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Early Mathematical Learning: Number Processing Skills and Executive Function at 5 and 8 Years of Age

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Abstract

This research investigated differences and associations in performance in number processing and executive function for children attending primary school in a large Australian metropolitan city. In a cross-sectional study, performance of 25 children in the first full-time year of school, (Prep; mean age = 5.5 years) and 21 children in Year 3 (mean age = 8.5 years) completed three number processing tasks and three executive function tasks. Year 3 children consistently outperformed the Prep year children on measures of accuracy and reaction time, on the tasks of number comparison, calculation, shifting, and inhibition but not on number line estimation. The components of executive function (shifting, inhibition, and working memory) showed different patterns of correlation to performance on number processing tasks across the early years of school. Findings could be used to enhance teachers' understanding about the role of the cognitive processes employed by children in numeracy learning, and so inform teachers' classroom practices.

Keywords : mathematics, number processing, executive function, early childhood education

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Introduction

An educational priority for the early years of school in Australia is to build the foundations of literacy and numeracy as the basis for future learning (Australian Curriculum, Assessment and Reporting Authority, 2012). In Australia, the release of the *Trends in International Mathematics and Science Study* ([TIMSS] International Association for the Evaluation of Education Achievement, 2012) raised concerns that between 29% and 37% of Year 4 students and Year 8 students performed below the intermediate international benchmarks in mathematics and science (Australian Council for Education Research, 2012). In the early years of school, children need to acquire the fundamental skills of numeracy in order to achieve successful learning outcomes in mathematics in later school education. The identification of modifiable factors that influence numeracy learning, especially for children at risk of poorer learning outcomes, can inform classroom interventions that will enhance children's competence in the early years of school. Specific number processing skills and cognitive control mechanisms, termed executive function, are important contributors to early mathematics achievement (Geary et al., 2009; Szucs & Goswami, 2013).

Executive function can be defined as the abilities to stay focused on a task, to switch attention between tasks, to inhibit impulsive responding, and to hold and manipulate information in working memory. These are critical skills influencing early learning (Gutman, Sameroff, & Cole, 2003; Lee et al., 2010). Executive function is the basis of self-regulatory behaviors (Caro, McDonald, & Willms, 2009). While there is not complete consensus about the nature of the developmental trajectories of executive functions, substantial improvements in executive function occur across the early childhood years. The relation between number processing skills and executive function in early childhood is a key focus in this research. Developmental competence in number processing and executive function is compared for children at the beginning of school and children in the third year of school, by which stage, children might be expected to have acquired the basic skills required to meet the goals of the mathematical curriculum in the primary school years.

This research investigates the associations between three executive function skills and three number processing skills for two age groups; children in the Preparatory (Prep) year of school and children in Year 3. The findings can inform teachers' classroom practices to enhance early numeracy, encompassing a focus on the cognitive control processes represented by executive function, as modifiable factors that influence mathematics achievement. Improving mathematical competence in the early years of school can produce lasting benefits across the school years (International Association for the Evaluation of Education Achievement, 2012). Effective interventions to enhance mathematical competence are important in order to children to achieve educational goals (Swanson & Jerman, 2006). While recent efforts to design early number processing interventions show promising results (Jordan & Levine, 2009; Ramani & Seigler, 2008; 2011), a greater focus on strategic learning behaviors, represented by executive function skills, in teachers' practices is likely to enhance early mathematical learning at school.

Literature Review

From international studies, there is evidence that when children begin school there are already considerable differences in children's numeracy capabilities (Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Jordan, Mulhern, & Wylie, 2009), as well changing competence in executive function skills (Best & Miller, 2010; Davidson, Amso, Anderson, & Diamond, 2006). In particular, children from families of lower socio-economic status (SES) are more likely than peers from higher SES backgrounds to begin school with lower preparedness for the academic demands of the school curriculum (Arnold & Doctoroff, 2003). The gap in mathematics achievement for low versus high SES children also widens with age (Caro et al., 2009). Children with mathematics learning difficulties may demonstrate mathematics behaviors and achievement several years behind age-matched peers (Geary, Hoard, Byrd-Craven & DeSoto, 2004). Recent research into the development of executive function has also shown some remarkable *catch up possibilities* for closing these gaps in the early school years. Strategic learning-related behaviors, such as effortful and inhibitory control and self-regulatory behaviors are important to early achievement (Ponitz, McClelland, Matthews, Morrison, & García Coll, 2009). These behavioral skills are particularly important for early school success (Forget-Dubois et al., 2007; McClelland, Acock, & Morrison, 2006).

