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*Growing Up in Australia:*
The Longitudinal Study of Australian Children (LSAC)

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# Executive Functioning—Use of Cogstate measures in the Longitudinal Study of Australian Children

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# 1 Introduction

## 1.1 The Longitudinal Study of Australian Children (LSAC)

*Growing Up in Australia: The Longitudinal Study of Australian Children* (LSAC) is a national study designed to provide an in-depth understanding of children's development in Australia's current social, economic and cultural environment, thereby contributing to the evidence base for future policy and practice development.

The study was initiated and is funded by the Australian Government Department of Social Services (DSS) through the National Centre for Longitudinal Data (NCLD) and is conducted in partnership with the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). A consortium of leading researchers and experts from universities and research agencies provide advice to the study.

The study commenced in 2004 with the recruitment of two cohorts: one cohort of 5,107 children aged 0 to 1-year-old (the birth or "B cohort") and another of 4,983 children aged 4 to 5-years-old (the kindergarten or "K cohort") and their families across all states and territories of Australia. Interviews with families are conducted every two years. By 2015, six waves of data were available. Detailed descriptions of the study design and procedures can be found in LSAC technical papers (Gray & Smart, 2009; Soloff, Lawrence, & Johnstone, 2005).

## 1.2 Executive functioning

Executive functioning (EF), also referred to as 'executive control' or 'cognitive control', is a multidimensional construct involving a set of cognitive abilities that allows us to control and coordinate our thoughts and behaviours in daily life (Karoly, 1993; Shallice, 1982). Such abilities include attention, reasoning, inhibition control, decision-making, working memory and future-behaviour planning when faced with novel tasks and situations (Miyake, Yoshino, Yamada, Hata, & Nishizawa, 2011; Pennington & Ozonoff, 1996). Executive processes develop throughout childhood and adolescence and play an important role in a child's cognitive function, learning, emotional control and social interaction.

Efficient functioning in everyday life requires the successful orchestration of different components of executive functioning. The key elements of executive functioning, as described by Anderson, Jacobs, and Anderson (2011) are:

- anticipation and deployment of attention
- impulse control and self-regulation
- initiation of activity
- working memory
- mental flexibility and utilisation of feedback
- planning ability and organisation
- problem-solving.

Various theoretical models of executive functioning have been developed and applied to research and clinical practice. The problem-solving framework of executive functioning (Zelazo, Carter, Reznick, & Frye, 1997) illustrates the way in which distinct executive processes operate in an integrative manner in order to solve a problem or achieve the goal state. According to this framework, executive functioning comprises four phases that are temporally and functionally distinct: (1) problem representation; (2) planning; (3) execution; and (4) evaluation. Studies examining factor structure of executive functioning found that items from executive functioning tests loaded on three to four factors. For example, Brocki and Bohlin (2004) found evidence for three independent dimensions, which they refer to as disinhibition, speed/arousal and working memory. Anderson (2002) conceptualised the executive control system as an overall control system, which comprise four distinct domains: attentional control, cognitive flexibility, goal setting and information processing. These domains are considered independent and exhibit different developmental trajectories. It has also been recently proposed that the processes that constitute executive functioning could be dichotomised as "cool" cognitive and "hot" emotional components (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Zelazo & Müller, 2002). The "cool" component of executive functioning

facilitates cognitive regulation and problem solving. In contrast, "hot" executive functioning is required when a situation is meaningful and involves the regulation of affect and motivation. Impairments in cool executive functioning affect the ability to learn or problem-solve, whereas impairments in hot executive functioning result in impulsivity and inappropriate social behaviour.

Developments in executive functioning among children and adolescents are critical to healthy and successful life outcomes and deficiencies in executive functioning are related to numerous poor outcomes. Individuals with executive functioning deficits may exhibit poor attention and planning, difficulties generating and implementing strategies, inability to utilize feedback and inflexibility of thinking (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Not surprisingly, executive functioning has been found to be positively associated with academic performance. Children's executive skills such as attention are important predictors in their school readiness and later achievement (Duncan et al., 2007). Bull, Espy and Wiebe (2008) assessed preschool children's executive functioning skills using a battery of cognitive measures and found that strong executive functioning skills at age 4 predicted high performances in math and reading throughout the first three years of primary school. Preschool children's attention, working memory and inhibitory control also predicted high levels of math achievement, learning–related behaviours and engagement (Brock et al., 2009). Executive functioning skills were also found to predict adolescents' performance in reading, science, mathematics and social studies (Latzman, Elkovitch, Young, & Clark, 2010). In addition, impaired executive functioning was found to be related to eating disorders in a population-sample of 669 Australian adolescents (Allen et al., 2013).

Executive functioning is not exclusive to cognitive and learning processes. It is also implicated in emotional responses and behavioural actions (Gioia, Isquith, Guy, & Kenworthy, 2000a). In particular, mood, energy level, initiative and social behaviour can be disrupted in children and adults exhibiting executive functioning deficits. Children with executive impairment are at higher risk of having aggression, delinquency, poor interpersonal skills and difficulties maintaining meaningful social relationships (Anderson et al., 2011; Hughes & Ensor, 2011). Among adolescents, the links between the role of executive functioning and mental health are significant (Hackman, Farah, & Meaney, 2010; Noble, McCandliss, & Farah, 2007). Executive functioning deficits are also associated with a number of psychiatric and developmental disorders, including obsessive-compulsive disorder, Tourette's syndrome, depression, schizophrenia, attention-deficit/hyperactivity disorder and autism (Paus, Keshavan, & Giedd, 2008; Zhou, Chen, & Main, 2012).

Executive functioning develops most rapidly during the preschool years and changes from childhood through to adolescence. Components of executive functioning have different developmental trajectories and some components have been shown to improve throughout adolescence (Anderson et al., 2011). However, in typically developing children, changes in executive functioning diminish in adolescence and become stable in late adolescence. For example, attentional control, cognitive flexibility, goal setting and information processing experience were found to develop before the age of 9 and are relatively mature by 12 years of age (Anderson, 2002). According to Williams et al. (2015), attention, working memory and processing speed improve consistently until approximately 15 years of age, with the rate of improvement being particularly fast in late childhood (9 to 12 years). Similarly, in a study of around 6,000 adolescents aged between 10 and 18 years, Cromer, Schembri, Harel and Maruff (2015) found that attention, working memory and learning changed more rapidly at younger ages and stopped changing between age 17 and 18.

## 1.3 Executive functioning data in LSAC

Executive functioning measures have been widely used in longitudinal studies (for example, the NICHD Study of Early Child Care and Youth Development in the United States and the Colorado Longitudinal Twin Study). In LSAC, executive functioning measures have been included in Wave 6 for the first time, but only for K cohort children (14 to 15 years). Inclusion of executive functioning tasks alongside a range of other measures will help to better understand what factors contribute to successful life outcomes. This information will have important policy implications. In current prevention and intervention approaches in childhood and adolescence there has been little integration of recent findings in neuropsychology and neuroscience (Blair & Diamond, 2008; Romer, 2010; Romer et al., 2009). The integration of prevention research and neuroscience in the context of interventions can promote resilience by improving the executive functioning of inhibition, planning, emotional regulation and attention in children and youth. In addition, across childhood and adolescence, there is evidence that executive functioning differs by socioeconomic status (SES) and family structure (Gioia, Isquith, Guy, & Kenworthy, 2000b; Sarsour et al., 2011). By further understanding these differences, effective interventions can be developed.

## 1.4 About this report

This paper aims to provide guidance to researchers on the executive functioning data in LSAC. With LSAC providing the major evidence base for understanding children's executive functioning in Australia, it is critical that researchers have a good understanding of, and confidence in, the executive functioning measures. First, executive functioning is a multidimensional construct that incorporates a number of inter-related skills. Therefore, it is critical for researchers to understand the definition and conceptualisation of executive functioning and how different components were assessed in LSAC. We provide information regarding the extent to which the tasks used to measure particular components of executive functioning are reliable indicators of each component. In addition, the data are complex. The Cogstate battery used in LSAC has three primary outcome measures along with over 60 variables. To effectively use these data, it is important that researchers understand the nature of these variables.

This report uses the K cohort data in Wave 6, when children's executive functioning was assessed for the first time. Section 2 describes the Cogstate cognitive testing battery as the measure of executive functioning. Section 3 presents an overview of the data collection and the completion rate of the executive functioning data in LSAC. It then examines the degree to which the sample of children with complete executive functioning data is representative of the LSAC Wave 6 sample. Section 4 describes how executive functioning data are stored in the LSAC data file. Section 5 describes the distribution of executive functioning scores in the LSAC sample overall and also across different sociodemographic groups The distribution of the executive functioning scores in LSAC were also compared to the Cogstate normative data. Section 6 explores the extent to which executive functioning scores are associated with the main socioemotional wellbeing, temperament, cognitive and learning measures used in LSAC. A summary concludes the report.

# 2 Assessment of executive functioning

## 2.1 The Cogstate cognitive testing battery

Executive functioning was assessed via direct cognitive assessment using the Cogstate cognitive testing battery. The Cogstate program produces a variety of cognitive tests, which can be found in http://www.Cogstate.com/. The program uses a game-like format, making it well-suited to child and adolescent participants.

Three Cogstate cognitive tests were used in LSAC. Details of each test and associated output variables are summarised in Table 1.

