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Pathways to Adolescent Executive Function in Australian Aboriginal and Torres Strait Islander Children: The Role of Early Skills and Learning Environments

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Understanding and strengthening the developmental pathways of Australian Aboriginal and Torres Strait Islander young people is of critical importance to efforts seeking to redress more than 200 years of disadvantage due to colonization. Although systemic factors play a key role in addressing disparities, individual-level capacities such as self-regulation and executive function are also essential for positive developmental outcomes and may act as protective factors. This study advances the first longitudinal model of adolescent executive functioning in Australian Indigenous children, examining the role of early home and learning environments and key developmental skills. Using longitudinal data for 473 young people from *Footprints in Time: The Longitudinal Study of Indigenous Children*, we found preschool visual motor and literacy skills ($\beta = .15$) and early school classroom self-regulation ($\beta = .18$) predicted adolescent executive function. Contextual factors, including socioeconomic status, preschool attendance, home learning engagement, and parent social support, were linked to early skill development but did not directly predict executive function outcomes. Children living in more remote areas had lower early skill capability, underscoring the important role of environmental constraints. Findings support strengths-based approaches, in which policy and programs reinforce families as children's first teachers in the home and build social capital for parents. Family and early learning services should be made equitably available, particularly in remote areas, and should focus on core skill development for children, as well as home learning and family social support, to ultimately enhance executive function development among Indigenous children.


Public Significance Statement


No studies to date have developed longitudinal models of adolescent executive function development specifically in the Aboriginal and Torres Strait Islander population, despite this developmental skill being vital for lifelong learning and well-being. Our study finds that higher preschool literacy and visual motor skills, and the ability to self-regulate in early school classrooms is associated with enhanced executive function skills more than 10 years later. These early skills are supported by a range of early childhood experiences including preschool attendance and home learning engagement. Strengths-based supports distributed equitably among urban and rural/remote communities should aim to boost these important developmental antecedents.


Keywords: self-regulation, executive function, Indigenous, Aboriginal, early childhood


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continued

A range of studies internationally have confirmed the important role of early childhood self-regulation and executive function skills in supporting later academic achievement, health, and well-being for population samples (Ahmed et al., 2021; Moffitt et al., 2011; Robson et al., 2020; Stucke & Doebel, 2024) and, in limited studies, specific Indigenous samples (He et al., 2021). Comparatively fewer studies have focused on executive function in adolescence and its important early childhood developmental antecedents. Adolescence is an important developmental period in which individuals make early decisions about education and employment pathways, while also being more at risk of emerging mental health and social challenges. Strong executive function skills are likely to support a positive transition through adolescence to adulthood. Although there is some research on adolescent executive functioning and its early childhood antecedents in non-Indigenous populations (Berthelsen et al., 2017; Drexler et al., 2024), there are few studies internationally, to our knowledge, that focus specifically on modeling adolescent executive function and its antecedents in Indigenous groups. This study addresses this critical gap for the first time by developing a longitudinal model involving early childhood pathways to adolescent executive function for Aboriginal and Torres Strait Islander people.

The Importance of Executive Functioning and Self-Regulation

The executive functions are a core set of cognitive abilities including working memory (holding information in mind and manipulating it), inhibition (impulse control to inhibit a dominant response in favor of a less dominant response), and cognitive flexibility (attentional and task shifting; Blair & Ku, 2022). These functions are considered the cognitive component of a hierarchical integrated system of self-regulation (Blair & Ku, 2022). Self-regulation refers to individuals' ability to regulate their own attention, thoughts, behavior, and emotions in the context of everyday actions, reaching goals, and managing stressors. The overall self-regulatory system includes reciprocally related cognitive, emotional, behavioral, physiological, and genetic levels (Blair & Ku, 2022). Self-regulation develops from birth through experiences of early co-regulation with caregivers which become more independent over time. Individual differences in executive function development emerge from 3 years of age with executive function continuing to develop into early adulthood as the prefrontal cortex and anterior cingulate cortex mature (Petersen & Posner, 2012).

Strong overall self-regulation and executive function skills, particularly early in life, have been linked with a range of positive lifelong outcomes, making them an important focus of developmental research. Stronger self-regulation and executive function have been linked with more positive peer relations, reduced mental health problems (Stucke & Doebel, 2024), reduced criminality and drug use (Robson et al., 2020), higher educational attainment

(Ahmed et al., 2021), and higher occupational attainment even decades later in adulthood (Schoon et al., 2021). Poorer executive function in early adolescence in particular has been linked with increased risk of social withdrawal (Vedechkina et al., 2024), symptoms of poor mental health (Briant et al., 2022), and poorer academic achievement (Shroff et al., 2024). In one of the few studies with a specific focus on Aboriginal children in Australia, an index of self-regulation and executive function by teacher report at school entry was associated with reading and numeracy achievement 3 years later (He et al., 2021). In American Indian adults, strong executive function skills have been linked with higher levels of social support and are considered to be a key mechanism supporting resilience to mental health risks (Wilhelm et al., 2024). In the context of socioeconomic risks in early childhood, including low income, self-regulation, and executive function skills have been identified as one of the key mechanisms through which socioeconomic disparities lead to associated achievement gaps (Blakey et al., 2020; Finders et al., 2021; Schoon et al., 2021). The corollary of this, also evidenced in multiple studies, is that strong self-regulation and executive function skills can act as a protective factor in the context of socioeconomic and other contextual risks (Barry et al., 2022; Wilhelm et al., 2024). For example, self-regulation skills have been found to mitigate the association between early household chaos and risk of behavior problems for children (Crespo et al., 2019).

The Development of Executive Functioning: The Role of Early Skills

Although much research has focused on self-regulation and executive function as predictors of other important life outcomes, there is a growing body of work concerned with how these integral skills develop and what important developmental pathways involving very early competencies can be identified. Three key early skills are frequently identified as important to sustained cognitive development over time and thus are likely to be associated with executive function development: visual motor skills, oral language, and early observed self-regulation (Berthelsen et al., 2017; Clemens et al., 2023; Schoon et al., 2021). Visual motor skills refer to the ability to integrate visual input with motor planning, often assessed through asking children to copy shapes with a pencil and paper. Stronger visual motor skills in early childhood have been associated with early mathematics achievement (Nesbitt et al., 2019), adult educational attainment in the context of socioeconomic risk (Schoon et al., 2021), and the development of self-regulation and executive function (Gandotra et al., 2022; Willoughby & Hudson, 2023). Oral language and self-regulation skills are considered to develop in an interactive fashion in early childhood, whereby skill in one begets skill in the other (Ollas-Skogster et al., 2023). Expressive vocabulary in particular has been identified as key to closing early academic

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achievement gaps (Williams et al., 2022) and addressing socioeconomic disparities in achievement (Clemens et al., 2023).