Developing number processing skills

Infants possess a core understanding of magnitude that is known as the *approximate number system* (Halberda & Feigenson, 2008). This non-symbolic system recognizes numerical differences of magnitude and provides the foundation for later acquisition of an 'exact number system' that is the basis of formal mathematics (Feigenson, Libertus, & Halberda, 2013). The development of mathematical understanding encompasses a mapping between the foundational non-symbolic representations (e.g., dot patterns, physical size) and the symbolic and verbal representations (e.g., 5, 'five', +) that is the basis of the *exact number system*, as described by researchers such as Geary (2013), and Kolkman, Kroesbergen, and Leseman (2013). The integration of these non-symbolic and symbolic representations of number and magnitude in early childhood is also likely to be influenced by the development across this period of other cognitive control processes, such as executive function, which includes attention (Geary, 2013) and working memory (Kolkman et al., 2013).

Number processing includes domain-specific components, such as *number sense*. This is the nonverbal ability to understand, represent, and manipulate numerical magnitudes; and the cognitive processes of executive function (Blair, 2006). Gelman (2000) noted that children's abilities to reason with numbers require number-relevant mental structures that enable understanding of the principles of counting and the relations between numbers. The presence of these structures allows children to attend to and assimilate number relevant information. Importantly, the demand on cognitive processes varies across early childhood as mathematical understanding progresses from applying the approximate number system to requiring exact calculation and specific procedural applications. In this study, this was examined by comparing children in the first year of formal schooling with those in Year 3.

Understanding the role of executive function in number processing skills

The cognitive control processes of executive function enable individuals to manage and direct their attention, thinking, and actions to meet adaptive goals (Best & Miller, 2010). These skills develop and change with age and experience through the development of the prefrontal cortex and associated neural networks. These capacities are also viewed as distinct from general cognitive ability (Blair, 2006).

Models of executive function commonly account for three cognitive control processes (Best & Miller, 2010): *Inhibition* as the capacity to resist distractions; maintain selective attention; and prioritize actions; *set-shifting* as cognitive flexibility to adjust to changed task demands and priorities; and *working memory* as the capacity to hold and manipulate information over short periods of time. Aspects of executive function mature at different rates during the school-age years and considerable maturation occurs between five and eight years (Best & Miller, 2010; Davidson et al., 2006). There is also evidence that these cognitive control processes are amenable to change through early interventions (Miyake et al., 2000).

A number of studies have linked executive function to mathematical skills in school-aged children. Bull, Espy and Wiebe (2008) found an association between the executive function of four-year old children and their mathematics performance at ages five, six, and seven, while Clark, Pritchard, and Woodward (2010) found that measures of inhibition, set-shifting, and planning at age four-years old were associated with mathematical achievement atsix-years old. However, these findings are limited because the research did not explore the relations between aspects of executive function and number processing skills at each phase of the research and focused only on mathematical achievement as the measured outcome. Thus, the specific nature of the relation between the development of executive function and number processing skills in the early school years remains less clear.

Research Questions

This research examined the relations between number processing tasks and components of executive function for children in a Prep class and children in Year 3 of school. Specific research questions (RQs) were:

1. What differences are there between the performance of children in the first year of formal schooling (Prep) and Year 3 on number processing and executive function tasks?
2. What are the relations between performance on executive function and number processing tasks, in the Prep year and in Year 3?
3. How do observer ratings for engagement and understanding of the number processes and executive function tasks reflect performance?

Method

The research was conducted in a large metropolitan city in Queensland, Australia. In the state of Queensland, the first full-time year of primary school is the Preparatory year (Prep) for which, at the time of data collection, children were required to have their fifth birthday by the 30th June in order to be enrolled in late January of that year. After the Prep year, children are likely to attend the same primary school through Year 1 to Year 6. Data were collected in September of the Australian school year that commences in late January and finishes in early December.

The Queensland University of Technology (QUT) Human Research Ethics Committee approved the project data collection and procedures and processes for protecting the confidentiality of children, families, teachers and schools. Parental consent was obtained for all participating children. Parents were encouraged to discuss the project with their children and gain their consent by inviting them to color in a smiley face on the consent form. The task administrator also sought each child's agreement to participate at the beginning of each session.

