral self-regulation, respectively, in a sample of preschoolers from families with low incomes.

1.4. Exploring individual differences in executive functions using person-centered analyses

To guide differentiated, targeted, and equitable preschool instruction, it is necessary to understand heterogeneity in directly assessed executive functions in children from low-income backgrounds and how these individual differences relate to foundational pre-academic skills. Person-centered analytical methods may be especially useful for meeting these aims. An increasing number of studies have used person-centered analyses, such as latent profile analysis (LPA), to capture patterns of individual differences in developmental constructs of interest (e.g., Lonigan et al., 2018; Scalise et al., 2021; Wu et al., 2019). Specifically, LPA is a statistical method that allows us to derive naturally occurring sub-groups of children in the sample from several observed indicator variables by maximizing within-group homogeneity and between-group heterogeneity (Spurk et al., 2020). Understanding heterogeneity in preschoolers' executive function has important implications for instructional practice. That is, finding evidence of consistently low or high executive function profiles may support uniformly focusing instructional time across executive function skills, while finding evidence of discordant profiles (e.g., groups of children who have relative strength in certain executive function skills over others) may support differentially focusing instruction to leverage relative strengths to support areas of need.

A limited number of studies have used LPA to investigate patterns of individual differences in executive function skills in preschool samples from low-income backgrounds. Williams and Bentley (2021) concentrated on a sample of Australian children from low-income backgrounds and derived profiles of directly assessed simple executive functions (working memory, inhibitory control, and cognitive flexibility) and their associations with school readiness. They found evidence of low, moderate, and high profiles and that children in the latter two profiles outperformed those in the low profile on assessments of school-readiness. Overall, their results did not provide evidence of discordance in directly assessed preschool executive functions, but they did not include direct measures of more complex or contextualized executive functions.

Bayly and Bierman (2022) included both direct and teacher assessments of executive functions and found evidence of low, moderate, and high profiles, as well as a discordant profile who were high in directly assessed executive functions (inhibitory control, cognitive flexibility, and working memory) but lower in teacher ratings of behavioral self-regulation in a sample of Head Start preschoolers in the United States. Litkowski et al. (2020) similarly found discordant executive function profiles, driven by teacher ratings of behavioral self-regulation in a nationally representative sample of kindergarteners. These studies both found evidence of discordance—that some children have relative strength in some executive function skills but not others. However, it is unclear whether finding discordant profiles in these studies was due to teacher ratings capturing more contextualized executive function skills (e.g., behavioral self-regulation) or from the different mode of assessment. These studies also did not include a measure of planning, and thus may not capture variability in how children from low-income backgrounds use simple executive functions in multi-step problem solving. To clarify these profiles and their associations with pre-academic skills in children from low-income backgrounds, research is needed that applies LPA to a comprehensive battery of directly assessed executive functions that includes complex and contextualized executive function skills.

2. The present study

In the present study, we used person-centered analysis with a sample of preschoolers from families with low incomes, guided by two research aims:

1. To identify empirically derived profiles of preschoolers based on their performance on five direct measures of executive functions.

As preschoolers from families with low incomes are often characterized as uniformly low in executive functions compared to their peers from middle- and high-income backgrounds, we sought to identify patterns of heterogeneity in working memory, inhibitory control, cognitive flexibility, complex planning, and behavioral self-regulation. Although LPA was employed as an exploratory analysis, we expected to identify consistently lower and consistently higher executive function profiles based on past research (Bayly & Bierman, 2022; Williams & Bentley, 2021). We also expected to find evidence of one or more discordant profiles, in line with LPA research that has used a mixed battery of directly assessed and teacher-rated executive functions (Bayly & Bierman, 2022; Litkowski et al., 2020). We specifically expected that any discordant profiles would be driven by the more complex and contextualized skills of planning and behavioral self-regulation, as children with simpler executive function skills may not have mastered the integration of these skills into planning or overt behavior (Jones et al., 2016; McClelland et al., 2014).

2. To examine whether the identified executive function profiles were associated with children's concurrent pre-academic skills in numeracy, vocabulary, and geometry.

Using a person-centered analytical approach, we extend on past research investigating associations of specific executive function skills with pre-academic skills using variable-centered approaches. Based on past correlational work (Blair & Razza, 2007; Harvey & Miller, 2017; Weiland et al., 2014), we expected to find that consistently lower and consistently higher executive function profiles would perform lower and higher, respectively, on measures of pre-academic skills. We also expected that discordant profiles may be able to capitalize on any relative strengths to perform higher on measures of pre-academic skills than consistently lower executive function profiles.

