Received: 21 December 2021 | Accepted: 24 December 2022

DOI: 10.1111/bjep.12582

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ARTICLE

The relationship between numerical mapping abilities, maths achievement and socioeconomic status in 4- and 5-year-old children

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Abstract

Background: Early numeracy skills are associated with academic and life-long outcomes. Children from low-income backgrounds typically have poorer maths outcomes, and their learning can already be disadvantaged before they begin formal schooling. Understanding the relationship between the skills that support the acquisition of early maths skills could scaffold maths learning and improve life chances.
Aims: The present study aimed to examine how the ability of children from different SES backgrounds to map between symbolic (Arabic numerals) and non-symbolic (dot arrays) at two difficulty ratios related to their math performance.
Sample: Participants were 398 children in their first year of formal schooling (Mean age = 60 months), and 75% were from low SES backgrounds.
Method: The children completed symbolic to non-symbolic and non-symbolic to symbolic mapping tasks at two difficulty ratios (1:2; 2:3) plus standardized maths tasks.
Results: The results showed that all the children performed better for symbolic to non-symbolic mapping and when the ratio was 1:2. Mapping task performance was significantly related to maths task achievement, but low-SES children showed significantly lower performance on all tasks.
Conclusion: The results suggest that mapping tasks could be a useful way to identify children at risk of low maths attainment.

KEYWORDS
mapping skills, mathematics achievement, non-symbolic skills, socio-economic status, symbolic skills

INTRODUCTION

Early numeracy knowledge is associated with later academic achievement (Barnes & Raghubar, 2017; Watts et al., 2014), positive life outcomes (Grinyer, 2006), and good health (Reyna & Brainerd, 2007). However, many children experience difficulties learning maths (Bugden et al., 2021), which affects their ability to perform daily activities (Gilmore et al., 2014).

Mathematical ability and SES have a lifelong association (Ritchie & Bates, 2013). For example, Rittle-Johnson et al. (2017) found that children from low-income families had weaker maths knowledge before formal schooling began. This included non-symbolic skills where children worked with quantities without using number symbols or words. Similarly, Fischer and Thierry (2021) reported that both non-symbolic and symbolic skills were predicted by family background in preschool children, with high-SES children consistently outperforming low-SES children. However, less is known about how symbolic skills relate to the development of formal symbolic learning (i.e. Arabic numerals; number words) during the first year of school. Understanding how SES and maths ability are related may provide the framework to support children in developing adequate numeracy skills and improve their life chances (Dougherty, 2003; National Numeracy, 2018).

Many factors influence maths attainment and a better understanding of these from the earliest stages of formal education could help identify which children are likely to struggle. Therefore, the current study could provide a valuable contribution to the field by examining the symbiosis between mathematical ability and socioeconomic status.

Socioeconomic status (SES) and maths attainment

Parental SES is a predictor of children's educational attainment. To explore why SES affects maths attainment, researchers have assessed the home numeracy environment (LeFevre et al., 2009; Zippert & Rittle-Johnson, 2020). DeFlorio and Beliakoff (2015) found that the quantity and quality of home preschool maths predicted kindergarten maths abilities with high SES parents having access to greater resources (see also Susperreguy et al., 2020; Von Stumm et al., 2020). Furthermore, high-quality home maths activities promote early maths skills, with the quality of maths activities related to SES (Berkowitz et al., 2015; Davis-Keen, 2005). However, it can be challenging to separate the influences of the home environment from the effects of the preschool curriculum on early numeracy skills. Collecting information regarding children's background will help us understand how family background relates to early attainment.

The SES difference in attainment begins early, with low SES associated with differences in maths abilities in preschool (Spaull & Kotze, 2015; Starkey et al., 2004). The SES difference is one example of an academic attainment gap and explains attainment differences more than factors due to race or gender in the United Kingdom (see Sosu & Ellis, 2014). Children from low SES backgrounds may also experience fewer high-quality educational opportunities. contributing to lower attainment levels than their higher SES peers (Lyu et al., 2019). Overall, the number of children with lower maths ability and subsequent improvement is disproportionate in the low SES group (Jordan et al., 2009); therefore, investigating school-entry differences and providing appropriate support may improve attainment. However, the mechanism driving the SES differences in early maths attainment remains unclear. We suggest numerical mapping ability as one factor which may identify early differences between children from different SES backgrounds.

Although between-group academic differences are well documented in the SES literature, differences also emerge within groups. Importantly, not all low-SES children are low academic achievers; similarly, not all high-SES children are high achievers (Huang & Zhu, 2017). In addition to SES differences, the child's rearing environment is involved in development.

Environmental influences

Evidence suggests that environmental influences may explain the SES differences in children's achievement. The parental environment may impact numeracy development, although little research has explored this directly. For example, Bick and Nelson (2017) outlined the harmful effects of adverse childhood experiences (ACE) on child brain development that may impact later academic achievement (see Blodgett & Lanigan, 2018, for an analysis of ACE exposure and academic achievement). Heritability and environmental factors may also influence the development of numeracy skills. With twin studies, Grasby et al. (2016) concluded that there is a strong heritability component to numeracy attainment: girls and boys respond differently to the same environment, with girls more influenced by the environment. However, this is with older children. Our study adds to the discussion on early numeracy attainment by examining the longitudinal progress of younger children from different background types. Although not directly examining the parenting environment, extensive research suggests that lower SES children are more likely to experience ACEs (Walsh et al., 2019).