**Table 1: Cogstate tests used in LSAC: task information and executive functioning assessed**

| Task code | Task name | Cognitive function tested | Administration time | Description |
|---|---|---|---|---|
| IDNT | Identification test | Choice reaction time; attention | 2 minutes | Q: Is the card red? |
| ONBT | One-back test | Working memory | 2 minutes | Q: Is the card the same as the previous card? |
| GMLT | Groton maze learning test | Spatial memory; impulse control and inhibition of erroneous responses | 5 minutes | Find the hidden pathway |

The **Identification task (IDNT)** uses a well-validated choice reaction time paradigm that assesses local processing and attention to detail (Cromer, Schembri, Harel, & Maruff, 2015). A study child (SC) must determine stimulus colour and then make a differential motor response (that is, pick the appropriate button) depending on the colour of the stimulus. The SC is asked whether the card currently being presented in the centre of the screen is red. In this task, participants are shown a playing card in the centre of the screen and asked to respond as quickly as possible to the question: "Is the card red?" Rapid and accurate responding requires children to pay attention to the colour of the card, but not its suit or number. Due to the increased demands on attention and perceptual abilities choice reaction time tasks require greater processing time. Choice reaction time tests are used to measure overt attention.

The **One-Back task (ONBT)** uses a well-validated n-back paradigm. N-back tasks require individuals to maintain information in working memory for a brief time (Shallice et al., 2002). In ONBT, a SC must consider the card in the centre of the screen and respond to the question: "Is this card the same as that on the immediately previous trial?" Children are required to remember the image of the last item they saw and compare the memory of this image to the next stimulus. Therefore, the ONBT is used as a measure of working memory.

The **Groton Maze Learning Test (GMLT)** is a neuropsychological measure of spatial working memory, learning efficiency and error monitoring (Pietrzak, Cohen, & Snyder, 2007). The GMLT is conceptually based on a hidden maze learning test developed by Barker (1931) and extended by Milner (1965). To complete the maze, a SC has to follow a hidden pathway (28 moves, 11 turns) through the grid from the top left corner to a flag in the bottom right corner. The GMLT has been found to be sensitive to detection impairment in procedural learning and diminished efficiency creating and accessing an internal spatial map to the master the hidden maze in 8 to 10-year-old children (Mayes, Snyder, Langlois, & Hunter, 2007). GMLT has also been demonstrated as a valid measure of simple visuomotor processing speed, visual attention and working information for spatial information (Pietrzak et al., 2008).

Thus, these Cogstate tasks can be considered to be measures of attention, working memory, learning efficiency, error monitoring and processing speed. The Cogstate tasks take approximately nine minutes to complete, plus two minutes for practice. These three tasks were selected because they: (1) comprised an adequate measure of key components of executive functioning; (2) were suitable for use with adolescents of varying developmental stages; and (3) could be administered in a time efficient manner as part of the broader LSAC assessment.

The Cogstate cognitive tasks were designed especially for repeated assessment with minimal practice effects (Falleti, Maruff, Collie, & Darby, 2006). The tests are computerised and the administration, scoring and reporting are automated and highly standardised. The clinical utility and psychometric properties of the Cogstate tests have been examined in previous studies and demonstrated high validity and reliability in assessing cognitive function in adults (Pietrzak et al., 2008), adolescents (Allen et al., 2013; Cromer et al., 2015) and children (Mollica, Maruff, & Vance, 2004), mild cognitive impairment (Darby, Maruff, Collie, & McStephen, 2002; Maruff et al., 2004), fatigue and alcohol use (Cairney, Clough, Jaragba, & Maruff, 2007; Falleti, Maruff, Collie, Darby, & McStephen, 2003) and cognitive effects of various medications (Collie, Maruff, Snyder, Darekar, & Huggins, 2006; Maruff et al., 2006). Information on publications and conference presentations of studies employing the Cogstate test battery is available at the Cogstate website (http://www.Cogstate.com/).

## 2.2 Task procedure

This section describes the task procedure and administration. The Cogstate tests are automated tasks administered during the computer-assisted self-interview (CASI). The Cogstate tests were performed at the SC's home. All three tasks were presented on a laptop provided by the interviewers and the test results were on the laptop after assessment.

The interviewer first familiarised the SC with how to respond (left- and right-hand responses on the keyboard) and also give brief exposure to the tasks. At the start of the Cogstate tasks, the SC learned to respond using the "Yes" and "No" response buttons. In LSAC, these correspond to the "K" and "D" keys on the keyboard, with "K" used to respond "Yes" and "D" used to respond "No". Stickers with these responses were included on the laptop, and the SC used a mouse to perform the task. The SC was encouraged to read the instructions thoroughly and told that the tasks would be timed, so the SC must go as fast as he/she could to complete each task.

The IDNT and ONBT follow the same general format. Task instructions are provided first and the SC then starts by viewing the top of a deck of playing cards on their laptop screen. The cards all start positioned face down. As soon as the top card of the deck flips over to reveal the card, the SC must respond "Yes" or "No" as quickly and accurately as possible depending on the instructions for IDNT and ONBT. After the SC responds, the face-up card then flips away from the deck, revealing the back of the next card. A series of cards are presented to the SC in quick succession, depending on the rate at which each SC selects the answer. If the SC answers correctly, the card flips off the top of the deck to the right.

There are two possible stimuli in IDNT—either a red or black joker card. The SC must work as quickly as possible to identify whether a card is red or not. The SC should respond by pressing the "Yes" key when the card is red and the "No" key when it is black (see Figure 1). The IDNT takes approximately 2 minutes to complete.

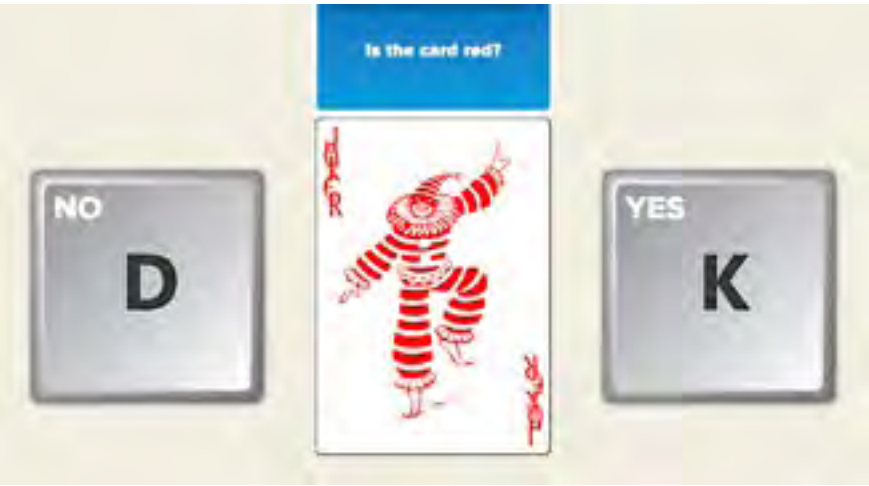



**Figure 1: A demonstration of the Identification task (IDNT)**

The ONBT uses any of the 52 standard playing cards in a deck as possible stimuli, but no jokers. The SC is asked, "Is this card the same as the previous card?" If the card presented is identical to the one presented

immediately before it, the SC should press the "Yes" key; if it is not the same, then the SC should press the "No" key. The ONBT takes approximately 2 minutes to complete (see Figure 2).

For incorrect responses, the card flips to the left. Audio feedback also tells the SC if a response was correct or incorrect. IDNT and ONBT record both speed and accuracy data for every trial.


**Figure 2: A demonstration of the One Back task (ONBT)**

The GMLT requires the SC to move correctly through a 10 x 10 grid of tiles along a specific pathway from the top left tile in the grid to the bottom right tile. In order to familiarise the SC with the test structure, an untimed practice was first administered. During the practice test the SC was asked to follow two rules: 1) only make vertical and horizontal moves; and 2) do not skip over any square (s) when moving towards the flag.

Then the "timed chase test" was administered over five trials (see Figure 3). The SC was required to make as many correct moves as possible while being timed for a short period (30 seconds). To complete the maze, the SC had to follow a hidden pathway through the grid from the top left corner to a flag in the bottom right corner. Each SC completed one of 20 well-matched alternate forms, which had been randomly selected by the computer program. Message bars at the top and bottom of the screen informed the SC whether a move was correct. If the move was correct, the SC was prompted to "Go On" by the message bar and a musical tone. If the move was incorrect, the SC had to move back to the previous square and try a new way. All perseverative errors were recorded. When the SC reached the flag the trial ended. The speed of completion and number of errors were measured. Given this is a test that evaluates the SC's ability to learn a hidden maze path over consecutive trials, the SC was asked to complete the maze five times in order to demonstrate his/her learning trajectory over time. This task takes approximately five minutes to complete.