3. Methods

3.1. Participants

Participants were 232 preschoolers (M_{age} = 52.15 months, SD_{age} = 6.70 months; 50 % female) from two midwestern states in the United States. Children attended either Head Start programs (n = 58) or prekindergarten programs housed in a school district (n = 174). All children in the sample came from families with low incomes, as designated by income-eligibility for Head Start or free/reduced price lunch programs. Based on parent report, 34 % of the sample were Latine or Hispanic, 31 % were White, 10 % were Asian, 7 % were Black, 14 % were Multiracial, and 4 % identified as other or did not answer the question. Based on teacher report, 20.7 % of our sample were English Learners (ELs). Level of primary caregiver education was also assessed via parent report and 4.8 % had an education of 8th grade or less, 12.5 % had completed some high school, 8.6 % had earned a GED, 22 % had earned a high school diploma, 19 % had completed some college, 7.3 % had earned an associate's degree, 12.9 % had earned a bachelor's degree, 4.7 % had earned a master's degree, and 0.4 % had earned a doctoral degree, with 7.8 % not answering the question. Data for this study were collected as part of pretest assessment for an intervention study aimed at improving school readiness skills in children from low-income backgrounds.

3.2. Measures

Assessments were given in English for all children who spoke English. For children who were ELs, all assessments were given in Spanish except the geometry measure, as we did not have access to the Spanish version.

3.2.1. Executive function indicators

Inhibitory Control. Children's inhibitory control was assessed using The Day-Night Stroop task (Gerstadt et al., 1994). Children were shown a card with either a moon and stars or a sun and instructed to say the opposite of what the card depicts (e.g., saying "day" when shown a moon and stars). Children were scored on 2 practice items and 14 testing items. Testing item scores range from a 0 for incorrect to a 1 for a similar word (i.e., sun instead of day)/self-correction to a 2 for a correct response. Thus, total possible scores range from 0 to 32. Internal consistency was $\alpha = 0.89$.

Cognitive Flexibility. Children's cognitive flexibility was assessed using the Card Sorting Task, based off the Dimensional Change Card Sort (Zelazo, 2006). Children were asked to sort cards depicting animals of different colors and sizes into one of four boxes. For the first subsection of six items, children were asked to sort the cards by shape. In the second subsection, children were asked to sort the cards by color. In the third subsection, children were asked to sort the cards by size. Children progressed to the fourth subsection only if they had answered at least five of the previous items correctly. In the fourth subsection, children were instructed to sort the cards by color if there was no border around the image and to sort the cards by size if there was a border. Total possible scores range from 0 to 24. Internal consistency was $\alpha = 0.93$.

Working Memory. Children's working memory was assessed using the Hide and Seek task (Garon et al., 2014). Children were shown a set of four boxes. For each of the 4 trials, a foam block was hidden inside a different box. Once the block was hidden, the boxes were covered with a sheet for 10 s. When the boxes were uncovered, the child was prompted to indicate where the block was hidden. The task assesses working memory in the first trial by requiring children to keep the location of the toy in mind for 10 s prior to searching. On subsequent trials, children also had to keep the location of the toy in mind despite potential interference of remembering the location from other trials. For each trial, children had up to four chances to try to find the block. Scores on each item range from 0 to 4 with 0 indicating they were unsuccessful and 4 indicating that they found the block on the first attempt. Total possible scores range from 0 to 16. Internal consistency was $\alpha = 0.77$.

Planning. Children's planning skills were assessed using a modified version of the Tower of Hanoi task, suitable for young children (Carlson et al., 2004). Children were told that they were going to play a game where they pretended that the wooden disks were monkeys and the three posts were trees. The child was asked to recreate the assessor's model for each level. The task consisted of six trials. The child was given two attempts at the trial, and the task was discontinued if the child responded incorrectly twice on one trial. Total possible scores range from 0 to 6 for the number of successful trials. Internal consistency was $\alpha = 0.71$.

Behavioral Self-Regulation. Children's behavioral self-regulation was assessed using the Head-Toes-Knees-Shoulders task (McClelland et al., 2014). The task was presented to children as a game where they were asked to follow a pair of rules by responding in the opposite way than requested (e.g., touching their head when the researcher said "touch your toes"). Each of three testing sections consisted of a set of practice items and 10 testing items. Each item was scored as 0 (incorrect), 1 (self-correct), or 2 (correct). Children had to receive a score of 4 to proceed to the next, more difficult section. Sum scores included practice items, as is common in the use of the measure to increase variability and avoid floor effects (e.g., Becker & Abi Nader, 2021; Finders et al., 2022; Fuhs et al., 2014); thus, total possible scores range from 0 to 94. Internal consistency was $\alpha = 0.97$.