Participants

Participants were recruited from two Prep classes and two Year 3 classes in the same state primary school. A total of 25 Prep students (Mean age = 5.5 years) and 21 Year 3 students (Mean age = 8.5 years) were recruited. In each age group, there were approximately equal numbers of boys and girls.

Research Design and Procedure

This research was a cross-sectional comparison study. Each child participated in an individual session of approximately 25 minutes. All tasks were administered to the children using the computer by one of the authors of this paper. Three automatic number processing tasks and three executive tasks were completed. Behaviors were measured using accuracy and reaction time. Additionally, the task administrator rated each child's engagement and understanding of each task (Research Question 3). These observations provided an independent assessment of the level of attention that each child gave to each task and its requirements. These observations provided additional information to understand the confidence that can be placed in the performance scores and the variations in the scores on the tasks that required levels of understanding of task requirements (task difficulty) and capacities to maintain engagement (attention).

The number processing tasks were *calculation*, *comparison*, and *number line estimation*. The executive function tasks measured *shifting*, *inhibition,* and *working memor*y. These tasks have been used in previous research (Halberda, Mazzocco, & Feigenson, 2008; Van der Ven, Kroesbergen, Boom & Leseman, 2012; White & Szucs, 2012). All tasks were administered on a laptop and all were programmed in E-Prime with the exception of the comparison task which was delivered using Panamath software (Halberda et al., 2008). For two of the tasks (comparison and number line) children responded directly on a keyboard. For the remaining four tasks, the experimenter entered responses. When a task required a quick verbal response from the child, the experimenter indicated the start of the response by pressing the spacebar and then rated the accuracy of the response. Reaction time and accuracy were always based on the first utterance of the child even if a quick self-correction occurred. A random number generator was used to develop six random patterns of task order and these were randomly assigned to participants. The trials within each task were presented in the same order for each child. Behaviors of Prep and Year 3 children were compared, and correlations between number processing and executive functions measures were investigated for each age group separately.

Measures

Number processing tasks

The three number processing tasks explored children's abilities to compare quantities, calculate and estimate.

Comparison. was tested using the non-symbolic dot comparison task (Halberda, et al. 2008), using the Panamath software. Children were shown yellow and blue dot arrays and were asked to judge which array of dots had more. Each array had between five and 21 dots and the ratio between the number of dots to be compared was systematically manipulated by the Panamath software. The dot arrays were presented for 600ms and children responded using the provided keyboard. Children completed two practice trials to ensure understanding and then were instructed to quickly and accurately complete as many comparisons as possible in two minutes. Children completed between 32 and 48 comparisons in the two-minute period. Reaction time and accuracy were recorded; with the correct number of responses per second the final score.

Calculation. involved single digit addition and subtraction (e.g., 2 + 1, 5 – 1). Children provided a verbal response which was recorded. Each stimulus (e.g., 4 + 3) was presented until a response was given. Similar to the Test for Early Mathematics Ability (Ginsburg & Baroody, 2003), the calculation task captured fluency by encouraging children to complete as many calculations as quickly and accurately as possible in two minutes. Children received four practice trials prior to commencing the task. There were 20 possible calculations that were repeated, if necessary. Children completed between eight and 56 calculations in the two-minute period. Reaction time and accuracy were recorded, and the rate of correct responses per second was used as the final score.

Number line estimation. was completed on a 0-100 number line and adapted from the work of White and Szucs (2012). Children were presented with a number line, after a short delay (1000ms) the target digit appeared in the left corner of the screen. After seeing the target digit (digits were spread across the full range: 5, 11, 18, 25, 33, 52, 40, 71, 85, 99), children were instructed to try and find an estimate for the location of the target digit on the number line. After 2000ms, a marker appeared on the number line and children needed to judge whether the marker was in the correct or incorrect location for the target digit. Children received three practice trials prior to commencing the task. There were 20 estimations completed, with each of the 10 target digits marked with a correct and incorrect location estimate. Children were asked to respond as quickly and as accurately as possible for the 20 trials. Reaction time and accuracy were recorded, and the rate of correct responses per second used as the final score.

Executive Function Tasks

The three executive function tasks examined children's abilities to focus and shift their attention, remember, and respond quickly to questions about various visual stimuli presented on the computer screen.