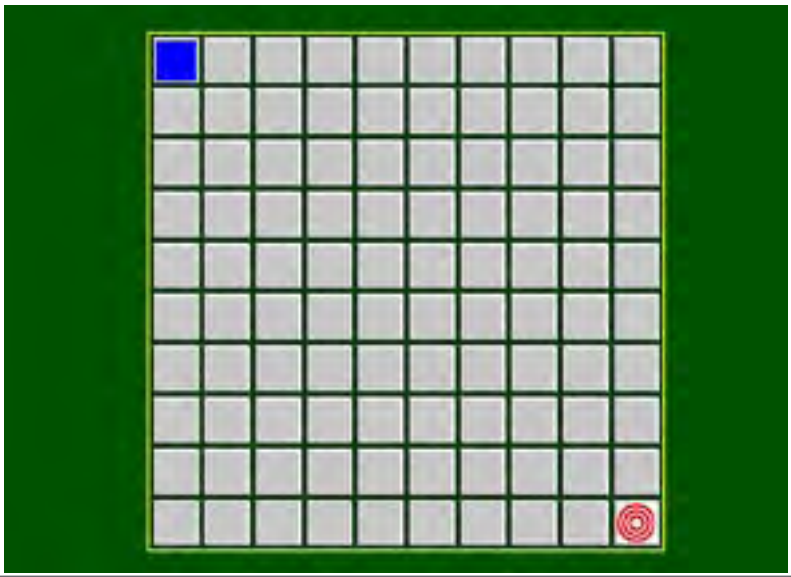


**Figure 3: A demonstration of the Groton Maze Learning Test (GMLT)**

# 3 Data completion and integrity

This section describes the process of EF data collection and the performance of the completed check in the collected EF data. Differences in demographic information across children who had completed EF data collected and those who did not have completed EF data collected were examined. In addition, integrity checks were applied to the completed executive functioning data to ensure that the SC was completing each test seriously.

## 3.1 Obtaining consent and collecting executive functioning data at interview

Executive functioning data were not collected when:

(a) a SC was not present at the assessment

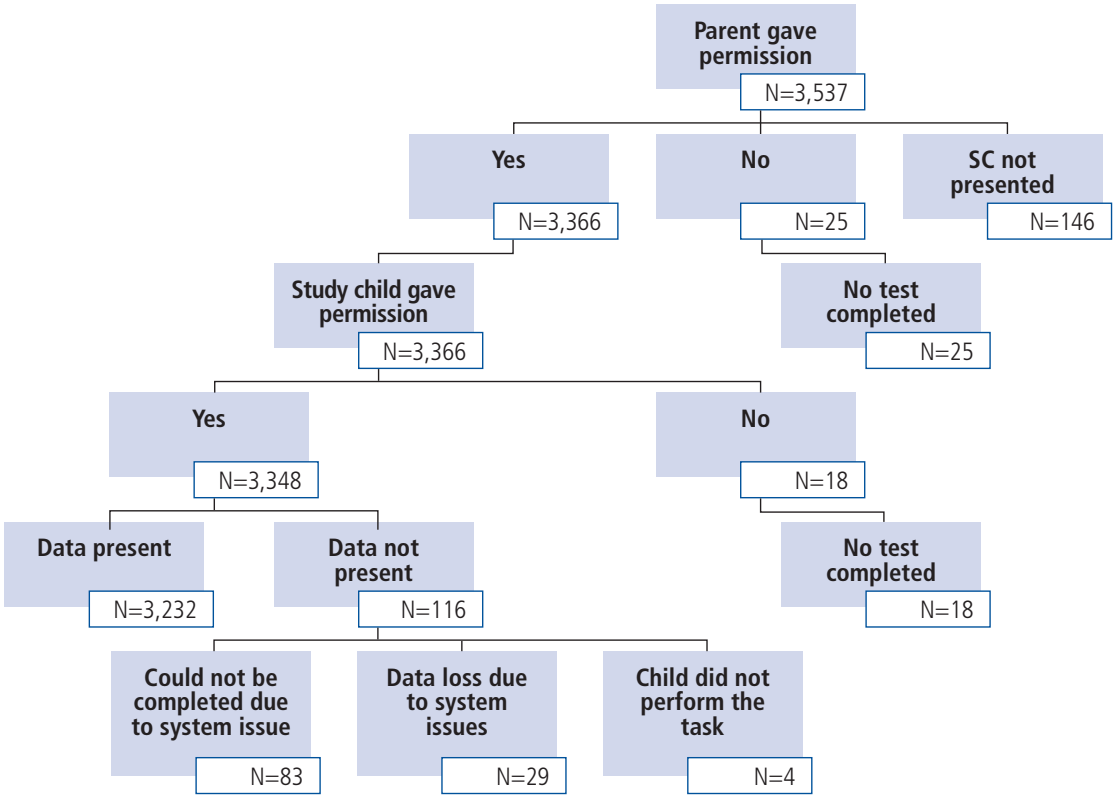
(b) consent for a SC to perform the Cogstate tasks was not obtained from a parent

(c) self-consent for a SC to perform the Cogstate tasks was not obtained from the child

(d) a parent and a SC gave consent but the child did not perform the tasks

(e) the task could not be completed or data were lost due to system issues.

Figure 4 displays the executive functioning data collection at the Wave 6 interview. First, parents were asked to give consent for their child to perform the Cogstate tasks. Of the 3,537 parents at the interview, 25 did not give permission for their children to perform the tasks and 146 were not asked because their children were absent. Of those 3,366 children whose parents gave consent, 18 were not willing to perform the tasks due to a range of reasons (for example, feeling tired, not interested). There were 3,348 children who gave consent to do the test. Four of them did not actually do the tasks and data were not collected from 112 of them due to system errors. In total, executive functioning data were collected from 3,232 children at Wave 6.




Note: Total sample size: N = 3,537.

**Figure 4: Executive functioning data collection procedure in LSAC, K cohort, Wave 6**

## 3.2 Task completion check

The second aspect of executive functioning data completion was the extent to which a SC provided sufficient responses to allow computation of reliable performance measures. The term "sufficient" is defined as a task completion criterion. Task completion checks were conducted on the 3,232 executive functioning observations in the data file.

Tasks were defined as 'completed' for each of the three tasks, as follows:

- IDNT: if 75 per cent or more of the trials were completed (≥ 23 responses)
- OBNT: if 75 per cent or more of the trials were completed (≥ 24 responses)
- GMLT: if 100 per cent of trials were completed (all 28 steps of the maze; correct moves = 140).

This information is crucial in the analysis of data when scores are based on only a small number of trials, as these scores are less likely to reflect accurately the SC's performance level. As specified in the Cogstate guidelines, data that does not meet the completion criteria should be omitted from the analysis (Cogstate, 2011).

Table 2 shows the completion rates of the executive functioning data collected at Wave 6. The vast majority of children have completed all three Cogstate tasks (98 per cent) and all of the children have completed at least one of the tasks.

**Table 2: Task completion for IDNT, ONBT and GMLT (N = 3,232)**

| Task completion | IDNT | ONBT | GMLT | Any | All three |
|---|---|---|---|---|---|
| Yes | 3,232 (100.0%) | 3,222 (99.7%) | 3,178 (98.4%) | 3,232 (100.0%) | 3,171 (98.4%) |
| No | 0 (0.0%) | 10 (0.3%) | 54 (1.6%) | 0 (0.0%) | 51 (1.6%) |
| Total | 3,232 | 3,232 | 3,232 | 3,232 | 3,232 |

Note: Executive functioning data presented at Wave 6, K cohort (N = 3,232).

## 3.3 Executive functioning data availability by sociodemographic variables

Executive functioning data were available for 3,232 SC (91.4 per cent) out of the total sample of K cohort children at wave 6 (N = 3,537), whereas executive functioning data were not collected from 305 children. It is important to assess whether these 3,232 children are representative of the wave 6 sample and, if not, what variables might be associated with this selectivity. Therefore, this subsection sought to examine the differences in parental and child characteristics across children with executive functioning data and children without executive functioning data available at wave 6.

### Child characteristics

- The SC's gender (girls vs. boys).
- Indigenous status—whether a SC was of Aboriginal and/or Torres Strait Islander background.

### Parental characteristics

- Country of birth for Parent 1 (Australia or New Zealand vs. overseas).
- Language spoken at home by Parent 1 (English vs. non-English).
- Family type (two-parent vs. single-mother families). Two-parent families are defined as those in which the child lives with two parents in the Parent 1 household. Single-mother families are those in which the child lives with one female parent only (who is not necessarily the child's biological mother). There are very few single-father families (fewer than 2 per cent), so these have been excluded from analyses comparing different family types.
- Unemployed household—two-parent families where Parent 1 and Parent 2 were unemployed or not in the labour force and single-parent families where Parent 1 was unemployed or not in the labour force.

- Parental education (university degree or higher vs. below university degree)—the highest level of education attainment attained by Parent 1 or Parent 2.
- Family region of residence (metropolitan vs. non-metropolitan areas)—measured using the ASC Census data to identify whether a SC lived in a metropolitan area (capital city statistical division) or non-metropolitan area (the rest of the state outside the capital city statistical division).
- Neighbourhood disadvantage (disadvantaged vs. non-disadvantaged)—measured using the Socioeconomic Indexes for Areas (SEIFA)—Disadvantage. Those families living in areas in the lowest 25 per cent SEIFA index of disadvantage are considered to be living in an area of socioeconomic disadvantage.

Table 3 presents demographic characteristics for two groups of children: 3,232 children with executive functioning data (column 1), and 305 children without executive functioning data (column 2) at Wave 6. Children without executive functioning data were more likely to be of Indigenous status, not to have a parent with a university degree, and to be living in a single-mother or unemployed household. In addition, children who lived in a disadvantaged neighbourhood were less likely to have executive functioning data available at Wave 6 compared to children who lived in a non-disadvantaged neighbourhood. There were no statistically significant differences in the availability of executive functioning data between boys and girls, children of different cultural backgrounds or residential locations.