Early self-regulation, particularly as observed by educators in classroom settings, is a strong predictor of future learning trajectories. Classroom self-regulation refers to observable behaviors of being organized, paying attention, and persisting in learning tasks. Early classroom self-regulation has been reciprocally related to executive function over time, with both predicting numeracy and literacy skills (Howard et al., 2021). Higher early self-regulation skills are linked with reduced risky behaviors in adolescence and higher academic achievement (Howard & Williams, 2018; Liu et al., 2024) and have also predicted longer term school engagement and persistence with postschool education following high school in the United Kingdom (Katsantonis et al., 2024). Taken together, it is clear that these three core capabilities of visual motor skills, language, and early self-regulation constitute a constellation of skills likely to be involved in executive function development over time. While prior population-based samples have incorporated Indigenous people as participants, to our knowledge, developmental pathways involving these early skills and later executive function have not been explored specifically in an Indigenous population.

Early Learning and Family Contextual Factors Involved in Self-Regulation and Executive Function Development

A range of early years contextual factors have been identified as important contributors to developmental pathways for children. Socioeconomic status including indicators such as family income and parental education level have been consistently associated with children's early development, with low socioeconomic status considered a risk factor for poorer language, self-regulation, and executive function (Rakesh et al., 2025; Raver & Blair, 2020; Vogel et al., 2021). Living in a more remote area has been linked with lower early literacy and numeracy skills and lower school attendance for Australian Aboriginal children (He et al., 2021). However, there are complex contextual considerations in terms of the interplay of geographic remoteness and socioeconomic status and the availability of important educational and support services which will be further discussed in the following section.

The early home learning environment, including the extent to which adults engage children in everyday activities such as storytelling, reading, talking, and playing, is a consistent predictor of children's development of skills including self-regulation and executive function (Hanlin & Zhou, 2024; Hughes & Devine, 2019; Joseph et al., 2024). Indeed, the extent to which early disadvantage impacts later educational attainment is considered to be largely mediated by impacts on the home learning environment (Joseph et al., 2024). In a New Zealand study with Māori people, parent-child oral narratives and reminiscing in the home learning environment were found to be particularly supportive of children's self-regulation development and early academic skills (Neha et al., 2020). Higher frequency of parent-child home learning activities has also been linked with stronger oral language skills in Aboriginal children (Williams et al., 2017).

The extent to which parents have access to social supports during the early years and the nature of the home environment may also be key contextual factors influencing child development. In a recent and novel finding, a study of Swiss children from low income homes found that children of parents who reported more access to help in

child-rearing had stronger early self-regulation capability (Rodcharoen et al., 2024). This positive influence of parents' social resources on children's self-regulation development was over and above the still important contributions of household income and maternal education level (Rodcharoen et al., 2024), suggesting such social capital acts as a protective factor. A range of studies have linked chaotic household environments, characterized by disorganization, poor physical conditions, high levels of noise, and overcrowding, with suboptimal child development outcomes including poorer self-regulation and cognitive development (Berry et al., 2016; Crespo et al., 2019; Garrett-Peters et al., 2019).

Preschool attendance prior to school is an important consideration given its well-documented role in boosting child developmental outcomes for most children (Schmutz, 2024; Yang et al., 2024) and, in particular, supporting self-regulation development (Melo et al., 2024). Preschool attendance is known to act as a protective factor in the context of low socioeconomic status, buffering the association between early economic stress, and lower cognitive and language outcomes for children (Rakesh et al., 2025). Preschool attendance is also important in the policy context of Australia, where there has been a focus on lifting preschool participation rates, particularly among Aboriginal and Torres Strait Islander children, to support early and ongoing achievement (National Indigenous Australians Agency, 2024). In one of the few studies with a specific focus on Aboriginal children, preschool attendance, along with early self-regulation, was associated with early literacy and numeracy skills, which in turn were associated with academic achievement 3 years later (He et al., 2021).

Cognitive Development in an Aboriginal and Torres Strait Islander Context

In Australia, the effects of colonization have resulted in intergenerational disadvantage for Aboriginal and Torres Strait Islander peoples. Government policy on "Closing the Gap" on Indigenous disadvantage identifies key target outcomes including social and emotional well-being, achieving full learning potential, and engagement in higher education and employment (National Indigenous Australians Agency, 2024). While not negating the role of system-level levers that must be addressed to achieve these outcomes, it is clear from prior research that strong self-regulation and executive function at the individual level, developed in the context of caregiving and early learning environments, will support positive well-being and achievement trajectories. Thus, it is essential to understand what factors and contexts in early childhood pave the way for a positive developmental pathway toward strong executive function for Aboriginal and Torres Strait Islander children. Yet, to our knowledge, no other study has explicated a longitudinal model of executive function development for Aboriginal and Torres Strait Islander children.

While our brief literature review of key developmental processes related to executive function drew on research with First Nations populations where possible, it is essential to note that findings are not likely to generalize to Aboriginal and Torres Strait Islander children living in Australia. Specifically, models that explicate links between early contextual risks and downstream developmental outcomes have been developed largely within White Western psychological studies (Alcalá, 2023). Overall, these studies tend to replicate models that link higher earlier risk (e.g., low socioeconomic status, living in a remote area) with poorer subsequent

development. However, these associations may be more complex for Aboriginal and Torres Strait Islander children due to the persistent impacts of colonization intersecting with cultural strengths and practices of the community and the systemic inequities inherent in many aspects of daily life.