3.2.2. Pre-academic skills

Numeracy. Children's numeracy skills were assessed using the Preschool Early Numeracy Skills assessment (PENS; Purpura, 2023). The PENS assessed knowledge of numerical identification, number order, ordinality, one-to-one correspondence, numerical comparison, set comparison, and number combination. Total possible scores range from 0 to 29. Internal consistency was $\alpha = 0.91$.

Vocabulary. Children's receptive vocabulary was assessed using the NIH Toolbox Picture Vocabulary Test (Hodes et al., 2013) using an iPad. Across practice and testing items, children were shown a set of four pictures and asked to select the picture that best depicted a spoken vocabulary word. The application utilized Computer Adaptive Testing as each item presented depended on a child's response to the previous item. Due to the adaptive nature of the task, we cannot present raw scores for this task, as with the other measures. We present theta scores, calculated through the NIH application using a one parameter Item Response Theory model. Theta scores have a mean of zero and standard deviation of one within the normed sample (Gershon et al., 2013). Theta scores represent the relative overall ability or performance of the participant.

Geometry. Children's early geometry skills were assessed using two geometric subtests of the Child Math Assessment (CMA; Klein & Starkey, 2004). In the Shape Recognition Subtest, children were asked to put a mark on each of the figures out of a set that was a specific shape for four shape types (e.g., "mark all of the circles"). In the Geometric Reasoning subtest, children were asked to reason about shapes that had been geometrically transformed (e.g., rotated, flipped). Total possible scores range from 0 to 7. Internal consistency was $\alpha = 0.77$.

3.3. Procedure

Study was approved by Purdue University's Institutional Review Board. Participants were recruited through enrollment packets sent home as part of preschool programs that agreed to participate. To mitigate order effects, children were randomly assigned to receive all assessments in one of four random orders. Assessments were administered one-on-one by trained research assistants in a quiet area of the child's preschool center over three to four assessment sessions that lasted approximately 20–30 min each.

3.4. Data analysis plan

We utilized MPlus, Version 8 (Muthén & Muthén, 2017) to conduct LPA using the five executive function indicator variables. Data were missing as follows: TOH ($n = 4$), HTKS ($n = 2$), DNS (n = 2), HAS (n = 2). Data were missing at random (Little's test: χ^2 (11) = 3.60, p = .98) and handled using Full-Information-Maximum-Likelihood (FIML). We first tested two- to five-profile solutions. Multiple starting values were used to replicate solutions, avoiding the discovery of local solutions, and allowing us to discover the global maximum (Berlin et al., 2014). We used several criteria to guide our choice of the optimal model. We compared Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values of all models, as lower values indicate better fitting models. We also considered two likelihood ratio tests, used to test the likelihood of a n profile solution to a n - 1 profile solution: the Boostrap Likelihood Ratio Test (BLRT) and the Vuong-Lo-Mendell-Rubin (VLMR) ratio test (Lo et al., 2001). For both tests, a p value < .05 indicates that a solution is significantly more likely than a n - 1 profile solution (Nylund et al., 2007). Next, we examined whether a solution had an entropy value >0.80, indicating acceptable probability of accurate profile characterization (Geiser, 2013). Finally, we considered the proportion of the sample predicted to belong in each profile – it is suggested that the smallest group not represent <8 % of the sample (Barbieri et al., 2021).

We next evaluated whether the concurrent pre-academic skills of numeracy, receptive vocabulary, and geometry differed by profile. We utilized a manual three-step approach of LPA (Asparouhov & Muthen, 2014). This method is used to handle the potential bias that can be introduced when assigning probable profile membership. We covaried for child age, sex, EL status, and parent education level.

4. Results

Descriptive statistics and correlations are presented in Table 1. As expected, there was significant variability in children's executive functions. Performance on most of the executive function measures were correlated, except for the working memory measure with the cognitive flexibility measure ($r = 0.10$, $p = .14$) and inhibitory control measure ($r = 0.09$, $p = .16$). The working memory task also had a high level of kurtosis (2.21).