**Table 3: Sample characteristics for SC with executive functioning data and SC without executive functioning data at Wave 6 (N = 3,537)**

| | Executive functioning data % | No executive functioning data % | *p* |
|---|---|---|---|
| **Child characteristics** | | | |
| Child gender (male) | 51.4 | 52.0 | 0.85 |
| Child Indigenous status (yes) | 2.4 | 5.0 | < 0.05 |
| Child mental health (depression) | 26.4 | 24.0 | 0.52 |
| **Parent characteristics** | | | |
| Single-mother households | 17.9 | 24.3 | < 0.05 |
| Parent 1 born overseas | 22.9 | 24.6 | 0.53 |
| P1 spoke language other than English at home | 16.2 | 19.4 | 0.23 |
| Parents' education (< University) | 61.0 | 68.5 | < 0.05 |
| Unemployed household | 8.0 | 12.6 | < 0.05 |
| Non-metropolitan | 38.2 | 42.0 | 0.28 |
| Disadvantaged neighbourhood | 27.4 | 33.6 | < 0.05 |
| **No. of observations** | **3,232.0** | **305.0** | |

Note: Chi-square tests were used to compare means and distributions across subgroups.

## 3.4 Performance integrity of executive functioning data

An integrity check was recommended to ensure that children were completing each executive functioning task as expected. Performance integrity refers to the extent to which performance on a task suggests that the SC was performing in accord with the task requirement. A SC was expected to reach a certain level of accuracy in order for the test results to be considered valid for him/her—that the SC understood the rule for the tasks and put forth sufficient effort.

The integrity criteria were that:

(1) the accuracy of performance in the IDNT was higher than 1.107 (that is, 80 per cent)

(2) the accuracy of performance in the ONBT was higher than 0.991 (that is, 70 per cent)

(3) the total errors in GMLT were <121.

The criteria for data integrity are derived statistically such that when trained and supervised appropriately, the relevant study population will achieve the said criterion for the respective task 95 per cent of the time when they are demonstrating the appropriate level of effort. Data integrity criteria are applied only when there are completed data for an outcome measure—for data that satisfy task completion criteria.

Table 4 presents the integrity rates of the IDNT, ONBT and GMLT. The vast majority of the executive functioning data has satisfied the integrity criteria. It should be noted that it is possible that individual children who understand the task requirement, who are well motived and well supervised return a performance that fails completion or data integrity criteria. Cogstate recommends scores that failed the integrity check be included in analysis. However, a separate analysis is recommended to be conducted without integrity fails to check on whether including those data changes the results compared to when they were excluded.

**Table 4: Performance integrity for IDNT, ONBT and GMLT (N = 3,232)**

| Performance integrity | IDNT | ONBT | GMLT | Any | All three |
|---|---|---|---|---|---|
| Yes | 3,098 (95.9%) | 2,913 (90.1%) | 3,141 (97.2%) | 3,225 (99.8%) | 2,771 (85,7%) |
| No | 134 (4.2%) | 309 (9.6%) | 37 (1.1%) | 3 (0.1%) | 400 (12.4%)* |
| NA a | 0 (0.0%) | 10 (0.3%) | 54 (1.7%) | 4 (0.1%) | 61 (1.9%) |
| Total | 3,232 | 3,232 | 3,232 | 3,232 | 3,232 |

Notes: Executive functioning data presented at Wave 6, K cohort (N = 3,232).
a NA values of performance integrity due to incomplete executive functioning data.
* Integrity was not available for at least one test.

# 4 Executive functioning data in LSAC

This section describes the key variables in detail. All variables on the data file are summarised in Appendix A and in the Data Dictionary: (http://www.growingupinaustralia.gov.au/data/datadict/index.html).

## 4.1 Data storage

LSAC executive functioning data are stored in the K cohort main data file and in a separate supplementary data file. The main reason for storing the executive functioning data across two data files is to simplify the process of using the executive functioning data. The executive functioning data contains a large number of variables. Cogstate recommends the use of a primary outcome variable for each task (discussed in detail next).

The main LSAC data file, thus, only contains three executive functioning primary outcome variables, along with the completeness and integrity variables and consents and interview information (see Table 5). The supplementary executive functioning data file contains the executive functioning data collected from the interview, which includes all the executive functioning variables. This data file is also provided to data users.

**Table 5: Executive functioning data storage in LSAC**

| Data file | Task | No. of variables | Variables |
|---|---|---|---|
| LSAC main data file | Consent | 4 | e.g., parent and child's permission to complete the tasks |
| | Interview characteristics | 1 | Child's dominant/preferred hand |
| | GMLT, IDNT, ONBT | 3 | Primary outcomes for each task |
| | | 3 | Completeness for each task |
| | | 3 | Integrity for each task |
| Supplementary executive functioning data file | Interview characteristics | 1 | Child's dominant/preferred hand |
| | GMLT | 8 | Overall GMLT outcomes (e.g., duration of test; illegal errors made) |
| | | 1 | Primary outcome (total errors made) |
| | | 1 | Completeness |
| | | 1 | Integrity |
| | | 40 | GMLT trial 1–5 variables |
| | IDNT | 1 | Primary outcome (Speed of performance) |
| | | 1 | Completeness |
| | | 1 | Integrity |
| | | 6 | Task variables (e.g., number of correct responses; number of stimuli presented) |
| | ONBT | 1 | Primary outcome (Speed of performance) |
| | | 1 | Completeness |
| | | 1 | Integrity |
| | | 6 | Task variables (e.g., number of correct responses; number of stimuli presented) |

Note: The K cohort main data file at wave 6 (N = 3,537); Supplementary executive functioning data file at wave 6 (N = 3,232).

## 4.2 Executive functioning variables

Although each of the three Cogstate tasks yield multiple outcome variables, Cogstate's own research has identified a single primary outcome measure for each task that is optimal for the detection of cognitive change in clinical trials at both the group and individual level (Falleti et al., 2006; Falleti et al., 2003; Maruff et al., 2009).

### 4.2.1 Primary outcome variables for analysis

Each primary outcome measure was selected as it has been shown to be optimal for the detection of change because:

(a) it is drawn from a data distribution that contains only a small probability of floor or ceiling effects and no restriction in the range of possible performance values; and/or

(b) it is drawn from a distribution that is distributed normally or which can be corrected to normal through the use of appropriate mathematical transformation (for example, logarithmic base 10) (Anastasi & Urbina, 1997).

Table 6 summarises the primary outcome measures for all three Cogstate tasks used in LSAC, the tests from which they were derived, the operational definition and the variable name in the data files. Cogstate recommends these variables for use in statistical analyses. The IDNT and ONBT capture both accuracy and speed outcome measures. Reaction times (RTs) of correct responses were recorded in millisecond (ms). Speed of responses is calculated by computing the mean of the individual log10 transformed RTs of each correct response for the tasks. Lower scores indicate better (faster) performance.

Performance on the GMLT is expressed as number of legal, perseverative and rule-break errors. If the move is incorrect, it is recorded as a "legal error" and the SC is instructed to go back to the last correct location and to try moving in a different direction. If two incorrect responses are made in a row, the second consecutive error is labelled a "perseverative error" and the SC is again instructed to move back to the previous correct location and to try a new way. If the SC fails to return to the last correct square after making two successive wrong moves, the third error is labelled as "rule-break error" and the location that corresponds to the last correct move begins to flash. The three types of errors made over five trials were summed to create the primary outcome measure of total error. Lower scores indicate better performance.

**Table 6: Primary outcome measures of IDNT, ONBT and GMLT**

| Task code | Outcome variable | Unit of measurement | Description |
|---|---|---|---|
| IDNT | hlc16c1a | Log10 milliseconds | Speed of performance; mean of the log10 transformed reaction times for correct responses |
| ONBT | hlc16c2a | Log10 milliseconds | Speed of performance; mean of the log10 transformed reaction times for correct responses |
| GMLT | hlc16c3c | Total errors | Total number of errors the SC made in attempting to learn the same hidden pathway on five consecutive trials at a single session |

### 4.2.2 Full description of data file

Here we describe all the executive functioning variables. Each task produces data for different outcome variables. Table 7 lists all the executive functioning variables (shown under abbreviations of task characteristics and outcomes) for IDNT, ONBT and GMLT.

#### Consent and interview variables

The **identification variable** 'hicid' is the same in both main and supplementary data files. This variable is used as a unique identifier across all LSAC datasets.

The variable 'hid40m' and the 'hid40n' indicate whether consent was obtained from the parent (**pcons**) and the SC (**scons)**.

The variable 'hid40o' presents the SC's main **reason for refusing to give consent** (**reason**).

SC was asked if they are **right or left handed** (**hand**); if both, which they prefer to use ('hid49a'; 1 = Right, 2 = Left).

Among children who gave permission to do Cogstate tasks, 'hid40o1' indicates whether **data was presented** (**data**) for those children (1= data present; 2 = data not present—no consent given; 3 = data not present—module could not be completed due to system issues; 4 = data not present—data loss due to system issues; 5 = data not present—child consented but did not perform tasks).

## IDNT & ONBT outcome variables

The **number of stimuli** (**sti**) is recorded for IDNT ('hlc16c1g') and ONBT ('hlc16c2g').

The **task completion** (**comp**) of the IDNT ('hlc16c1i') and ONBT ('hlc16c2i') was identified using the number of stimuli (0 = task complete; 1 = task incomplete). The IDNT ('hlc16c1g' ≥ 23) and ONBT ('hlc16c2g' ≥ 24) are complete if at least 75 per cent of stimuli were completed.

The **accuracy of performance** (**acc**) of IDNT ('hlc16c1c') and ONBT ('hlc16c2c') is the arcsine transformation of the square root of the proportion of correct responses. Higher scores indicate better performance.