One key example is residential location. While living in rural and remote areas of Australia is typically considered a developmental risk factor at the population level (Baffour et al., 2024), in some domains associated with development, living remotely is a protective factor for Aboriginal and Torres Strait Islander children. For example, a prior report using the same data set as in the present study found children in remote areas experienced less racist bullying than their urban peers and attended schools that embedded more Indigenous education initiatives, both likely related to a higher density of Aboriginal and Torres Strait Islander children in these areas (Rogers et al., 2022). Children in remote areas were also as engaged in school as their urban peers (i.e., highly engaged) and were more likely to be bilingual or multilingual. Experiences such as these, including positive peer relationships, school engagement and belonging, and multilingualism, have all been previously documented as typically supportive factors for longer term cognitive development in primarily Western populations (Lecce et al., 2020; Sankalaite et al., 2021; Tran et al., 2019). Yet, living remotely in Australia is also associated with access to far fewer education and health services. This includes inequitable access to English as second-language teachers despite many children in remote areas having an Indigenous language as their first language and limited access to early intervention services to address any developmental concerns that arise (Rogers et al., 2022). Taken together, it is unclear whether some of the more positive experiences of Aboriginal and Torres Strait Islander children living remotely, when compared to their urban peers, can outweigh the impacts of systemic risks and service barriers in terms of cognitive development over time.

Another contextual example is that of household composition or specifically household crowding, represented in our study as the number of individuals living in the house. In largely Western studies household crowding is typically considered a risk factor in relation to child development due to the impacts of limited shared resources, noise pollution, and general disorganization or household “chaos” (Crespo et al., 2019; Oloye & Flouri, 2021). However prior research with Indigenous children in Australia has found housing conditions including crowding to play a relatively minor role in children’s development (Dockery, 2022). In Aboriginal and Torres Strait Islander culture child-raising is often reliant on a network of kin, with simultaneous multiple caregiving by extended members of kinship networks (Wright et al., 2025). While these kin networks need not cohabit, it is possible that higher numbers of individuals in the household equates to stronger extended kinship networks for children which may support rather than impede cognitive development. On the other hand, it is also possible that higher number of individuals in the household relates to local housing scarcity and other sociodemographic and systemic barriers commonly correlated with impeded child development.

The Present Study and Its Context

In this study, we draw on longitudinal data from *Footprints in Time: The Longitudinal Study of Indigenous Children* (LSIC), an ongoing national panel study managed by the Australian Government

Department of Social Services (2024). This study takes a strengths-based approach to understanding the developmental pathways for children, their families and communities, and to ultimately inform supports provided by government and policy. LSIC has a number of guiding research questions, and, in this study, we sought to contribute toward addressing: “What helps Aboriginal and Torres Strait Islander children to stay on track or get them to become healthier, more positive and strong?” (Australian Government Department of Social Services, 2020, p. 5). In particular, our research question for the present study was: How do early home and community learning contexts and children’s key early developmental skills contribute to stronger executive function in Aboriginal and Torres Strait Islander adolescents? To our knowledge, this is the first study that develops a longitudinal model of adolescent executive function for this population.

Method

LSIC is governed by the LSIC Steering Committee, which consists of predominantly Aboriginal and Torres Strait Islander leaders who oversee the use of LSIC data to improve outcomes for Aboriginal and Torres Strait Islander children (Dodson et al., 2012; Thurber et al., 2015). The study cohort comprises 1,759 Indigenous children and their caregivers, who were recruited across 2008–2009. Sampling was conducted through selection of 11 sites including locations ranging from very remote communities to major urban centers across six Australian states/territories. All eligible families within each of the 11 sites were invited to consent to participating in the study using residential addresses provided by Centrelink, Medicare Australia, and informal local connections and word of mouth (Thurber et al., 2015). Consenting participants were part of two cohorts, those aged 0.5–2 years (B cohort) and those aged 3.5–5 years (K cohort) in 2008. Although data were collected from diverse locations and communities, due to the diversity of Aboriginal and Torres Strait Islander peoples LSIC is not representative of all Indigenous children in Australia (Walter et al., 2017). Data collection is conducted annually by Aboriginal and Torres Strait Islander research administration officers who complete interviews with families. Parents, children, and children’s teachers provide data on a range of areas across health, education, relationships, culture, and community. At the time of this study, 14 waves of data had been publicly released, with our research team also accessing an early release of the executive function measure taken at Wave 15 under agreement with the data custodians. Prior to the global pandemic in 2020, LSIC retention rates ranged from 85.9% in Wave 2 to 68.5% in Wave 12. For Wave 13 (conducted in 2020), the retention rate was 43%, and in Wave 14 (2021), 53.2% (Australian Government Department of Social Services, 2024).

Ethics approval for the LSIC study was initially obtained from the Australian Government Department of Health Departmental Ethics Committee. From mid-2018, ethics approval was granted by the Australian Institute of Aboriginal and Torres Strait Islander Studies Human Research Ethics Committee, which is the primary Human Research Ethics Committee for the study.

The Research Team

Our authorship team is a mix of Aboriginal (JR, TR, SE) and non-Indigenous (KW, DB, KL, EC, LP) researchers. The team have worked together carefully to use the LSIC data in line with its original intent (Walter et al., 2017) and to embed Indigenous perspectives in

terms of which research questions are asked, and how findings are interpreted (Rogers et al., 2022). We were informed by the approach to Indigenous quantitative methodology described by Andersen and Walter (2013). We also sought to ensure that: (a) We approached Indigenous data with the respect and principles outlined by the Australian Institute of Aboriginal and Torres Strait Islander Studies Code of Ethics for Aboriginal and Torres Strait Islander Research (Australian Institute of Aboriginal & Torres Strait Islander Studies, 2020); (b) our analyses aligned with the methodology and overarching research questions set out by the LSIC Steering Committee (Walter et al., 2017).

Participants

In this analysis, we combined the B and K cohorts for LSIC to identify 473 Aboriginal and Torres Strait Islander children in the study who completed an assessment of executive function during adolescence (27% of the total sample). The executive function assessment (see further details below) was implemented in Wave 10 for the K cohort and Wave 15 for both cohorts. We combined the cohorts and cleaned and interrogated the executive function data as described below to identify 375 young people from the K cohort and 98 from the B cohort aged between 12 and 17 years of age at time of executive function testing ($M = 13.5$ years, $SD = 13$ months) to include in our analytic sample. A total of 53.7% of included participants were females. Missing data on the executive function measure were primarily related to children not participating in the face-to-face data collection component of the study due to COVID pandemic restrictions. We then gathered earlier data from LSIC, as described below, to index two important developmental periods. First, we were interested in the first 2 years of school—when children were 5–7 years old—as a key period for school adjustment and early learning behaviors that may be important in the developmental pathway to adolescent executive function. We drew data from across Waves 1 to 8 in LSIC to identify data for children during this time period. Second, we were interested in the prior-to-school period, that is, when children were under 5 years of age and not yet in formal school. We drew from Waves 1 to 6 of LSIC to locate this data.