4.1. Aim 1: latent profiles of executive function

Using scores from the five executive function measures as continuous indicators, we compared the model fit of two- to five- latent profile solutions (Table 2). Although the five-profile solution had lower AIC and BIC values than the four-profile solution, it was not statistically more likely than the four-profile solution, as the VLMR test was not significant ($p = .191$). Furthermore, the smallest profile in the five-profile solution included only 5 % of the sample, while the smallest profile in the four-profile solution included 10 % of the sample. The entropy of the four-profile solution was 0.95. Finally, the posterior probabilities for the four-profile solution were all >0.90 for one profile and <0.10 for another profile (Table 3). As such, we retained the four-profile solution as the most optimal model.

The four derived profiles were named according to observed relative differences in the indicators between profiles, as is common in LPA literature. Profiles are visually presented in Fig. 1 and descriptives are in Table 4. They included a *below average executive function* profile (67 % of the sample), *above average executive function* profile (12 % of the sample), *high executive function* profile (10 % of the sample), and a discordant *high executive function with below average behavioral self-regulation* profile (11 % of the sample).

The largest proportion of children belonged to the *below average executive function* profile, in which children's performance on direct executive function measures were estimated to range from 0.12 to 0.51 standard deviations below the sample mean. The *above average executive function* profile's scores were generally <0.5 standard deviations above the mean, except for their behavioral self-regulation (1.1 *SD* above the mean). The *high executive function* profile, which included the smallest proportion of the sample, were estimated to score 0.25 to 2.5 standard deviations above the sample mean. The final profile (*high executive function with below average behavioral self-regulation*) was the only truly discordant profile with estimated performance ranging 0.25 to 1.5 standard deviations above the mean for all tasks except behavioral self-regulation, which was estimated at 0.40 standard deviations below the sample mean. Significant differences ($p < .05$) between profiles are indicated on Fig. 1.

Table 3
Average posterior probabilities for the four-profile model.

	1	2	3	4
1: Below average	0.98	0.00	0.00	0.02
2: Above average	0.02	0.98	0.04	0.01
3: High	0.00	0.01	0.99	0.00
4: High w/ below average behavioral self-regulation	0.06	0.01	0.00	0.94

4.2. Aim 2: associations with pre-academic skills

We used a three-step approach to assess estimated differences in numeracy, vocabulary, and geometry skills by executive function profile, covarying for child age, sex, EL-status, and parent education level. Overall, results revealed statistically significant differences in pre-academic skills by profile for numeracy ($F (3, 209) = 21.36$, $p < .001$), vocabulary ($F (3, 209) = 35.02$, $p < .001$), and geometry ($F (3, 209) = 6.26$, $p = .004$). See Fig. 2 for a visual depiction by profile in concurrent numeracy, receptive vocabulary, and geometry and Table 5 for descriptives.

Pairwise difference tests showed no significant differences in numeracy skills between the *above average executive function* and *high executive function with below average behavioral self-regulation* profiles ($p = .569$). However, these profiles were estimated to perform 1.08 to 1.24 standard deviations higher on the numeracy assessment, on average, than those in the *below average executive function* profile ($ps < 0.001$). They were estimated to perform 0.65 to 0.75 standard deviations lower than those in the *high executive function* profile, on average ($ps < 0.020$).

A different pattern emerged for receptive vocabulary performance, as children in the discordant *high executive function with below average*

Table 1
Descriptive statistics.

Variable	*M (SD)*	Range (min-max)	Skew	Kurt.	1	2	3	4	5	6	7
1. Planning	2.00 (1.77)	0–6	0.92	0.02	–						
2. BSR	13.89 (22.20)	0–82	1.60	1.64	0.32	–					
3. Cog. Flexibility	10.15 (5.72)	2–23	0.96	−0.60	0.42	0.48	–				
4. Inhibitory Control	19.86 (9.52)	0–32	−0.43	−0.81	0.39	0.28	0.30	–			
5. Working Memory	13.52 (3.29)	0–16	−1.64	2.21	0.21	0.14	0.10	0.09	–		
6. Numeracy Skills	11.49 (6.00)	0–29	0.41	0.01	0.43	0.53	0.57	0.41	0.17	–	
7. Receptive Vocab	−5.61 (2.29)	−11 –2	0.04	−0.10	0.26	0.24	0.39	0.39	0.08	0.36	–
8. Geometry	3.28 (2.20)	0–7	−0.12	0.07	0.30	0.30	0.42	0.40	0.14	0.56	0.25

Note. All correlations except those underlined are statistically significant at $p < .05$. Planning = Tower of Hanoi task. Behavioral Self Reg. = Head-Toes-Knees-Shoulders task. Cognitive Flexibility = Dimensional Changed Card Sort task. Working Memory = Hide and Seek task. Numeracy Skills = Preschool Early Numeracy Skills Screener. Receptive Vocabulary = Picture Vocabulary Test; presented as theta scores. Geometry = Child Math Assessment—Geometric Subtests.