The **integrity** (**integ**) of IDNT ('') and ONBT ('hlc16c2c') was defined using the accuracy of performance (0 = integrity check passed; 1 = integrity check failed).

The **consistency of performance** (**lsd**) of IDNT ('hlc16c1b') and ONBT ('hlc16c2b') is the standard deviation of the $\log_{10}$ transformed reaction times for correct response.

The number of **correct responses** (**cor**) and the number of **errors** (**err**) the SC made during IDNT ('hlc16c1e' and 'hlc16c1f') and ONBT ('hlc16c2e' & 'hlc16c2f') were summed to create the **total number of responses** (**presnt**) for IDNT ('hlc16c1d') and ONBT ('hlc16c2d').

The **speed of performance** (**lmn**) is the primary outcome variables of IDNT ('hlc16c1a') and ONBT ('hlc16c2a'). It is the mean of the $\log_{10}$ transformed reaction times the SC spent for correct responses and expressed as $\text{Log}_{10}$ milliseconds.

## GMLT outcome variables

**GMLidx** ('hlc16c3') is the index number of the maze path that was presented in the test session, ranging from zero to 20.

**Duration of the task** (**dur**) is provided for the overall ('hlc16c3b') and each of the five GMLT trials ('hlc16c3b1', 'hlc16c3b2', 'hlc16c3b3', 'hlc16c3b4', 'hlc16c3b5'), which is recorded in milliseconds. The duration of the total GMLT is equal to the total time it takes for the participant to complete the five trials in the test and the time the SC spends on the instruction screens throughout the test.

The number of **correct moves** (**cmv**) the SC made during each GMLT trials are recorded. To complete the maze, the SC has to follow a hidden pathway of 28 moves. Therefore, the cmv for each GMLT trial ('hlc16c3g1', 'hlc16c3g2', 'hlc16c3g3', 'hlc16c3g4', 'hlc16c3g5') has a value of 28 and the cmv of the overall GMLT ('hlc16c3g') has a value of 140.

The **completion** (**comp**) **of GMLT** ('hlc16c3i') was defined by using the number of correct moves (0= completed if cmv = 140; 1 = incomplete if cmv < 140).

The **efficiency of performance** is expressed in moves per second (**mps**) and it is calculated by the number of the correct moves through the hidden path divided by the total time taken for the maze.

The number of **legal errors** (**ler**) for each of the five GMLT trials ('hlc16c3d1', 'hlc16c3d2', 'hlc16c3d3', 'hlc16c3d4', 'hlc16c3d5') is summed to indicate the number of legal errors for the overall GMLT ('hlc16c3d').

The **rule break error** (**rer**) refers to the number of errors that break the rules of the maze task for the overall GMLT ('hlc16c3a') and each individual trial ('hlc16c3a1', 'hlc16c3a2', 'hlc16c3a3', 'hlc16c3a4', 'hlc16c3a5').

The **perseveration error** (**per**) refers to the number of errors due to perseveration for the overall GMLT ('hlc16c3a') and each individual trial ('hlc16c3a1', 'hlc16c3a2', 'hlc16c3a3', 'hlc16c3a4', 'hlc16c3a5').

**Total number of errors** (**ter**) is the primary outcome variable of GMLT ('hlc16c3c'). It is the sum of rule-breaking, legal and preservative errors made in attempting to learn the same hidden pathway on five consecutive trails ('hlc16c3c1', 'hlc16c3c2', 'hlc16c3c3', 'hlc16c3c4', 'hlc16c3c5') at a single session. Lower scores indicate better performance.

The **integrity** (**integ**) of GMLT ('hlc16c3j') was defined by using the total number of errors ('hlc16c3c' <121).

**Table 7: Executive functioning variables for IDNT, ONBT and GMLT**

| Task code | Task characteristics | | | | | Outcome | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | hicid | pcons | scons | hand | data | comp | integ | lmn | lsd | acc | cor | err | presnt | sti | GMLidx | cmv | rth | mps | dur | ter | ler | rer | per |
| **IDNT** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | | | |
| **ONBT** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | | | |
| **GMLT** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GMLT1 | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GMLT2 | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GMLT3 | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GMLT4 | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GMLT5 | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# 5 Executive functioning scores in LSAC

This section describes the distribution of executive functioning scores in the LSAC K cohort sample overall and across different sociodemographic groups. The distribution of executive functioning scores in LSAC was compared to the distribution of scores in the Cogstate normative dataset. All results presented in this section were produced using the primary outcome measures in the main data file.

Variables were analysed in Stata version 13.1 using the survey methods procedure to weight the analyses for participants' unequal probability of selection into the sample, and for the multi-stage, clustered sampling design when means and proportions were estimated.

## 5.1 Overall and subgroup executive functioning scores

As discussed in section 3.2, children with completed executive functioning data were included in analysis. Primary outcomes for IDNT (N = 3,232), ONBT (N = 3,222) and GMLT (N = 3,178) are presented separately in Table 8.

As described in Table 6, the primary outcome measure for IDNT and ONBT is the speed of performance, which is the mean of the $\log_{10}$ transformed reaction times for correct responses. The primary outcome measure for GMLT is the total number of errors made in attempting to learn the same hidden pathway on five consecutive trials. For all three primary outcome measures, lower scores indicate better performance.

**Table 8: Means and standard deviations for the primary outcomes on Cogstate tasks in LSAC**

| | Performance speed | | Total error | |
|---|---|---|---|---|
| | *M (SD)* | *N* | *M (SD)* | *N* |
| IDNT | 2.68 (.08) | 3,229 | - | - |
| ONBT | 2.86 (.10) | 3,222 | - | - |
| GMLT | - | - | 53.56 (20.04) | 3,178 |

Notes: Completed executive functioning data on IDNT (N = 3,232), ONBT (N = 3,222) and GMLT (N = 3,178) at Wave 6.
Differences in sample size are due to missing values in primary outcome measures.

Table 9 shows children's executive functioning scores across different groups within the sample (for example, child gender, parents' education, parent 1's language spoken at home, SC's mental health status, family type, and parents' occupational prestige).

The analysis showed no significant difference in children's performance in IDNT and GMLT according the SC's gender; however, there were significant gender differences found for the ONBT, with faster speed in the ONBT among boys than girls.

Children who did not report depressive feelings were significantly faster on the IDNT than children who reported depressive feelings, although the difference was small. Children who had symptomatic depression made significantly more errors on the GMLT than children who did not have symptomatic depression.

Parent 1's language background makes little difference to executive functioning outcomes. There was no significant difference observed in children's average executive functioning scores according to parent 1's language. A comparison of children who lived in two-parent families with those who lived in single-mother households regarding executive functioning scores revealed no significant differences in any of the tasks.

Table 9 also shows differences in executive functioning scores by parental education. Children from families where at least one parent had a university degree scored significantly lower (faster speed) on IDNT than children from families where the highest educational attainment was Year 12. There were no statistically significant differences in children's performance on ONBT and GMLT across different educational groups.

The executive functioning scores for the children differed according to the occupational status of their parents. Children whose parents came from the highest occupational group (manager/professional) achieved faster speed in IDNT than did those children whose parents came from the other three occupational groups. Children whose parents came from the highest occupational group had significantly better performance on

ONBT than did those children whose parents came from the lowest occupational group (not in paid work). In addition, those children whose parents came from the highest occupational group and clerk/skilled work groups made fewer errors in GMLT than did those children without a parent in paid work.

Table 9 also shows the difference in executive functioning scores by children's region of residence. Children who lived in regional areas were slower in IDNT and ONBT than children who lived in metropolitan areas. The differences were small but statistically significant. Children's performance on GMLT did not differ significantly by the region of residence.

On the IDNT, children in non-disadvantaged areas were significantly faster than children who lived in disadvantaged areas. Children who lived in non-disadvantaged areas also made significantly fewer errors on GMLT when compared to children lived in disadvantaged areas.

**Table 9: The primary executive functioning outcome mean scores across sociodemographic groups**

| | Performance speed | | Total error |
|---|---|---|---|
| | IDNT | ONBT | GMLT |
| **Child gender** | | | |
| Boys (ref.) | 2.68 | 2.85 | 53.42 |
| Girls | 2.68 | 2.87*** | 53.70 |
| **Child's mental health status** | | | |
| Normal (ref.) | 2.68 | 2.86 | 52.23 |
| Symptomatic for depression | 2.69** | 2.86 | 56.73*** |
| **Child language spoken at home** | | | |
| English (ref.) | 2.68 | 2.86 | 53.30 |
| Non-English | 2.68 | 2.85 | 55.25 |
| **Family type** | | | |
| Two-parent family (ref.) | 2.68 | 2.86 | 53.27 |
| Single-mother family | 2.68 | 2.86 | 54.51 |
| **Parent education** | | | |
| Year 12 or below (ref.) | 2.69 | 2.86 | 55.08 |
| Diploma/certificate | 2.69 | 2.86 | 53.92 |
| University or higher | 2.67*** | 2.85 | 52.58 |
| **Parent occupation** | | | |
| Manager/professional (ref.) | 2.67 | 2.85 | 53.20 |
| Clerk/skilled worker | 2.68** | 2.86 | 51.88 |
| Sales/machinery/labourer | 2.69* | 2.87 | 55.74 |
| Not in paid work | 2.70*** | 2.87* | 59.24*** |
| **Region of residence** | | | |
| Metropolitan (ref.) | 2.68 | 2.85 | 54.05 |
| Regional | 2.69* | 2.86* | 52.78 |
| **Disadvantaged neighbourhoods[1]** | | | |
| Disadvantaged (ref.) | 2.69 | 2.86 | 55.57 |
| Non-disadvantaged | 2.68*** | 2.86 | 52.80** |
| **No. of observations** | **3,229.00** | **3,222.00** | **3,178.00** |

Notes: Completed executive functioning data on IDNT (N = 3,232), ONBT (N = 3,222) and GMLT (N = 3,178) at Wave 6.
Statistic significances from $Chi^2$ tests were noted: * $p < 0.05$,** $p < 0.01$, *** $p < 0.001$.