Shifting. was tested through the animal shifting task developed by Van der Ven et al. (2012) in which children were required to name stimuli presented on the computer screen as quickly as possible. The stimuli were either fruit (strawberry, pear, cherry, banana) or animals (cat, dog, bird, fish). The task consisted of a baseline block, a practice block, and a testing block. In the baseline block, children were presented with one image at a time, each preceded by a 700ms fixation cross, and were required to name the images as quickly as possible. In the practice block, children were shown pairs of images together (one fruit and one animal) and taught to name the animal when the background screen color was purple and the fruit when the screen was yellow. Four practice trials were completed before the testing block began. The testing block consisted of 22 trials in which children gave a verbal response as quickly as possible. The number of shifting items answered correctly per second was used as the final score.

Inhibition. was tested through the animal stroop test (Wright, Waterman, Prescott & Murdoch-Eaton, 2003). An adaptation of this task by Van der Ven et al. (2012) was used. In this task, animals are presented that are composed of the body of one animal and the head of another. The participant has to name the animal body rather than the more salient animal head. The task consisted of a baseline block, a practice block, and a test block. In the baseline and testing blocks, animal stimuli were presented one at a time, preceded by a 400ms fixation cross. The stimuli remained on the screen until the child responded. The child named each animal as quickly as possible.

The baseline block consisted of four normal animal stimuli with congruent heads (cow, sheep, duck or pig), each presented four times, yielding a total of 16 items. In the practice block, children were shown incongruent images; for example, a cow with a duck head, and taught to name the animal based on the body. A total of eight practice trials were completed. The test block was a mixed block of control stimuli with human heads and incongruent stimuli with incorrect animal heads. Twelve different stimuli per condition were each presented four times, yielding a total of 48 control and 48 incongruent items. The number of incongruent items answered correctly per second was used as a final score.

Working memory. was tested using the keep track task (Van der Sluis, De Jong, & Van der Leij, 2007). A modified version of the computerized test developed by Van der Ven et al. (2012) was used. Children were shown pictures belonging to one of the following five categories: sky (sun, moon, stars, cloud); fruit (strawberry, pear, cherry, banana); shapes (square, triangle, circle, heart); animals (dog, cat, fish, bird); and toys (teddy bear, scooter, LEGO®, car). After one practice trial which was repeated as necessary, children were presented with several series of 10 pictures with each picture displayed for 3500ms. The child was asked beforehand to pay special attention to one or more designated categories.

During the series, small pictures symbolizing the to-be-remembered categories were shown in the bottom of the screen, serving as a reminder. During the series, the child had to name each picture. At the end, the child had to recall the last item of the designated categories. Prep children were presented with two series with one designated category to remember in each, and two series with two designated categories to remember in each. Children in Year 3 were presented with these same tasks, with the addition of two more series, each with three categories to be remembered. Early testing showed that this task presented a significant challenge to children of Prep age, and so persisting with additional tasks of increasing difficulty was not deemed necessary. Each correct answer was noted. Depending on the length of the sequence, there could thus be a maximum of one, two, or three (for the Year 3 children) correct answers yielding a maximum possible score of six correct answers for Prep children and 12 correct answers for Year 3 children.

Data Analysis

In all tasks, except working memory, accuracy and reaction time information were collected. A multistage data screening process was conducted with reaction time data (Lee et al., 2010). First, trials with incorrect responses were filtered out. These included any response times that were less than 100 milliseconds, as this was considered to be a mis-trial. Second, the mean and standard deviation (SD) for the response time (RT) for each set of tasks for each child was calculated. Third, trial data that deviated by more than three SDs from a child's mean were removed. The correct rate per second score was then calculated (Van der Ven et al., 2012). Using the correct rate per second scores, the population mean and SD for each task was computed, and any individual scores that were more than three SDs from the population mean were replaced by values at three SDs. The individual scores (correct rate per second) were entered into the subsequent analyses.

Data analysis was completed using SPSS Version 22 and had three stages. First, descriptive statistics were calculated using separate accuracy and reaction time data. Second, an independent samples t-test was used to compare the performance of Prep and Year 3 children. If the Levene's Test indicated that the assumption of homogeneity of variance had been violated, the more conservative t-statistic was used, with adjusted degrees of freedom and significance level. Effect size was calculated using effect size *r* using the t-statistic and degrees of freedom. Third, for each year group, Pearson product-moment bivariate correlations were calculated to investigate relations between the number processing and executive functioning tasks at each level of schooling. From a cross-sectional perspective, this analysis enabled comparisons across age groups.