Table 2
Latent profile model fit comparisons.

Profiles	AIC	BIC	BLRT	VLMR	Entropy	Proportion of smallest profile
2	7231.17	7286.92	<0.001	<0.001	0.95	0.28
3	7116.61	7193.28	<0.001	<0.001	0.98	0.12
4	7030.38	7127.95	<0.001	0.02	0.95	0.10
5	6998.45	7095.93	<0.001	0.19	0.95	0.05

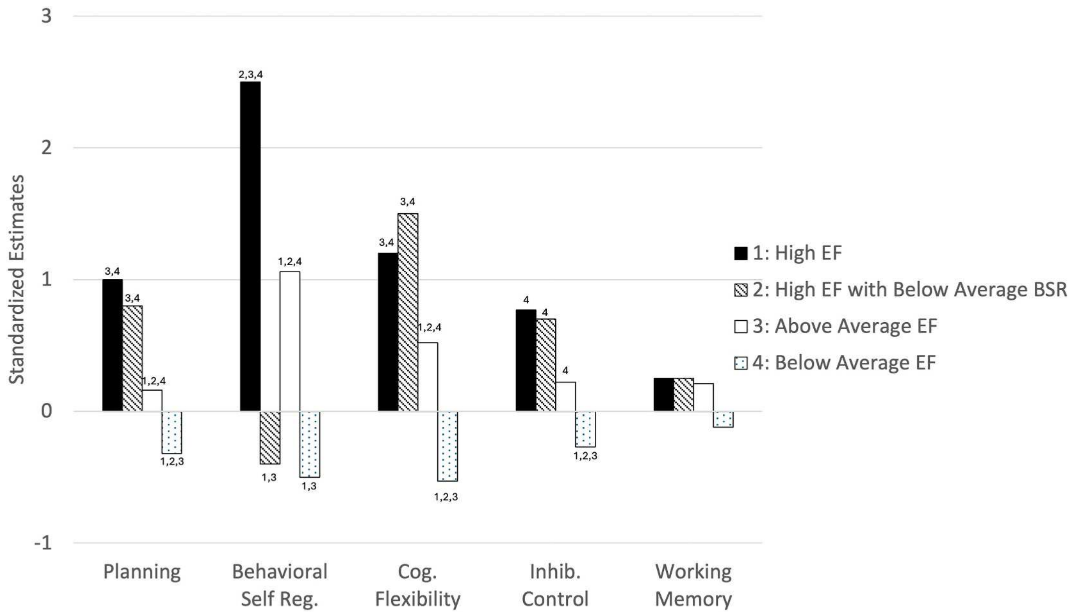

Fig. 1. Latent profiles of children's executive function skills.
Note. Superscripts indicate which profiles were statistically different at $p < .05$. Working memory did not differ significantly between any profiles.

Table 4
Probabilities and descriptives of executive function indicators by profile.

Profile	Proportion	Probability	Planning *M (SE)*	Behavioral self-regulation *M (SE)*	Cog. Flex *M (SE)*	Inhib. Control *M (SE)*	Working Memory *M (SE)*
Below average	0.67	0.98	1.44 (0.12)	2.92 (0.40)	6.99 (0.24)	17.17 (0.78)	13.14 (0.28)
Above average	0.12	0.97	2.27 (0.28)	37.69 (2.06)	13.06 (1.35)	21.76 (1.35)	14.26 (0.58)
High	0.10	0.99	3.77 (0.40)	69.38 (2.12)	16.91 (1.01)	27.12 (1.49)	14.37 (0.50)
High w/ below average behavioral self-regulation	0.11	0.94	3.30 (0.49)	4.89 (1.08)	18.34 (0.73)	26.03 (1.55)	14.19 (0.62)