Measures

Executive Function in Adolescence

Executive function was measured with three tasks from Cogstate (<https://www.cogstate.com>), delivered as a screen-based activity on a notebook computer. Each task had a short practice session in which the LSIC interviewer explained the task, and a practice trial was completed. An overall measure of executive function was derived by combining the standardized performance scores from each task to develop a composite executive function outcome measure. This suite of measures has been established as appropriate, valid, and reliable for Indigenous adolescents (Dingwall et al., 2009; Lewis et al., 2010) and have been used in Australia's population study *Growing up in Australia: The Longitudinal Study of Australian Children* (Yu & Daraganova, 2017). The three tasks were selected for both data collections, because they comprised an adequate measure of key components of executive function, were suitable for use with adolescents, and could be administered in a time efficient manner as part of broader data collection protocols

(Yu & Daraganova, 2017). We align our approach to creating a composite score from three selected tasks with that of prior research in the Australian context (Berthelsen et al., 2017), and with recommendations that composite measures are superior to single task scores as single tasks are subject to greater variability due to potential measurement error (Cuevas et al., 2014).

Identification Task. This task measured information processing, requiring visual attention, and measured through choice reaction time. In this task, rapid responding required participants to pay attention to the color of a playing card (but not its suite or number), a task with increased demands on attentional abilities and thus requiring greater processing time (Yu & Daraganova, 2017). Therefore, the choice reaction time is a valid measure of attentional deployment, long considered a core component of executive functioning (P. Anderson, 2002). A playing card was displayed briefly on screen, and the participant made a judgment as to whether it was red or black. If it was red, then the participant pressed “yes” (a marked key on notebook keyboard); if it was not red, the participant pressed “no” on the keyboard. The speed at which the participant was able to accurately process the onscreen information and react by pressing the correct key was measured, across 30 trials presented in 2 min. Participants were required to complete 75% of test trials to receive a score. Performance integrity was based on an accuracy score. Accuracy of performance was computed by taking the arcsine square root of the proportion of correct responses (integrity failure if >80% of trials). The primary performance measure for this task was reaction time in milliseconds (speed), which was normalized using a log10 transformation. Lower scores represent faster reaction time and therefore a higher skill level in attention.

One-Back Task. This task assessed working memory and required the participant to mentally retain information before being able to make a response. A pack of playing cards was displayed. On each trial, the card at the front was moved to the back of the pack and the next card was shown. As soon as the second card was displayed, the participant was asked to decide whether or not the card displayed was identical to the previous card. The participant used a computer key marked “yes” to denote the cards were the same, and a key marked “no,” if they were not the same. Correct responses were counted across 30 trials presented in 2 min. Participants were required to complete 75% of test trials to receive a score. Performance integrity was based on an accuracy score. Accuracy of performance was computed by taking the arcsine square root of the proportion of correct responses (integrity failure if >70% of trials). The accuracy score was normalized using an arcsine square-root transformation, with this being used as the final outcome score.

Groton Maze Learning Test. This task measured visual-spatial memory, planning, and problem-solving skills. This task has been evidenced as a valid measure of processing speed, attention, and working memory for spatial information (Pietrzak et al., 2008) and loads well on an overall latent construct for executive function (Nordenswan et al., 2020). Participants were asked to find a hidden pathway through a maze, by learning the directions of the pathway with each move made, and receiving feedback after each move. Participants had the opportunity to learn the rules of the task on a small practice grid. In the main task, the participant, by trial and error, was required to locate the hidden pathway (28 steps), from the top left corner to bottom right corner on a 10 × 10 grid of tiles. There were five trials, using the same pathway, of 2 min each. After an incorrect move, the participant was required to return to the last

position to make a different choice on direction. When a participant made a correct move, a green tick mark was presented on screen and when a participant made a move to a tile not on the pathway, this incorrect move was indicated by a red cross. Performance integrity failure was defined as >120 errors. The summary outcome measure used was total errors, which is the sum of legal and rule-break errors, with higher scores indicating less strong performance on this measure.

An additional filter was also applied to the data for each task in which scores below/above three standard deviations were not included. A composite score for executive function was constructed using the three measures, following procedures described in Maruff et al.'s (2013). For each task, the mean and standard deviation were computed and standardized. A composite score was computed by averaging the standardized scores for the three tasks; restandardized using the mean and standard deviation for the composite score; transformed once more so that each had a mean of 100 and a standard deviation of 10 and multiplied by -1 , so that higher scores indicated more competent performance (for the identification and Groton maze tasks only). If data were available for at least two of the three tests, a composite executive function score for the participant was created. As the bivariate correlation between age of LSIC participant at testing and executive function score was not significant ($r = .043, p > .05$), age was not included in modeling.

Classroom Self-Regulation in the Early School Years

We position classroom self-regulation in the early school years as a predictor of later executive function. This aligns with prior longitudinal studies (Berthelsen et al., 2017) and developmental theory suggesting that where children are more highly self-regulated in early learning environments, they are more likely to capitalize on instruction and learning experiences, thus boosting cognitive development overall. Concurrent measures of teacher-reported self-regulation and executive function in the early school years are moderately correlated ($r = >.50$; Howard et al., 2021). Thus, while we did not have access to an executive function measure in the data set in children's earlier years, our teacher-reported index of self-regulation is likely to be correlated with unmeasured executive function at that time, therefore representing early skills related to our adolescent outcome measure.

Teachers completed six items from a subscale of the *Social Skills Rating Scale* (Gresham & Elliott, 1990). Items ask the teacher to report how often the study child demonstrated the following behaviors in the past month or two: keeps belongings organized; shows eagerness to learn new things; works independently; easily adapts to changes in routine; persists in completing tasks; pays attention well. The response scale included *never* (1), *sometimes* (2), *often* (3), and *very often* (4). A mean of the available data for each of the six items was computed for each participant for each of their first 2 years of formal school, and then these were averaged to create an index of classroom self-regulation in the early school years, with scores ranging from 1 to 4. The calculated scale demonstrated good internal consistency ($\alpha = 0.93$).

Visual Motor and Literacy Skills in the Preschool Period

The *Who am I?* is a developmental assessment that requires the child to write their name, copy shapes, and write letters, numbers, and words in a small booklet, with simple instructions and encouragement

from the interviewer (Australian Council for Educational Research, 2007). The *Who am I?* is not language dependent and is suitable for children with limited English (Buckley et al., 2013; De Lemos, 2002). The assessment takes about 10 min to complete and is suitable for preschool children and children in the first 2 years of school. In LSIC, the full *Who Am I?* assessment was collected in Waves 2 and 3 for the K cohort and Waves 5 and 6 for the B cohort. Here, we averaged scores across waves for data available when children were aged under 5 years old, creating a variable indexing visual motor and literacy skills in the preschool period.