Observations of task engagement and understanding were coded using a three-point ordinal scale, with 1 = low engagement/understanding, and 3 = high engagement/understanding. The engagement and understanding of Prep and Year 3 children were compared using a Mann-Whitney test. Effect size (*r*-value) was calculated using the standardized test statistic divided by the square root of the number of total observations.

Results

Overall, task completion took longer for the children in Prep. The Prep children took an average of 27.6 minutes, to complete the six tasks, while the Year 3 children took an average 24.2 minutes. The results relevant to each of the three research questions are presented below.

RQ 1: Differences in Task Performance between Prep and Year 3

The ranges, means and SDs for accuracy are presented in Table 1. In almost all tasks, accuracy of response was above chance, with the exception of the Prep group number line (44 ± 11.3%) and working memory (39 ± 26.2%) performance. For accuracy, children in Prep demonstrated the greatest variability in the working memory and calculation tasks.

The ranges, means, and SDs for the reaction time data, after the multistage data screening, are presented in Table 2. For reaction time, children in Prep demonstrated the greatest variability in the calculation (M = 6525 ± 2413 ms) and number line (M = 4054 ± 2027 ms) tasks. In contrast, Year 3 children had less variability in reaction time for the calculation (M = 2867 ± 774 ms) and number line (M = 2613 ± 1069 ms) tasks. In the calculation task this may be attributable to the reduced exposure of the children in Prep to symbolic mathematics notation, such as subtraction. In the number line task, this may be linked to the complex task demands and use of multiple representations (symbolic number representation and spatial representation).

For comparison of task performance, t-tests were completed to identify differences in the performance outcomes between Prep and Year 3 children. As might be expected, Year 3 children had significantly higher performance on nearly all tasks, as evidenced by the probability values and effect sizes (r) presented in Table 3. There was no significant difference between Prep (M = .33 ± .21 correct/sec) and Year 3 (M = .42 ± .13 correct/sec) children for the number line task (t (44) = -1.76, p = .086, r = .256).

Table 1. *Percentage Correct for Tasks*

	Prep year (n = 25)			Year 3 (n = 21)		
	M	SD	Range	M	SD	Range
Comparison	88	9.7	63 - 97	88	6.4	68 - 97
Calculation	55	24.9	6 - 92	94	6.3	77 - 100
Number line	44	11.3	15 - 70	77	12.4	50 - 90
Shifting	88	9.3	54 - 100	94	1.5	75 - 100
Inhibition	92	6.4	75 - 100	95	6.2	83 - 100
Working memory	39	26.2	0 - 83	74	16.7	42 - 100

Table 2. *Reaction Time (in milliseconds) for Tasks*

	Prep year (n = 25)			Year 3 (n = 21)		
	M (ms)	SD	Range (ms)	*M* (ms)	SD	Range (ms)
Comparison	1618	561	910 - 3269	1103	353	725 - 2486
Calculation	6525	2413	2782 - 13545	2867	774	1531 - 4150
Number line	4054	2027	909 - 8600	2613	1069	1214 - 6101
Shifting	2846	582	1840 - 4065	2175	419	1651 - 3193
Inhibition	2218	669	1412 - 4093	1573	417	1119 - 2790

Table 3. *Number of Correct Responses per Second for Prep and Year 3.*

	Prep (n = 25)	Year 3 (n = 21)				
	M (SD)	*M* (SD)	t	df	p	r
Comparison	0.68 (0.20)	0.96 (0.19)	-4.90	44	<.001	.594
Calculation	0.17 (0.06)	0.38 (0.11)	-7.41	30.94	<.001	.800
Number line	0.33 (0.21)	0.42 (0.13)	-1.76	44	.086	.256
Shifting	0.37 (0.08)	0.47 (0.08)	-4.66	44	<.001	.575
Inhibition	0.49 (0.12)	0.67 (0.14)	-4.86	44	<.001	.591
Working memory^	38.67 (26.23)	73.81 (16.73)	-5.50	41.26	<.001	.650

^ This task was not timed and so results are presented as percent correct.

RQ 2: Relations among Task Performance for each Age Group

The correlations for task performance at the Prep year level and Year 3 level were calculated. For the Prep children, the correlations between the six tasks are presented in Table 4 and for children in Year 3 in Table 5.