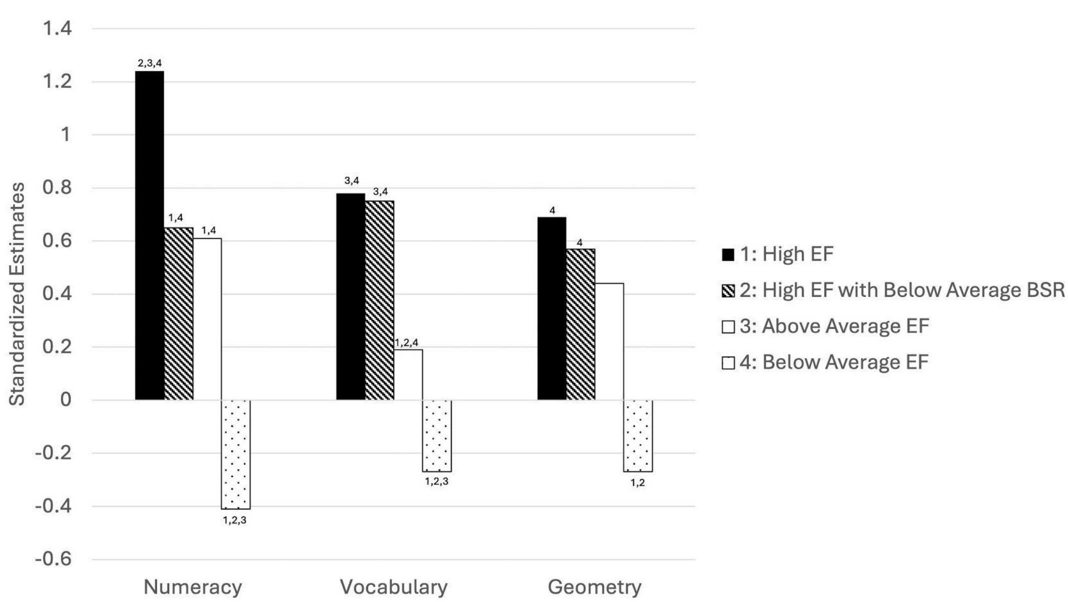

Fig. 2. Performance on numeracy, vocabulary, and geometry by executive function profile.
Note. Superscripts indicate which profiles were statistically different at $p < .05$. Estimates account for child age, sex, EL-status, and parent education level.

behavioral self-regulation profile performed similarly to those in the *high executive function* profile ($p = .824$). Both groups were estimated to score significantly higher than the *above average executive function* profile (0.75 standard deviations and 0.90 standard deviations above, on average, for the discordant profile and the *high executive function* profile, respectively; $ps < 0.001$). In turn, children in the a*bove average executive function* profile were estimated to score 0.50 standard deviations higher in vocabulary than those in the *below average executive function* profile,

Table 5
Means and standard errors of concurrent pre-academic skills by profile.

Profile	Numeracy		Vocabulary		Geometry	
	M	*S.E.*	*M*	*S.E.*	*M*	*S.E.*
Below average	8.79	0.42	−6.20	0.19	2.62	0.19
Above average	15.10	0.93	−5.22	0.34	3.90	0.35
High	18.93	1.18	−3.81	0.32	4.78	0.39
High w/ below average behavioral self-regulation	15.49	0.88	−3.70	0.42	4.62	0.35

Note. Estimates account for child age, sex, EL-status, and parent education level.

on average ($p = .021$). As Spanish and English versions of the vocabulary measure were normed in different samples, we wanted to ensure that results did not vary for children assessed in Spanish. We assessed whether the relation between predicted executive function profile and receptive vocabulary was moderated by EL-status. The interaction was not significant ($b = -0.34$, $p = .432$), suggesting the relations between profile and vocabulary scores were similar for ELs and non-ELs in the sample.

Finally, comparisons revealed that children in the *high executive function, above average executive function*, and discordant *high executive function with below average behavioral self-regulation* profiles scored similarly in early geometry ($ps > 0.05$). Both the high and discordant profile scored significantly higher than the *below average executive function* profile in geometry ($ps < 0.01$), but the *above average executive function* profile did not ($p = .119$).

5. Discussion

Studying executive functions in young children from low-income backgrounds in comparison to their more affluent peers has promoted a deficit narrative that they are uniformly lacking in skills (Miller-Cotto et al., 2022). This study aimed to identify patterns of individual differences in directly assessed executive functions and their associations with foundational pre-academic skills in a sample of preschoolers from low-income backgrounds. As expected, we found evidence of heterogeneity in a group often discussed as a monolith. Four distinct executive function profiles emerged, including a discordant profile with mostly higher executive functions but below average behavioral self-regulation. Despite below average behavioral self-regulation, this profile was estimated to perform similarly to children with consistently above average to high executive functions on measures of pre-academic skills. These findings highlight the utility of person-centered methods for considering individual differences in cognitive development, an especially important goal for disrupting deficit perspectives in research with under-resourced communities.