Expressive Vocabulary in the Preschool Period

The *Renfrew Word Finding Vocabulary Test* (Renfrew, 1998) assesses children's expressive vocabulary, that is, children's ability to name pictures of objects with increasing levels of difficulty (score range 0–50; Buckley et al., 2013). Most of the objects illustrated have no alternative names, so the responses of children can be quickly measured. The assessment contains 50 line-drawn pictures and is suitable for children aged between 3 and 9 years old. If children responded in an Indigenous language and the assessor was able to ascertain the naming was correct, the item was scored correct. This test was administered in Waves 1–3 for the K cohort and Waves 4–6 for the B cohort. Children's total scores for the word finding vocabulary test were standardized in each wave. The mean of the standardized scores within the preschool period was then computed for each child.

Attendance at a Preschool Program in the Year Prior to Formal Schooling

The national Closing the Gap strategy (National Indigenous Australians Agency, 2024) includes a specific target to increase the proportion of Aboriginal and Torres Strait Islander children enrolled in the year before full-time schooling early childhood education to 95%. In this study, attendance at a preschool program in the year before school was included as a dichotomous indicator: yes = 1 (63% of analytic sample); no = 0 (37% of analytic sample). While dosage (number of days attending) has been an important predictor of development in other studies (He et al., 2021), here, we focus on the dichotomous indicator to best align with government policy and reporting. Further, we see important qualitative differences in groups of children who attend preschool at all compared to those who do not, that are likely to be more critical than differences between those children who might attend 1 or 2 days compared to those who attend 4 or 5 days. Specifically, accessing any preschool at all in the year prior to school is likely associated with broader family engagement in education and community services, and may also reflect a systemic enabler in terms of having local access to preschool services.

Home Learning in the Preschool Period

Parents were asked to respond "yes" (1) or "no" (0) to a series of questions asking whether they or another family member engaged in any of the following activities during the last week with the study child: told an oral story; engaged in drawing, arts, craft; engaged in music and dance; engaged in housework or cooking; played indoors; played outdoors; took child shopping; and listened to child read. A

maximum score for each item (activity) was computed using data across all available waves, and these scores were then summed to create an overall index of preschool home learning engagement between adults and children in the family.

Parent Social Support in the Preschool Period

Parents were asked to identify their most frequent sources of advice or information about looking after their child from a range of choices provided under the broad categories of family or friends, professionals, or media. We focused on the family or friend category in which participants could select “yes” (1) or “no” (0) to each subcategory of: partner; family living in house; family not living in this house; friends; and neighbors. We summed the yes responses for these items within each wave of the preschool period. To derive one variable for the preschool developmental period, the minimum of the summed variables from each wave within this period was computed. This final score (ranging from zero to four) therefore represented the minimum level of parenting social support reported by parents in the preschool period.

Socioeconomic Status

The *Index of Relative Indigenous Socioeconomic Outcomes* is a composite, rank-order variable derived from information on the employment, education, income, and housing characteristics of Aboriginal and Torres Strait Islander communities from Indigenous regions across Australia (Biddle et al., 2019). This variable ranges from 1 to 10 (deciles), where higher numbers reflect higher socioeconomic outcomes. *Index of Relative Indigenous Socioeconomic Outcomes*’ correlations for children across time in LSIC tend to be $>.85$ (Rogers et al., 2022), showing stability in this construct. We gathered *Index of Relative Indigenous Socioeconomic Outcomes* for each child across the preschool years and used the minimum across those years in our analyses.

Remoteness

The *Australian Statistics Geographical Standard* ratings consist of five categories: *major cities of Australia* (1), *inner regional Australia* (2), *outer regional Australia* (3), *remote Australia* (4), and *very remote Australia* (5). Correlations across time in LSIC for children on this item are high ($>.90$) suggesting invariance across time (Rogers et al., 2022). We identified the maximum (i.e., most remote) of these geographical ratings for each child for all available waves within the preschool period to use as a variable in our models.

Total Number of People in the Household

Parents provided information on the total number of people living in their house in each wave of LSIC. For our analyses, we calculated the maximum number of people in the household (from any wave of data available within the preschool period).

Approach to Analysis and Missing Data

Path analyses were used to estimate the direct and indirect effects of theoretically derived relationships among the variables of interest using MPlus Version 8.11. Model 1 was an unadjusted direct effects model testing the direct relations between preschool vocabulary,

visual motor, and literacy skills, early school classroom self-regulation, and adolescent executive function. Model 2 built on the first model by including early contextual factors likely to influence both the preschool and early school skills and executive function. We simultaneously tested both direct (in relation to adolescent executive function) and indirect associations (i.e., through preschool and early school skills). Study analysis code can be attained by contacting the first author. The analyses were not preregistered.

Missing data ranged from 14.5% for preschool sociodemographic variables to 50% on teacher-reported classroom self-regulation (due to teacher nonresponse). There were no missing data on our outcome variable of executive function due to our analytic sample selection procedure. We used maximum likelihood with robust standard errors to account for nonnormal and missing data. We include the variances of all predictor variables in the model, allowing the software to make distributional assumptions and make predictions based on observed data including those with missing data, avoiding listwise deletion. Our models were only just identified meaning interpretation of fit indices was not possible [$\chi^2(0) = 0$, comparative fit index = 1; root-mean-square error of approximation = 0].

Transparency and Openness

Data are available for access through application to the data custodians, accessed via the Australian Government Dataverse, see <https://dataverse.ada.edu.au/dataverse.xhtml?alias=lsic>. Study analysis code can be accessed at <https://osf.io/bcgmk/>. This study and analytic plan were not preregistered. We have reported here our sample selection, variable selection, and analytic approaches.