For Prep children, the working memory task was the only measure of executive function that was moderately correlated with a number processing task (calculation; r = .49). Those children with higher accuracy in the working memory task were likely to answer correctly more addition and subtraction calculation per second.

The pattern of correlations found in the Prep year data was not present in the Year 3 children's data. In the Year 3 data, inhibition and shifting executive function tasks were moderately (and positively) correlated with both comparison (Inhibition: r = .48; Shifting: r = .53) and calculation (Inhibition: r = .63; Shifting: r = .51) number processing tasks. This is in contrast to the Prep year (Table 4), where there was a negligible (negative) correlation of shifting with comparison (r = -.18), and with calculation (r = -.02) tasks.

Table 4. *Correlations Among Tasks for Prep children*

	Comparison	Calculation	Number line	Shifting	Inhibition	Working memory
Comparison						
Calculation	.03					
Number line	.50*	-.13				
Shifting	-.18	-.02	.16			
Inhibition	.34	-.02	.20	.21		
Working memory	-.22	.49*	-.24	.27	.11	

* $p < 0.05$

Table 5. *Correlations Among Tasks for Year 3 children*

	Comparison	Calculation	Number line	Shifting	Inhibition	Working memory
Comparison						
Calculation	.44*					
Number line	.29	.19				
Shifting	.53*	.51*	.05			
Inhibition	.48*	.63*	.08	.43		
Working memory	-.28	.06	-.17	.14	-.33	

* $p < 0.05$

RQ 3: Observer ratings for engagement in, and understanding of, number processing and executive function tasks

Administrator observations indicated that children were not anxious when completing any of the computerized tasks, and overall, the tasks were well understood and engaging to the children across the age groups participating. Engagement in, and understanding of, the number processing and executive function tasks are in Table 6 and 7, respectively. There were group differences in engagement in all three of the executive functioning tasks (*p*s < .05) and this demonstrated a medium ($r > .3$) effect size (Table 6). The Prep children demonstrated greater variability in observer rating of engagement, compared to the Year 3 children. In understanding of the task, the number line and working memory tasks demonstrated group differences in observer ratings (*p*s < .05; Table 7). For the working memory task in particular, Prep children had a lower median observer rating than Year 3 children, and greater variability, which resulted in a large effect size ($r > .5$).

Table 6. *Observer Ratings of Task Engagement for Prep and Year 3 Children.*

	Prep (n = 25)	Year 3 (n = 21)				
	Mdn (range)	*Mdn* (range)	U	z	p	r
Comparison	3 (2 - 3)	3 (2 - 3)	254.0	-.438	.661	-.064
Calculation	3 (1 - 3)	3 (3 - 3)	220.5	-1.896	.058	-.280
Number line	3 (1 - 3)	3 (3 - 3)	241.5	-1.310	.190	-.193
Shifting	3 (2 - 3)	3 (2 - 3)	180.5	-2.531	.011	-.373
Inhibition	3 (2 - 3)	3 (3 - 3)	210.0	-2.147	.032	-.317
Working memory	3 (1 - 3)	3 (1 - 3)	186.5	-2.189	.029	-.323

Table 7. *Observer Ratings of Task Understanding for Prep and Year 3 Children.*

	Prep (n = 25)	Year 3 (n = 21)				
	Mdn (range)	*Mdn* (range)	U	z	p	r
Comparison	3 (2 - 3)	3 (3 - 3)	252.0	-.917	.359	-.135
Calculation	3 (1 - 3)	3 (3 - 3)	220.5	-1.895	.058	-.279
Number line	3 (1 - 3)	3 (1 - 3)	199.5	-2.376	.018	-.350
Shifting	3 (1 - 3)	3 (3 - 3)	231.0	-1.623	.105	-.239
Inhibition	3 (3 - 3)	3 (3 - 3)	262.5	.000	1.000	.000
Working memory	2 (1 - 3)	3 (1 - 3)	132.0	-3.476	.001	-.513

Discussion

There are ongoing national education policy concerns about numeracy and mathematical competence across the school years (Australian Council for Education Research, 2012). The rationale for the current study was to explore the relations between number processing tasks and components of executive function for Prep children and those in Year 3. It was hoped that establishing how number processing skills differ across the early years of formal schooling, and how those differences vary by executive function skills, might help in the design of pedagogical strategies to target both number processing and executive function within early mathematics interventions. Understanding how executive function is implicated in the development of early mathematical competence opens up opportunities to be more explicit in what and how specific skills are targeted in interventions that may mediate later mathematical skills.