5.1. Executive function profiles

As expected, we found multiple profiles that were mostly consistent across indicators; a below average, above average, and high profile. As analyses were focused on within-sample variability, “average” performance referred to the sample average. Differences between these profiles were primarily driven by cognitive flexibility, complex planning, and behavioral self-regulation skills. That there were less differences between profiles in inhibitory control and working memory than cognitive flexibility may be in line with Garon et al.'s (2008) analysis suggesting that working memory and inhibitory control processes develop earlier in childhood and lay a foundation for the development of cognitive flexibility. That is, cognitive flexibility has been posited to be more complex than the other simple executive function skills, and thus may act as a better indicator variable for profile differentiation along with planning and behavioral self-regulation.

Our finding of a discordant profile also highlights heterogeneity in early executive functions that may not be captured by variable-centered approaches. The discordant profile specifically diverged on behavioral self-regulation, as measured by the HTKS task which requires children to apply other executive function skills to their overt behavior to follow the rules of a Simon Says-like game (McClelland et al., 2014). Our study also included a measure of complex planning, a higher-order executive function skill that has not been investigated in past person-centered early childhood executive function research. We expected that the presence of a discordant profile would be driven by both the behavioral self-regulation and complex planning tasks. Children in the discordant profile still had high estimates of planning scores, suggesting that they did not have relative weakness in integrating the simpler executive functions into complex skills more generally, as was expected.

Jones et al.'s (2016) framework identifies planning as a complex, proximal skill which requires the integration of the simpler executive functions, while behavioral self-regulation is classified as an “umbrella” skill that includes multiple skills across regulation-related domains. McClelland et al. (2015) further suggest that behavioral self-regulation includes not only the top-down effortful coordination of the simpler executive functions (similar to complex planning), but also more automatic bottom-up aspects of regulating thoughts and behavior. Potentially, children in the discordant profile show a relative weakness with behavioral self-regulation, rather than complex skills more generally, due to these additional demands. An alternative interpretation of the results is that task demands inherent to the HTKS have led to the presence of the discordant profile. For example, the task requires coordinated gross motor behavior, not required by the other executive function measures. It is possible that children in the discordant profile have relative weakness in motor skills rather than regulating behavior.

Previous studies applying LPA to study early executive function skills have found discordant profiles driven by teacher ratings of behavioral self-regulation (Bayly & Bierman, 2022; Litkowski et al., 2020). Bayly and Bierman's (2022) results are particularly relevant for comparison, as they also assessed patterns of individual differences in a sample of preschoolers from low-income backgrounds. They included directly assessed working memory, inhibitory control, and cognitive flexibility and assessed behavioral self-regulation through teacher ratings of children's aggression and self-control. As in our study, they found evidence of a consistently lower profile, an average to above average profile, and a high profile, across indicators. They also found a discordant profile who had higher direct measures of executive functions but lower teacher ratings of behavioral self-regulation. Our findings align with these results, while using a direct measure of behavioral self-regulation. Convergence across studies using different modes of assessment suggests that the discordant profiles may be due to children's developing competence with applying executive function skills to contextualized overt behavior.

5.2. Relations among profiles and pre-academic skills

Overall, we found that performance on measures of numeracy, vocabulary, and geometry differed by executive function profile. However, the specific patterns of differences varied by pre-academic skill, extending upon existing variable-centered research on the relations of specific executive function skills to pre-academic skills. Aligned with findings from variable-centered analyses (e.g., Blair & Razza, 2007; Harvey & Miller, 2017), we found that children in the high executive function profile had the highest scores on measures of pre-academic skills and children in the below average executive function profile had the lowest scores, with those in the above average profile performing at an intermediate level.

Children in the discordant profile, with high executive function skills except for behavioral self-regulation, performed similarly to the consistently above average and high profiles on a measure of geometry. They also scored similarly to the consistently high profile (and significantly above the above average profile) on a measure of vocabulary, suggesting that their strength in other executive functions, especially cognitive flexibility and complex planning, may have mattered more for vocabulary than their relatively lower behavioral self-regulation. Positive associations among complex planning (Carlson, 2005) and cognitive flexibility (Weiland et al., 2014) with vocabulary have been identified in past work. However, on the numeracy measure, the discordant profile (along with the above average executive function profile) performed around half a standard deviation below the consistently high executive function profile. Potentially, this difference aligns with past work highlighting the importance of behavioral self-regulation for mathematics outcomes and learning, specifically. For example, Ponitz et al. (2009) found that early behavioral self-regulation (measured by the HTKS) predicted gains in mathematics, but not vocabulary or reading over the kindergarten year.