Results

Descriptive Statistics

Descriptive statistics, including bivariate correlations among variables used in analyses are presented in Table 1. Higher socioeconomic status in preschool was associated with living in a less remote area, with fewer people in the house, and with higher skills for children in preschool vocabulary, visual motor and literacy, and adolescent executive function. Higher socioeconomic status was also associated with higher levels of engagement in home learning activities by parents. Children who lived in more remote areas during their preschool years were more likely to have more people living in the house and have lower preschool skills in vocabulary, visual motor and literacy, early school classroom self-regulation, and adolescent executive function. Living in more remote areas was also associated with a lower likelihood of attending formal preschool. Having a higher number of people living in the home in the early years was associated with lower levels of preschool parent social support, lower preschool vocabulary scores, and lower adolescent executive function. Girls had stronger preschool visual motor and literacy skills and early school classroom self-regulation skills than boys. Children’s preschool skills of vocabulary, visual motor, and literacy were positively correlated with each other as well as being correlated with early school classroom self-regulation skills and with adolescent executive function. Preschool vocabulary skills were also positive correlated with preschool levels of parent social support and engagement in home learning activities.

Table 1
Descriptive Statistics and Bivariate Correlations for Key Model Constructs

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Female	—										
2. Socioeconomic status	.03	—									
3. Remoteness	-.05	-.55**	—								
4. Number of people in house	.02	-.27**	.34**	—							
5. Vocabulary	.05	.27**	-.40**	-.24**	—						
6. Visual motor and early literacy	.22**	.23**	-.18**	-.08	.38**	—					
7. Classroom self-regulation	.30**	.07	-.22**	.00	.26**	.39**	—				
8. Executive function	-.03	.17**	-.20**	-.14**	.18**	.24**	.27**	—			
9. Attended preschool	.07	.08	-.14**	-.05	.15**	.20**	.12	.06	—		
10. Parent social support	.04	.07	-.03	-.15**	.17**	.10	.11	.05	-.02	—	
11. Home learning	.04	.07	-.03	-.15**	.17**	.10	.11	.05	-.02	-.13*	—
Range	NA	1–10	1–5	2–21	35.75–45.52	3–32	1.33–4	69.17–127.69	NA	0–4	0–8
<i>M</i>		6.07	2.43	4.93	40.41	16.68	3.4	100		2.25	6.90
<i>SD</i>		2.15	1.39	1.90	1.90	5.13	0.74	10		0.50	1.22

Note. NA = not applicable.
* $p < .05$. ** $p < .01$.

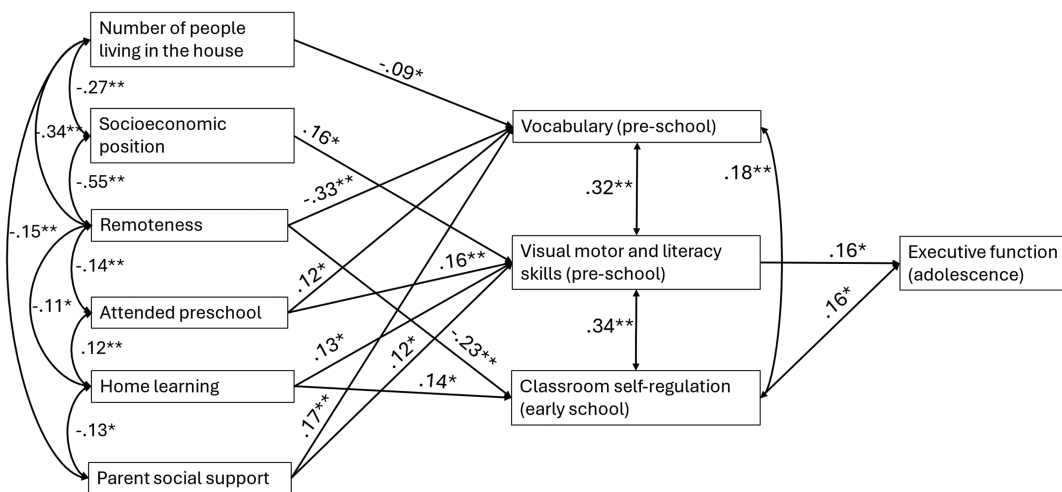
Path Models

The first model tested the direct relations between preschool vocabulary, visual motor and literacy skills, early school classroom self-regulation, and adolescent executive function. Visual motor and literacy skills ($\beta = .15$) and classroom self-regulation ($\beta = .18$) were significantly associated with adolescent executive function scores, with this model accounting for 10% of variance in executive function. Although there was no statistically significant association between preschool vocabulary and adolescent executive function, vocabulary was significantly correlated with both preschool visual motor and literacy skills ($r = .39$) and early school classroom self-regulation ($r = .25$), which were also correlated with each other ($r = .39$).

The second model built on the first model by including early contextual factors likely to influence preschool and early school skills and executive function. We simultaneously tested both direct associations of these early contextual factors with adolescent executive function, and indirect associations through the preschool and early school skills included in Model 1. Standardized regression coefficients and correlations for the statistically significant paths only are presented in Figure 1. See Appendix for all standardized estimates, including nonsignificant paths and confidence intervals.

The significant associations found in Model 1 between each of preschool visual motor and literacy skills, and early school classroom self-regulation with executive function measured up to 10 years later

Figure 1
Final Path Model of Adolescent Executive Function Development



Note. Estimates are standardized with only significant paths shown. All correlations among contextual variables and all direct paths between contextual variables and later executive function were also estimated.
* $p < .05$. ** $p < .01$.

remained. In terms of contextual variables, there were no direct effects of these in relation to executive function; however, many were significantly associated with early skills. Having attended formal preschool in the year prior to school was associated with significantly higher vocabulary and visual motor and literacy skills in the preschool period. Higher levels of home learning engagement between adults and children was associated with better preschool visual motor and literacy skills as well as higher classroom self-regulation in the early years of school. Higher levels of parent social support in the preschool period was linked with better preschool vocabulary, visual motor, and early literacy skills. A higher socioeconomic position was associated with better visual motor and early literacy skills. Living in a more remote area was associated with poorer preschool vocabulary and early school classroom self-regulation. More people living in the house during the preschool period was associated with poorer preschool vocabulary. Overall, the model accounted for 12% variance in executive function; 23% variance in preschool vocabulary; 11% variance in preschool visual motor and literacy skills; and 8% variance in early school classroom self-regulation.