Early number processing is associated with specific brain regions and, in its most elementary form, can be assessed using tasks that involve viewing, comparing, adding, and subtracting quantities. It has been shown that prior to school, children are able to make comparisons of quantities to determine 'which is more/less'. This approximate number system represents the foundation on which education imposes more abstract and symbolic knowledge of mathematical concepts (e.g., numeric symbol systems, digits, fractions). If executive function mediates mathematical learning then it makes sense to support the development of executive function skills (e.g., attention, working memory, mental flexibility) in the context of completing specific mathematical tasks, especially with children who struggle with mathematics, rather than just focus exclusively on the mathematical processes and terminology.

There were two main findings in this research. First, in relation to Research Question 1, there were significant differences in children's performance between Prep year and Year 3 on all tasks except for the number line estimation task. Year 3 children consistently outperformed the Prep children on the comparison, calculation, shifting, inhibition, and working memory tasks. The finding of no significant difference on number line task performance was unexpected, as current number line estimation studies (e.g., White & Szucs, 2012) have reported that, by Year 2 of school, children's understanding of the associations between symbolic number and spatial representations becomes automatic and demonstrates a developmental shift. In this study, a significant difference was expected for number line performance because the participants were in the Prep year and Year 3, spanning the period of this developmental shift. This finding is discussed later in conjunction with observer ratings of task understanding.

The second main finding, related to Research Question 2, was that moderately substantial correlations for the different developmental stages (Prep and Year 3) separated performance on the executive function tasks. In the Prep year, working memory was the only executive function task moderately correlated with a number processing task. In Year 3, shifting and inhibition, but not working memory, were the executive function tasks that had moderate correlations with number processing tasks. This provides initial evidence that the components of executive function (shifting, inhibition, and working memory) have a different pattern of relationship to number processing across the early years of school. Similarly, research into mathematics learning difficulties (Geary et al., 2009) has found number and cognitive processing contribute differently to mathematics learning in early childhood, so any criteria for identifying mathematics learning difficulties needs to take this into account. This information has important implications for classroom practice and for the design of intervention programs. Educators should carefully consider the demands of mathematics tasks and determine if and what cognitive supports are necessary. However, it is important to note that the present findings warrant further investigation and replication because of the relatively small sample size in this study.

Additionally, this research also examined whether observer ratings for engagement and understanding reflected task performance (Research Question 3). Engagement in all of the executive function tasks was lower for the Prep children and this generally aligns with performance on the tasks. This is consistent with existing research (Blair & Razza, 2007) that has identified changes in executive function at the beginning of school. Observer ratings of understanding highlighted that the Prep children had greater difficulty understanding the number line and working memory tasks. These two tasks were the most complex, and the accuracy of responses was low, particularly for the Prep children.

The number line task completed in the present study was complex. It may be that the task required too much cognitive demand for the Prep children, or that the Prep children had less familiarity with larger numbers up to 100, which was required by this task. However, in comparing the rate of correct responses per second on this task, there were no significant differences between the Prep and Year 3 children. An alternative explanation could be that the use of correct rate per second as the final score (Van der Ven et al., 2012), after a multistage screening procedure (Lee et al., 2010), may have filtered out potential group variability. Further studies with a larger sample, a larger number of trials, and different number ranges (e.g., 0-20 and 0-100) may shed more light on this current finding related to number line estimation.

The findings from this study have identified the importance of understanding the relations between number processing and executive function skills in the early years of school. It underscores the need for further research to explore the nature of the mediating role of the skills that constitute the construct of executive function in the development of early number processing skills and early mathematical achievement. Blair and Razza (2007) have emphasized that the relation of executive function to mathematics ability is particularly salient if one considers what children are expected to accomplish in solving the kinds of mathematical and number processing tasks explored in this research. Such competence requires children to reason and problem-solve through representation of number information in working memory, then to shift and focus their attention appropriately on elements of the number problem, as well as to inhibit any responses that focus only on the most salient or recent aspect of the task. For children, mathematical tasks require effortful problem-solving capacities, as represented by executive function capacities. Attention to the skills of executive function as a means through which early mathematical development may be supported is an important direction to inform professional practice.

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