In any case, despite below average behavioral self-regulation, children in the discordant profile may have leveraged other high executive function skills to perform similarly to children in consistently above average to high executive function profiles on measures of the pre-academic skills. Notably, this pattern of results diverges from Bayly and Bierman (2022), who found that the discordant group performed similarly to the consistently low profile on kindergarten outcomes of interest (measures of academic achievement and social competence), significantly below the other profiles. Differences in these results might be due to estimating concurrent versus predictive relations or the differences in the specific measured outcomes. Differences may also relate to varying measures of behavioral self-regulation between studies.

Directionality of these relations is unclear, as our data on pre-academic skills were collected concurrently to executive function skills and past variable-centered work has documented bi-directional associations among executive functions and early numeracy (Wolf & McCoy, 2018) and vocabulary (Schmitt et al., 2019). Future work is needed to consider how executive function profiles and pre-academic skills relate over time.

5.3. Limitations and future directions

Our findings should be interpreted considering several limitations. First, although we had a priori expectations for the nature of the executive function profiles we would find based on prior literature (e.g., Bayly & Bierman, 2022; Litkowski et al., 2020), we used LPA as an exploratory technique. Our sample size was also relatively small for conducting LPA (Nylund-Gibson & Choi, 2018; Tein et al., 2013). Future research should aim to replicate these profiles in larger and varied samples of children from under-resourced communities. As a primary aim of this study was to challenge the monolithic view of executive functions in children from low-income backgrounds, it is also important to note that the present sample was comprised of preschoolers from two Midwestern states in the United States and that profiles may differ in other low-income samples. We also do not have information on the number of children in each classroom from which our participants were recruited, as numbers shifted due to COVID-19 related closures, and thus cannot calculate a participation acceptance rate for the present study. This may limit generalizability of findings to populations outside those included in the study.

We chose to focus specifically on income-level, as family income is often used as an eligibility requirement for access to government-subsidized early education. Parent education level, another important indicator of socioeconomic status, varied within our sample from less than 8th grade to a doctoral degree. Although we controlled for parent education level in our Aim 2 analyses, future work may explore variability in home context within low-income samples and its relation to patterns of individual differences in executive functions.

There were ceiling effects on the working memory task, which may have impacted its usefulness as an indicator for separating profiles. Future work will be needed to validate these profiles using a more robust measure of working memory. We were further limited by the complex nature of executive function measurement in early childhood. Researchers have indicated the issue of task impurity (e.g., the Day Night Stroop task likely requires employment of working memory as well as inhibitory control; e.g., Miyake et al., 2000). We categorized executive function tasks based on the constructs they have traditionally been used to measure, but the issue of task impurity should be noted. Furthermore, we used directly assessed executive function measures, as these are primarily the tasks used in studies comparing executive function skills of children from low-income backgrounds to their more affluent peers. However, there have been recent criticisms of the ecological validity of these measures (e.g., Doebel, 2020; McCoy, 2019), especially for children from marginalized groups for whom novel experimental tasks may be particularly unfamiliar (Miller-Cotto et al., 2022). Future work may identify more meaningful heterogeneity in children from low-income backgrounds using tasks that map directly to children's daily lives, using multiple types of assessments for each construct.

Finally, future research is also needed to explore how these findings can be used to guide targeted and differentiated instruction. For example, our results suggest that targeted instructional support helping children with high executive functions and lower behavioral self-regulation integrate executive function skills into gross motor behavior may be especially beneficial for mathematics outcomes. However, this hypothesis needs to be tested in an empirical study.

6. Conclusions

Results from our study provide evidence of within-sample heterogeneity in patterns of directly assessed executive functions for children from low-income backgrounds and differential relations with pre-academic skills. Our findings provide meaningful information for guiding differentiated preschool instruction to support executive functions and pre-academic skills. Furthermore, our use of a person-centered approach identified within-group variability in a sample from low-income backgrounds, disrupting deficit perspectives pervasive in research with under-resourced communities.

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CRediT authorship contribution statement

Brianna L. Devlin: Writing – original draft, Formal analysis, Conceptualization. **Elyssa A. Geer:** Writing – review & editing, Data curation. **Jennifer K. Finders:** Writing – review & editing. **Tracy M. Zehner:** Writing – review & editing, Project administration. **Robert J. Duncan:** Writing – review & editing, Project administration. **David J. Purpura:** Writing – review & editing, Project administration. **Sara A. Schmitt:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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