## 5.2 Compare the EF scores in LSAC and Cogstate normative sample

The distribution of executive functioning scores in LSAC sample was compared to the distribution of corresponding Cogstate scores in pediatric normative sample to determine whether they aligned or produced different results. The Cogstate normative sample is based on a healthy population of children and adolescents, ages 4 to 17 years, who enrolled in a series of dedicated normative studies as well as other research and academic studies. Irrespective of where the data was sourced, only baseline sessions were included in the normative database and only a single session was included for each participant. All participants in the normative database had completed at least one practice assessment prior to their baseline assessment (Cogstate, 2016). The EF scores of age groups 14 and 15 years in the Cogstate normative sample were compared to the EF scores in LSAC at Wave 6. The full Cogstate pediatric normative dataset is available upon request. Table 10 below presents the sample size, means and standard deviations of the IDNT, ONBT and GMLT results of LSAC and Cogstate sample for the age groups of 14 and 15 years.

**Table 10: Means and standard deviations for the primary outcomes on IDNT, ONBT and GMLT tasks in LSAC Wave 6 K cohort and Cogstate normative datasets**

| Primary outcomes | | Performance speed | | | | Total error | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | LSAC | | Cogstate | | LSAC | | Cogstate | |
| Test | Age | *M (SD)* | *N* | *M (SD)* | *N* | *M (SD)* | *N* | *M (SD)* | *N* |
| IDNT | 14 | 2.68 (0.09) | 1,909 | 2.69 (0.07) | 7,876 | - | - | - | - |
| | 15 | 2.68 (0.08) | 1,320 | 2.68 (0.07) | 7,708 | - | - | - | - |
| ONBT | 14 | 2.86 (0.10) | 1,902 | 2.87 (0.09) | 7,876 | - | - | - | - |
| | 15 | 2.86 (0.10) | 1,320 | 2.86 (0.09) | 7,708 | - | - | - | - |
| GMLT | 14 | - | - | - | - | 53.13 (18.74) | 1,880 | 44.32 (17.83) | 22 |
| | 15 | - | - | - | - | 54.13 (21.56) | 1,298 | 47.33 (19.25) | 21 |

Notes: Completed executive functioning data on IDNT, ONBT and GMLT at Wave 6 LSAC; IDNT, ONBT and GMLT scores of the age groups of 14 and 15 years in the Cogstate pediatric normative sample in 2016.

The comparison between the LSAC and Cogstate normative datasets shows very limited differences on the IDNT and ONBT results. The performance on GMLT was better in the Cogstate sample than in the LSAC sample as children from the Cogstate normative sample made fewer errors than children from the LSAC sample. However, the sample size was very small in the Cogstate normative sample for the GMLT test; this difference should be interpreted with caution.

## 5.3 Association between executive functioning scores and LSAC measures

This section examines the correlation between the executive functioning scores and the socioemotional wellbeing, anti-social behaviour, cognitive and learning measures in the LSAC database.

As mentioned in the introduction, executive functioning has been found to be associated with a number of developmental and behavioural outcomes. Executive functioning impairments have been established as important risk factors for the development of physical aggression, antisocial behaviours and delinquency (Ogilvie, Stewart, Chan, & Shum, 2011; Séguin & Zelazo, 2005). Executive functioning deficits are associated with obsessive-compulsive disorder, Tourette's syndrome, depression, schizophrenia,

attention-deficit/hyperactivity disorder and autism (Paus et al., 2008; Zhou et al., 2012). The links between mental health and executive functioning are significant among adolescence (Hackman et al., 2010; Noble et al., 2007). Children and adolescents with executive functioning deficits were also found to be at high risk for significant impairments in academic functioning (Biederman et al., 2004). Therefore, it is expected that the executive functioning scores will be correlated with LSAC measures of socioemotional wellbeing, anti-social behaviour, cognitive and learning development.

The Pearson correlation was used to test the association of executive functioning with other LSAC measures. The Pearson correlation coefficient is an indicator of the strength and direction of association that exists between two continuous variables. The Pearson correlation generates a coefficient, denoted as r, with value range from -1 for a perfect negative linear relationship to one for a perfect positive linear relationship. A value of zero indicates no relationship between two variables. In addition, the correlation coefficient r is considered to be small if its absolute value is less than or equal to 0.3, medium if its absolute value is more than 0.3 but less than or equal to 0.5 and large if it is more than 0.5 in magnitude (Cohen, 1988).

## Executive functioning scores and LSAC socioemotional wellbeing measure

Social and emotional wellbeing relates broadly to children's thoughts and feelings about themselves and their conduct and interactions with others (Hamilton & Redmond, 2010). A child's socioemotional behaviour assessed with the Strength and Difficulties Questionnaire (SDQ) at Wave 6 was used to compare with the executive functioning scores. The SDQ scores focus on both positive and negative aspects of children's social and emotional wellbeing.

The SDQ consists of 25 items, which cover five domains of behaviour:

1) prosocial behaviour, for example, considerate of other people's feeling
2) hyperactivity, for example, restless, overactive, cannot stay still for long
3) emotional symptoms, for example, many worries or often seems worried
4) peer problems, for example, picked on or bullied by other young people
5) conduct problems, for example, often loses temper.

There are five items corresponding to each component (see Appendix B for a full list of items). Children were asked to assess their behaviour over the last six months or this school year. Each item has three response categories—'not true', 'somewhat true' or 'certainly true'—which are coded as 0, 1 or 2. A total difficulties score is derived by adding the scores of each of the scale, except the prosocial behaviour domain, producing a total score ranging from zero to 40. Higher scores on difficulties reflect more problematic behaviour. Lower scores on the prosocial behaviour subscale (zero to 10) reflect more problematic behaviour.

Examination of Table 11 suggests that LSAC children's ratings of their prosocial skills were significantly and negatively correlated with children's scores on IDNT ($r$ = -0.05) and GMLT ($r$ = -0.05)—that is, better prosocial skills were correlated with better performance on these two tasks. However, the magnitudes of the correlations were very small. Children's ONBT scores were not correlated with their prosocial skills. SC's socioemotional problems were negatively correlated with children's IDNT and GMLT scores but not ONBT scores. Higher levels of hyperactivity, peer, conduct and total problems were significantly correlated with slower performance on IDNT and GMLT. Again, the magnitudes of these correlations were very small, especially between children's socioemotional problems and their IDNT scores.

**Table 11: Correlation coefficients for executive functioning scores and LSAC Socioemotional outcomes (SDQ)**

| LSAC | Executive functioning | | |
|---|---|---|---|
| **Socioemotional outcomes at Wave 6** | **IDNT** | **ONBT** | **GMLT** |
| Pro-social | -0.05* | 0.00 | -0.05** |
| | *N* = 3,205 | *N* = 3,199 | *N* = 3,159 |
| Hyperactivity | 0.04* | -0.01 | 0.09*** |
| | *N* = 3,203 | *N* = 3,197 | *N* = 3,158 |
| Emotional problems | 0.02 | 0.03 | 0.07*** |
| | *N* = 3,203 | *N* = 3,197 | *N* = 3, 158 |
| Peer problems | 0.07*** | 0.04* | 0.12*** |
| | *N* = 3,203 | *N* = 3,197 | *N* = 3,158 |
| Conduct problems | 0.06*** | 0.00 | 0.14*** |
| | *N* = 3,204 | *N* = 3,198 | *N* = 3,159 |
| Total problems | 0.06*** | 0.02 | 0.13*** |
| | *N* = 3,203 | *N* = 3,197 | *N* = 3,159 |

Notes: Statistic significances from Pearson correlations were noted: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Completed executive functioning data at on IDNT (N = 3,232), ONBT (N = 3,222) and GMLT (N = 3,178) at Wave 6.

### 5.3.1 Executive functioning scores and LSAC anti-social behaviour measure

This section assesses associations between children's executive functioning scores and their anti-social behaviour. A short form of the Moffitt and Silva (1988) Self-Report of Delinquency scale was used to measure adolescents' involvement in antisocial behaviour. At 14 to 15 years, children in the K cohort were asked how many times in the last 12 months they have been involved in different forms of anti-social behaviour: for example, got into physical fights in public; carried a weapon like a knife, gun or piece of wood; stolen something from a shop (see Appendix B for a full list of items). Response categories recorded the number of times that respondents had committed each act, ranging from zero (not at all) to five or more times. For the purpose of this report the outcome measure was calculated as a sum of responses across all items. The higher score reflects greater level of anti-social behaviour. Correlations between children's executive functioning scores and anti-social behaviour at age 14 to 15-years-old were assessed in this paper.

As can be seen in Table 12, the correlations between children's anti-social behaviour and executive functioning scores on ONBT and GMLT were not significant. Children's scores on IDNT were significantly correlated with anti-social behaviour, that is, higher levels of anti-social behaviour were correlated with slower speed on IDNT. Again, the strength of the correlation was weak ($r = 0.09$). Correlation analysis for samples that excluded executive functioning data that failed integrity check reveals similar trends (see Table C2 in Appendix C).