Discussion

This study is the first, to our knowledge, to document a longitudinal model of adolescent executive function development in a large Indigenous population. We found that stronger adolescent executive function was supported by core early childhood competencies of visual motor and literacy skills in the preschool period and classroom self-regulation as observed by teachers in the first 2 years of school. Although preschool vocabulary was not directly linked with adolescent executive function, its significant correlations with these other core skills suggests an important role in development overall. Turning to early learning and home contextual factors, although there were bivariate correlations among these and executive function in adolescence, these were completely mediated by children's early childhood functioning on core skills. Specifically, core early skills were supported by preschool attendance, positive home learning environments, and parents' social resources. Children in homes in less remote areas and those with higher socioeconomic position were also more likely to have higher early skills. A higher number of people living in the household was associated (negatively) only with children's preschool vocabulary skills.

Taken together, our results largely mirror those from prior studies of general population samples that included non-Indigenous and Indigenous children, which document the importance of early developmental skills and early learning environments in shaping longer term cognitive outcomes such as executive function (Berthelsen et al., 2017; Clemens et al., 2023; Schoon et al., 2021). The relevance of early visual motor and literacy skills and classroom self-regulation aligns with prior work and suggests that these should be a key focus of early learning programs. Children who are able to maintain focus and task persistence in the early school years are most able to capitalize on the learning opportunities provided and typically also have more positive relationships with both teachers (Acar et al., 2021) and peers (Westermann et al., 2024), which is important for school belonging and ongoing engagement. Early visual motor and literacy skills, as measured here, tap into children's experience with paper-and-pencil activities as well as their

coordination of visual input and motor planning skills. Early learning programs that provide play-based opportunities for children to engage in these kinds of activities, as well as distribution of home-based resources to encourage this kind of skill development, are recommended.

Preschool vocabulary did not predict adolescent executive function in our model, though at the bivariate level these constructs were modestly and positively correlated, which is pertinent given the data time points were at least 7 years apart. While prior research suggests that vocabulary and executive function codevelop during the early years, likely in a bidirectional manner (Shokrkon & Nicoladis, 2022), there is little longitudinal evidence linking early language development with adolescent executive function. One prior Australian study with a population data set documented a small positive association with preschool vocabulary and adolescent executive functioning (Berthelsen et al., 2017) but did not include a measure of visual motor and literacy skills as per our model. In our model vocabulary was moderately correlated with concurrent visual motor and literacy skills and had a small correlation with early classroom self-regulation, which were both associated with later executive function. Taken together the pattern of findings suggest the relevance of early visual motor and literacy skills, along with teacher-reported self-regulation to longer term executive functioning, with vocabulary clearly playing a role in supporting these key skills. Future research could aim to better explicate the direct and indirect developmental paths among these constructs over time using repeated measures.

Our findings align with others in highlighting the vital role of adult-child engagement in the home learning environment in terms of supporting early core skills including visual motor and literacy and self-regulation (Hughes & Devine, 2019; Joseph et al., 2024). Policy and programs that value parents' and other adult caregiver's roles as children's most important first teachers can support these vital everyday interactions. Community-based programs, such as playgroups, which bring local families together for play-based activities, are known to increase home learning engagement in the general population (Bennett et al., 2025) and for Aboriginal and Torres Strait Islander families (Williams et al., 2017). Indeed, Australian playgroup-based interventions in general populations (Bennett et al., 2025) and with Aboriginal families (Page et al., 2019) have been successful both in boosting parent-child interactions and in subsequently enhancing child developmental outcomes, including those related to self-regulation and language. Such intergenerational programs that bring parents and children together also enhance social capital for parents (Williams et al., 2018), which, in our and others' studies (Rodcharoen et al., 2024), is also linked with enhanced developmental outcomes for children.

Our findings suggest a focus on support for families living in remote areas and in low socioeconomic contexts is warranted. At the bivariate level, living in a more urban area in early childhood and having a higher socioeconomic position were associated with higher executive function skills in adolescence. Although in our path model there was only one significant effect for socioeconomic status, with higher status related to better early visual motor and literacy skills, socioeconomic status was simultaneously negatively correlated with remoteness. The latter which represented the strongest correlation in our model and likely influenced a range of our findings. For example, although socioeconomic status was not related to vocabulary in our model (but was at the bivariate level) or to classroom self-regulation,

remoteness was. Further, while there was no correlation between socioeconomic status and attending preschool either at the bivariate level or in our full model, children in more remote areas were less likely to attend preschool with implications for visual motor and literacy development as per our model. Families living in more remote areas were also more likely to have more people living in the house, have lower rates of engagement in the adult-child home learning activities measured here, and were less likely to have children attending preschool. Even accounting for these correlations among contextual variations, living in a more remote area was still associated with poorer preschool vocabulary for children and poorer early school classroom self-regulation, with some of the strongest effects in our model for these paths.

These findings highlight the interwoven and complex nature of living in a remote area for Aboriginal and Torres Strait Islander children which has been previously documented (He et al., 2021; Rogers et al., 2022). While children in remote areas are more likely to have access to elders, connection to land and country, and speak an Indigenous language, systemic inequities mean they are less likely to have access to early childhood education and care and English as second-language teachers in school (Hurley et al., 2022; Rogers et al., 2022). Future research could seek to better disentangle some of the developmental pathways for children from urban versus rural/remote areas with one approach to estimate multigroup models comparing the two groups, thus treating residential location as a moderator rather than a predictor in the model. Such future research could also attempt to account for service access and systemic barriers associated with geographic residence as well as the cultural and community strengths that support children to grow up strong and differ by location.

We found limited effects in terms of our measure of number of people living in the house, as a proxy for crowding, with a small association between more people in the house and lower preschool vocabulary for children. At the bivariate level, more people living in the house was associated with lower socioeconomic status, living in more remote areas, lower levels of parent social support and engagement in fewer home learning activities during early childhood, and with poorer executive function adolescence. While other studies find measures of household chaos in general to be associated with poorer child developmental outcomes, where components of chaos are investigated there tend to be limited effects for overcrowding. Instead, aspects such as a lack of routine and noise (e.g., always having the television on) appear more impactful (Oloye & Flouri, 2021). Our study is limited by the inclusion of only one indicator of household environment but indicates that enhancing housing affordability and availability particularly in remote areas may be a key policy lever to support children's early fundamental skills and ongoing cognitive development.

It is important to note that our model was successful in explaining only 12% of variance in adolescent executive function, which while relatively low, is similar to a prior Australian population longitudinal study (10% explained; Berthelsen et al., 2017). To understand unmeasured influences on executive function development over time in this population, future studies should seek to measure and model child, family, and community practices and strengths valued by the Aboriginal and Torres Strait Islander community. For example, it has been proposed that key to executive function development for Indigenous children are aspects of being engaged in and responsible for household chores and a high level of support for autonomy and

agency, both of which provide important contexts for exercising key cognitive skills. Future studies could aim to understand between-child variation in these kinds of experiences, along with cultural capital and strengths represented in models of Aboriginal and Torres Strait Islander social-emotional well-being (Dudgeon et al., 2025; Gee et al., 2014) to develop enhanced explanations of executive function development.