**Table 12: Correlation coefficients for executive functioning scores and LSAC temperament outcome**

| LSAC | Executive functioning | | |
|---|---|---|---|
| | IDNT | ONBT | GMLT |
| Antisocial behaviour | 0.09*** | -0.03 | 0.02 |
| | 3,229 | 3,222 | 3,178 |

Notes: Statistic significances from Pearson correlations were noted: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Completed executive functioning data at Wave 6 (N = 3,232).

## 5.3.1 Executive functioning scores and LSAC cognitive measures

To assess the correlation between executive functioning scores and LSAC cognitive outcomes, the following measures were selected: (a) Peabody Picture Vocabulary Test, 3rd edition (PPVT-III); and (b) the Matrix Reasoning.

The PPVT-III is a test to assess children's receptive vocabulary abilities (Dunn & Dunn, 1996). It is used as a screening tool of verbal skills in children and adults. A higher score represents a better cognitive outcome. The PPVT data was collected from Wave 1 to Wave 3. The Matrix Reasoning Test is part of the Wechsler Intelligence Scale for Children, 4th edition (WISE-IV) and measures non-verbal intelligence (Wechsler, 2003). A higher score represents a better cognitive outcome. These data were collected from Wave 1 to Wave 4 in LSAC. In this section, children's executive functioning scores were correlated to the most recent data of PPVT (collected at Wave 3, 8 to 9 years) and Matrix reasoning (collected at Wave 4, 10 to 11 years).

Table 13 presents correlation results of executive functioning sores and PPVT and Matrix Reasoning. The PPVT is negatively correlated with executive functioning scores on all executive functioning tasks. This suggests that children who achieved higher PPVT scores tended to perform faster on the IDNT ($r$ = -0.16), ONBT ($r$ = -0.12), and made fewer errors on GMLT ($r$ = -0.12). The correlations were significant but weak.

The Matrix Reasoning Test was also negatively correlated with all executive functioning scores, with the largest correlation coefficient being with the IDNT ($r$ = -0.26). This suggests that children with better non-verbal problem-solving ability demonstrated higher levels of executive functioning skills. As it can be seen in Table C3 (Appendix C), excluding executive functioning data that failed integrity check for GMLT yielded similar correlations between PPVT, Matrix Reasoning and executive functioning scores.

**Table 13: Correlation coefficients for executive functioning scores and cognitive outcomes**

| LSAC | Executive functioning | | |
|---|---|---|---|
| | IDNT | ONBT | GMLT |
| **Receptive vocabulary at Wave 3** | | | |
| PPVT | -0.16*** | -0.12*** | -0.12*** |
| | $N$ = 3,138 | $N$ = 3,131 | $N$ = 3,088 |
| **Nonverbal ability at Wave 4** | | | |
| Matrix Reasoning | -0.26*** | -0.18*** | -0.21*** |
| | $N$ = 3,134 | $N$ = 3,127 | N = 3,085 |

Notes: Statistic significances from Pearson correlations were noted: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Completed executive functioning data at Wave 6 (N = 3,232).
Different sample size due to unmatched cases in PPTV and Matrix Reasoning.

## Executive functioning scores and LSAC academic outcomes

Children's academic achievement was measured using NAPLAN scores. NAPLAN is an annual test administered to all Australian students in Years 3, 5, 7 and 9 in the domains of reading, writing, language conventions (spelling, grammar and punctuation) and numeracy. The NAPLAN score is calculated separately for each domain and ranges from zero to 1,000. For more details on the NAPLAN data contained in LSAC, please refer to Daraganova, Edwards, and Sipthorp (2013). In this chapter, Year 7 NAPLAN results on numeracy and reading tests were used, as not all children had had an opportunity to sit Year 9 NAPLAN tests by the time of the Wave 6 data collection.

Table 14 presents correlation results of executive functioning scores and Year 7 NAPLAN numeracy and reading scores. Both NAPLAN scores are negatively correlated with executive functioning scores on all executive functioning tasks. This suggests that children who achieved higher NAPLAN scores performed faster on the IDNT and ONBT and made fewer errors on GMLT. The correlations were significant but not large in magnitude, that is, absolute value of correlation coefficients varied from 0.16 to 0.3.

**Table 14: Correlation coefficients for executive functioning scores and NAPLAN**

| LSAC | Executive functioning | | |
|---|---|---|---|
| | IDNT | ONBT | GMLT |
| **NAPLAN Year 7 numeracy** | -0.30*** | -0.25*** | -0.26*** |
| | N = 2,873 | N = 2,880 | N = 2,880 |
| **NAPLAN Year 7 reading** | -0.26*** | -0.16*** | -0.16*** |
| | N = 2,886 | N = 2,892 | N = 2,900 |

Notes: Statistic significances from Pearson correlations were noted: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Completed executive functioning data at Wave 6 (N = 3,232).

# 6 Conclusion

For the first time in LSAC, at Wave 6 we measured the development of a set of cognitive abilities that have a role in controlling and coordinating children's thoughts and behaviours for the K cohort. These data included attention, reasoning, working memory, learning efficiency, inhibition and error monitoring. The inclusion of executive functioning data in LSAC allows the examination of associations between children's executive functioning and different individual and family characteristics. It also provides an opportunity to test how socioemotional wellbeing, anti-social behaviour, cognitive skills and learning measures used in LSAC are associated with executive functioning test scores. These data, in turn, provide valuable information for academic researchers and policy-makers to use in their decision-making.

Out of the 3,537 K-cohort children responding at Wave 6, 3,232 children completed at least one of the executive functioning tasks. This report documents how executive functioning data has been measured, collected and stored in LSAC. A number of key components of executive functioning were measured by using three direct assessments from the Cogstate cognitive testing battery that included: IDNT (attention, choice reaction time), ONBT (working memory) and GMLT (spatial memory, impulse control, learning efficiency, inhibition and erroneous responses).

This report is not prescriptive in making recommendations, as each analysis has its own purposes and attributes. Rather, the report highlights, in broad terms, some of the key pieces of information of which users of LSAC executive functioning data should be aware:

- Executive functioning data was collected from 3,232 SC (91.4 per cent) out of the total sample of K cohort children at Wave 6.
- Tasks on the executive functioning assessment were considered to be complete if at least 75 per cent of the trials for IDNT and ONBT and all 28 steps of the maze path of GMLT were completed. Incomplete executive functioning data should be excluded from any analysis. In the current data, all the 3,232 SC with executive functioning data collected have completed at least one executive functioning task;
- A number of child and parent characteristics are associated with the availability of executive functioning data, such as the child's Indigenous status, family type, parents' education, employment and neighbourhood disadvantage.
- An integrity check is recommended to ensure the accuracy of the results. Although data that fail the integrity check can be kept in the sample, we recommend conducting a separate analysis excluding those who failed the integrity data checks.
- Although each executive functioning test yields multiple outcome measures, a single primary outcome measure for each task is provided and recommended for general purpose analysis.
- Children's executive functioning performance tends to be different across different sociodemographic groups (for example, child's mental health status, parents' education and occupation).

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# Appendix A: EF data structure

| Variable Name | Task | Variable Label | Unit of measurement |
|---|---|---|---|
| hicid | Admin | HICID | Number |
| hid49a | Admin | Child's preferred hand | 1 Right; 2 Left |
| hlc16c1a | IDN | Performance speed | Log10 milliseconds |
| hlc16c1b | IDN | Consistency | Log10 milliseconds |
| hlc16c1c | IDN | Accuracy | Log10 milliseconds |
| hlc16c1d | IDN | Total number of responses | Count (number up to 3 digits) |
| hlc16c1e | IDN | Number of correct responses | Count (number up to 3 digits) |
| hlc16c1f | IDN | Number of errors | Count (number up to 3 digits) |
| hlc16c1g | IDN | Number of stimuli presented | Count (number up to 3 digits) |
| hlc16c1i | IDN | Task completion | 1 Not completed; 0 Completed |
| hlc16c1j | IDN | Performance integrity | 1 Failed integrity; 0 Passed integrity |
| hlc16c2a | ONB | Performance speed | Log10 milliseconds |
| hlc16c2b | ONB | Consistency | Log10 milliseconds |
| hlc16c2c | ONB | Accuracy | Log10 milliseconds |
| hlc16c2d | ONB | Total number of responses | Count (number up to 3 digits) |
| hlc16c2e | ONB | Number of correct responses | Count (number up to 3 digits) |
| hlc16c2f | ONB | Number of errors | Count (number up to 3 digits) |
| hlc16c2g | ONB | Number of stimuli presented | Count (number up to 3 digits) |
| hlc16c2i | ONB | Task completion | 1 Not completed; 0 Completed |
| hlc16c2j | ONB | Performance integrity | 1 Failed integrity; 0 Passed integrity |
| hlc16c3 | GMLT | Maze path presented | Integer (-1, 1–20) |
| hlc16c3a | GMLT | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b | GMLT | Duration of test | Milliseconds |
| hlc16c3c | GMLT | Total errors made | Count (number up to 3 digits) |
| hlc16c3d | GMLT | Legal errors made | Count (number up to 3 digits) |
| hlc16c3e | GMLT | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f | GMLT | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g | GMLT | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h | GMLT | Return to head errors | Count (number up to 3 digits) |
| hlc16c3i | GMLT | Task completion | 1 Not completed; 0 Completed |
| hlc16c3j | GMLT | Performance integrity | 1 Failed integrity; 0 Passed integrity |
| hlc16c3a1 | GMLT 1 | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b1 | GMLT 1 | Duration of test | Milliseconds |
| hlc16c3c1 | GMLT 1 | Total errors made | Count (number up to 3 digits) |
| hlc16c3d1 | GMLT 1 | Legal errors made | Count (number up to 3 digits) |