Limitations and Future Directions

Although our study makes an important contribution given the dearth of longitudinal models of Aboriginal and Torres Strait Islander executive function development, it is not without limitations. First, as a secondary data analysis, we were constrained by the available sample and variables. It is important to note that neither the original LSIC sample nor the analytic sample selected for this study are representative of the entire Aboriginal and Torres Strait Islander population of Australia (Walter et al., 2017). Our selection of variables aimed to cover a diverse set of contextual variables and important early childhood skills; however, there are many other potentially influential variables such as children's motor skill development and cultural experiences that were not included. In particular, experiences such as early untreated ear infection, developmental disability, and delay are likely to have important implications for cognitive development over time but were not included in this study (I. Anderson et al., 2017; Morrow et al., 2023). Future studies should seek to gain a more nuanced understanding of complex pathways of cognitive development including these individual characteristics and cultural aspects and experiences. With a larger data set, and thus more power, moderation analyses would be valuable to understand variation in developmental pathways, for example, by remote versus urban groups. The sensitivity and specificity of measures of predictor variables could also be further considered in future studies. For example, while we drew on a dichotomous indicator of attendance at a preschool or not in the year prior to school, future studies may consider a more nuanced examination of preschool attendance level such as in He et al.'s (2021). We cannot know how much children attended and what type of program or learning experiences they participated in. Second, it should be noted that data for this study were drawn from LSIC waves with two cohorts undertaken across 2008–2011 for the preschool period, 2008–2015 for the early school years period, and across 2017–2022 for the adolescent executive function measure. It is likely that a range of changes in policy and social contexts, including the effects of the global pandemic (2020–2022), have influenced variation in the kinds of key indicators we used in our model. The extent to which the nature of relationships shown in our model of cognitive development have also changed will only be understood with ongoing longitudinal research, and the establishment of new birth cohorts for important studies such as LSIC.

Conclusion

This study has developed a longitudinal model of cognitive development, specifically adolescent executive function, for a large sample of Aboriginal and Torres Strait Islanders for the first time. Strong executive function in adolescence is likely to contribute to positive downstream educational and employment outcomes aligned with national priorities for addressing Aboriginal and Torres Strait

Islander outcomes. Alongside ongoing approaches to address institutionalized racism and system-level effects of colonization, investing early in child, family, and early education contexts represents a positive opportunity to boost developmental trajectories. Findings suggest that current efforts to enhance housing affordability, as well as to boost investment and equitable access to early parenting supports and early learning programs across diverse geographic locations, are well justified and have the potential for far-reaching effects. These early settings can focus on building social supports for parents and developing key early vocabulary, visual motor and literacy, and self-regulation skills for young children, which are important for laying the foundation for strong executive function development.

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(Appendix follows)

Appendix

Path Model Estimates

Path	Standardized estimate	95% CI	<i>p</i>
Predicting executive function in adolescence			
Visual motor and literacy skills (preschool)	.16	[.04, .28]	.01
Classroom self-regulation (early school)	.16	[.02, .30]	.02
Vocabulary (preschool)	.001	[-.12, .14]	.91
Socioeconomic position	.05	[-.07, .18]	.41
Remoteness	-.09	[-.22, .04]	.16
Attended preschool	.004	[-.09, .10]	.94
Parent social support	-.01	[-.11, .09]	.89
Home learning	-.06	[-.15, .03]	.21
Number of people in house	-.08	[-.19, .02]	.13
Predicting visual motor and literacy skills (preschool)			
Attending preschool	.16	[.05, .26]	<.01
Parent social support	.11	[.01, .22]	.03
Socioeconomic position	.16	[.03, .30]	.02
Remoteness	-.06	[-.18, .07]	.36
Number of people in house	.01	[-.09, .12]	.80
Home learning	.13	[.03, .24]	.01
Predicting classroom self-regulation in early school			
Remoteness	-.23	[-.39, -.07]	<.01
Home learning	.14	[.01, .26]	.04
Socioeconomic position	-.03	[-.19, .13]	.72
Number of people in house	.08	[-.08, .23]	.33
Attended preschool	.05	[-.09, .19]	.47
Parent social support	.11	[-.02, .23]	.09
Predicting vocabulary (preschool)			
Parent social support	.16	[.07, .25]	<.01
Home learning	.07	[-.03, .15]	.17
Attended preschool	.12	[.03, .21]	.01
Number of people living in the house	-.09	[-.17, -.003]	.04
Remoteness	-.33	[-.44, -.23]	<.01
Socioeconomic position	.05	[-.06, .16]	.40
Correlations			
Visual motor and literacy skills (preschool) ↔ Vocabulary	.32	[.22, .42]	<.01
Visual motor and literacy skills (preschool) ↔ classroom self-regulation	.34	[.23, .46]	<.01
Vocabulary ↔ classroom self-regulation	.18	[.05, .30]	<.01
Remoteness ↔ socioeconomic status	-.55	[-.62, -.47]	<.01
Remoteness ↔ home learning	-.11	[-.21, -.02]	.02
Remoteness ↔ number of people living in the house	.34	[.27, .42]	<.01
Remoteness ↔ attended preschool	-.14	[-.24, -.04]	<.01
Remoteness ↔ parent social support	-.03	[-.13, .07]	.55
Remoteness ↔ home learning	-.11	[-.21, -.02]	.02
Socioeconomic status ↔ number of people living in the house	-.27	[-.37, -.18]	<.01
Socioeconomic status ↔ attended preschool	.08	[-.02, .18]	.10
Socioeconomic status ↔ parent social support	.07	[-.032, .17]	.14
Socioeconomic status ↔ home learning	.09	[-.01, .18]	.08
Number of people living in the house ↔ parent social support	-.15	[-.24, -.06]	<.01
Number of people living in the house ↔ attended preschool	-.05	[-.15, .05]	.34
Number of people living in the house ↔ home learning	-.02	[-.14, .11]	.82
Home learning ↔ attended preschool	.12	[.02, .22]	.02
Home learning ↔ parent social support	-.13	[-.23, -.03]	.01

Note. CI = confidence interval.

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