| Variable Name | Task | Variable Label | Unit of measurement |
|---|---|---|---|
| hlc16c3e1 | GMLT 1 | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f1 | GMLT 1 | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g1 | GMLT 1 | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h1 | GMLT 1 | Return to head errors | Count (number up to 3 digits) |
| hlc16c3a2 | GMLT 2 | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b2 | GMLT 2 | Duration of test | Milliseconds |
| hlc16c3c2 | GMLT 2 | Total errors made | Count (number up to 3 digits) |
| hlc16c3d2 | GMLT 2 | Legal errors made | Count (number up to 3 digits) |
| hlc16c3e2 | GMLT 2 | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f2 | GMLT 2 | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g2 | GMLT 2 | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h2 | GMLT 2 | Return to head errors | Count (number up to 3 digits) |
| hlc16c3a3 | GMLT 3 | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b3 | GMLT 3 | Duration of test | Milliseconds |
| hlc16c3c3 | GMLT 3 | Total errors made | Count (number up to 3 digits) |
| hlc16c3d3 | GMLT 3 | Legal errors made | Count (number up to 3 digits) |
| hlc16c3e3 | GMLT 3 | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f3 | GMLT 3 | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g3 | GMLT 3 | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h3 | GMLT 3 | Return to head errors | Count (number up to 3 digits) |
| hlc16c3a4 | GMLT 4 | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b4 | GMLT 4 | Duration of test | Milliseconds |
| hlc16c3c4 | GMLT 4 | Total errors made | Count (number up to 3 digits) |
| hlc16c3d4 | GMLT 4 | Legal errors made | Count (number up to 3 digits) |
| hlc16c3e4 | GMLT 4 | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f4 | GMLT 4 | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g4 | GMLT 4 | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h4 | GMLT 4 | Return to head errors | Count (number up to 3 digits) |
| hlc16c3a5 | GMLT 5 | Number of moves per second | Count (number up to 5 decimal places) |
| hlc16c3b5 | GMLT 5 | Duration of test | Milliseconds |
| hlc16c3c5 | GMLT 5 | Total errors made | Count (number up to 3 digits) |
| hlc16c3d5 | GMLT 5 | Legal errors made | Count (number up to 3 digits) |
| hlc16c3e5 | GMLT 5 | Illegal errors made | Count (number up to 3 digits) |
| hlc16c3f5 | GMLT 5 | Preservation errors | Count (number up to 3 digits) |
| hlc16c3g5 | GMLT 5 | Number of correct moves | Count (number up to 3 digits) |
| hlc16c3h5 | GMLT 5 | Return to head errors | Count (number up to 3 digits) |

# Appendix B: Measures of socioemotional wellbeing, anti-social behaviour, cognitive development and learning outcomes

| Socioemotional wellbeing | | Categories | Items |
|---|---|---|---|
| Hyperactivity problem | Average of SDQ hyperactivity problem subscale (5 items) | 1 Not true<br>2 Somewhat true<br>3 Certainly true | Restless, overactive, cannot stay still for long;<br>Constantly fidgeting or squirming;<br>Easily distracted, concentration wanders;<br>Thinks things out before acting;<br>Good attention span, sees tasks through to the end. |
| Emotional problem | Average of SDQ emotional problem subscale (5 items) | 1 Not true<br>2 Somewhat true<br>3 Certainly true | Often complains of headaches, stomach-aches or sickness;<br>Many worries or often seems worried;<br>Often unhappy, depressed or tearful;<br>Nervous in new situations, easily loses confidence;<br>Many fears, easily scared. |
| Peer problem | Average of SDQ peer problem subscale (5 items) | 1 Not true<br>2 Somewhat true<br>3 Certainly true | Would rather be alone than with other youth;<br>Has at least one good friend;<br>Generally liked by other young people;<br>Picked on or bullied by other young people;<br>Gets along better with adults than with other young people. |
| Conduct problem | Average of SDQ conduct problem subscale (5 items) | 1 Not true<br>2 Somewhat true<br>3 Certainly true | Often loses temper;<br>Generally well behaved, usually does what adults request;<br>Often fights with other youth or bullies them;<br>Often lies or cheats;<br>Steals from home, school or elsewhere. |
| Pro-social behaviour | Average of SDQ pro-social subscale (5 items) | 1 Not true<br>2 Somewhat true<br>3 Certainly true | Considerate of other people's feelings;<br>Shares readily with other youth, for example books, games, food;<br>Helpful if someone is hurt, upset or feeling ill;<br>Kind to younger children;<br>Often volunteers to help others (parents, teachers, other children). |
| Total socio-emotional problems | Average of SDQ total problems | 0 (low) to 40 (high) | Total scores of SDQ hyperactivity, emotional, peer and conduct problems; |

| Anti-social behaviour | | Categories | Items |
|---|---|---|---|
| Negative social behaviour | Sum across all responses | 0 Not at all;<br>1 Once;<br>2 Twice;<br>3 Three times;<br>4 Four times;<br>5 Five or more times | Got into physical fights in public;<br>Carried a weapon like a knife, gun or piece of wood;<br>Used force or threats to get money or things from someone;<br>Gone around with a group of three or more kids damaging property or Getting into fights;<br>Stolen something from a shop;<br>Stolen money or other things from another person;<br>Stolen something out of a parked car;<br>Broken into a house, flat or vehicle;<br>Taken a vehicle (e.g., car, motorbike) for a ride or drive without permission;<br>Drawn graffiti in public places;<br>Purposely damaged or destroyed others' property;<br>Damaged a parked car (e.g., broken an aerial, slashed tyres, scratched paint); and<br>Started a fire in a place where you should not burn anything.<br>Run away from home and stayed away overnight or longer;<br>Skipped school for a whole day;<br>Been suspended or expelled from school; and<br>Been caught by police for something you had done. |

# Appendix C: Association between EF scores and LSAC measures—Correlation results of EF data that satisfied integrity criteria

**Table C1: Correlation coefficients for EF scores and LSAC Socioemotional outcomes (SDQ), excluding EF data that failed integrity check**

| LSAC | Executive functioning | | |
|---|---|---|---|
| **Socioemotional outcomes at Wave 6** | **IDNT** | **ONBT** | **GMLT** |
| Pro-social | -0.06** | 0.01 | -0.05* |
| | *N* = 3,075 | *N* = 2,895 | *N* = 3,123 |
| Hyperactivity | 0.03 | 0.01 | 0.09*** |
| | *N* = 3,073 | *N* = 2,894 | *N* = 3,122 |
| Emotional problems | 0.02 | 0.02 | 0.05** |
| | *N* = 3,073 | *N* = 2,894 | *N* = 3,122 |
| Peer problems | 0.06*** | 0.04* | 0.12*** |
| | *N* = 3,073 | *N* = 2,894 | *N* = 3,122 |
| Conduct problems | 0.06** | 0.01 | 0.15*** |
| | *N* = 3,074 | *N* = 2,895 | *N* = 3,123 |
| Total problems | 0.05** | 0.02 | 0.13*** |
| | *N* = 3,073 | *N* = 2,894 | *N* = 3,122 |

Notes: EF data passed both completion and integrity checks on IDNT (N = 3,098), ONBT (N = 2,913) and GMLT (N = 3,141) at Wave 6.

**Table C2: Correlation coefficients for EF scores and LSAC anti-social behaviour measure, excluding EF data that failed integrity check**

| LSAC | Executive functioning | | |
|---|---|---|---|
| **Anti-social behaviour** | **IDNT** | **ONBT** | **GMLT** |
| | -0.08** | -0.03 | -0.01 |
| | *N* = 3,098 | *N* = 2,913 | *N* = 3,141 |

Notes: EF data passed both completion and integrity checks on IDNT (N = 3,098), ONBT (N = 2,913) and GMLT (N = 3,141) at Wave 6.

**Table C3: Correlation coefficients for EF scores and cognitive outcomes, excluding EF data that failed integrity check**

| LSAC | Executive functioning | | |
|---|---|---|---|
| **Receptive vocabulary at Wave 3** | **IDNT** | **ONBT** | **GMLT** |
| PPVT | -0.17*** | -0.14*** | -0.09*** |
| | *N* = 3,013 | *N* = 2,839 | *N* = 3,053 |
| **Nonverbal ability at Wave 4** | **IDNT** | **ONBT** | **GMLT** |
| Matrix Reasoning | -0.26*** | -0.20*** | -0.21*** |
| | *N* = 3,007 | *N* = 2,828 | *N* = 3,051 |

Notes: EF data passed both completion and integrity checks on IDNT (N = 3,098), ONBT (N = 2,913) and GMLT (N = 3,141) at Wave 6. Different sample size due to unmatched cases in PPTV and Matrix Reasoning.

**Table C4: Correlation coefficients for EF scores and learning outcomes, excluding EF data that failed integrity check**

| LSAC | Executive functioning | | |
|---|---|---|---|
| | IDNT | ONBT | GMLT |
| NAPLAN Year 7 numeracy | -0.30*** | -0.30*** | -0.25*** |
| | 2,767 | 2,602 | 2,802 |
| NAPLAN Year 7 reading | -0.28*** | -0.19*** | -0.13*** |
| | 2,776 | 2,614 | 2,813 |