However, family background is not the only factor that contributes to early attainment. Another factor influencing maths ability is an intuitive sense of number, known as the Approximate Number System (ANS; Feigenson et al., 2004).

Development of non-symbolic and symbolic representations of number

Non-symbolic representations of numbers and maths skills

The Approximate Number System (ANS) is considered a rudimentary innate cognitive system that supports the mental representation, comparison and manipulation of non-symbolic numerical magnitudes (De Smedt et al., 2013; Feigenson et al., 2013; Odic & Starr, 2018). It provides approximate, noisy estimations of quantity (although see Clarke & Beck, 2021, for an alternative view).

Non-symbolic comparison tests assess ANS abilities (Halberda et al., 2008; Libertus et al., 2011). Participants compare two dot arrays and select the array that contains more dots. This exercise does not require language skills or knowledge of symbolic number names. Indeed, these numerical abilities appear to emerge just hours after birth (Izard et al., 2009; Leibovich-Raveh & Gregg, 2020). Furthermore, successful task completion is possible by non-numerate adults (Pica et al., 2004) and many animal species (Agrillo et al., 2010; Beran et al., 2012; Flombaum et al., 2005), providing additional support for the innate argument.

Children's performance on comparison tasks, measured by accuracy and response time, varies depending on the ratio of the dot arrays. Accuracy is greater, and participants' response time is quicker for arrays with larger ratios such as 1:2 (e.g. 6 vs. 12) than smaller ratios like 2:3 (e.g. 6 vs. 9; Chen & Li, 2014). ANS acuity also varies between individuals. Although the perceptual features of dot arrays (density; area; volume) partly explain individual differences (Dehaene, 2011; Stoianov & Zorzi, 2012), there may also be a connection to early non-symbolic skills that predict later maths achievement (Barnes & Raghubar, 2017; Ritchie & Bates, 2013). For example Libertus et al. (2011) and Halberda et al. (2008) reported that children's preschool non-symbolic task accuracy and ANS acuity were associated with maths achievement (though see Bugden et al., 2021).

Symbolic numbers and maths skills

Symbolic numbers are sophisticated symbol systems (e.g. Arabic numerals; Suzhou numeral system) that enable manipulations of large quantities. Although most human cultures use symbolic number representations, number symbols do not exist universally (see Everett, 2013, for a description of anumeric cultures). This suggests that symbolic representations are acquired, related to language development

(Pica et al., 2004; Xenidou-Dervou et al., 2018). Representing exact quantities (Izard & Dehaene, 2008; Mussolin et al., 2014), with practice, symbolic systems can accurately process increasingly large amounts (Halberda et al., 2008).

Although children learn to recite the counting sequence and associate number words with numerals from 3 years old, understanding that quantities correspond to specific numerals develops over time (Aunio et al., 2006; Hannula & Lehtinen, 2005). Evidence suggests that symbolic skills also predict later maths achievement. For example, Vasilyeva et al. (2018) found that preschool symbolic number experience improves later mathematical skills, and De Smedt et al. (2009) found that Grade 1 symbolic task performance, predicted maths performance in Grade 2. However, as both non-symbolic and symbolic number skills have been related to maths performance, uncertainty remains on the direction of the relationship (Lyons et al., 2018).

Non-symbolic skills, symbolic skills and SES

SES differences in maths performance are commonly, but not universally, found. For example, Vanbinst et al. (2018) found that children's symbolic numerical magnitude processing skills did not vary by SES during the first 3 years of primary school. Although children's abilities improved with age, the weakest performers at the first testing had the poorest performance at later time points. Vanbist et al.'s work demonstrates persistent individual differences in symbolic task abilities, regardless of SES status. However, SES differences explained more of the performance difference on non-symbolic tasks, with high-SES children demonstrating greater accuracy than low-SES children. Furthermore, no relationship between symbolic and non-symbolic performance emerged, challenging the notion that non-symbolic skills scaffold later symbolic skill development. However, others reported SES differences in early symbolic performance. Fischer and Thierry (2021) suggest that SES differences in symbolic knowledge at preschool are due to environmental differences, since disadvantaged children receive less exposure to symbolic number than higher SES children.

Some suggest non-symbolic maths skills develop through innate ability, regardless of SES and preschool non-symbolic differences are less apparent. For example, Jordan et al. (2009), and later, Gilmore et al. (2010), used non-verbal arithmetic tasks with children and found no SES differences in ability. Fischer and Bocerean (2004) also conducted non-verbal calculation tasks. However, they found that higher SES children had the best performance.

More recently, Fischer and Thierry (2021) conducted a study with preschoolers and found that family income and maternal education were correlated with performance on symbolic tasks. However, unlike earlier studies, these factors were also related to non-symbolic performance.

How non-symbolic and symbolic representations of number relate to maths development: learning and outcome

From the literature, both symbolic and non-symbolic processing appear linked to maths development. One argument proposes that non-symbolic numerical magnitude representations underpin the symbolic numerical magnitude system (Piazza, 2010), suggesting that non-symbolic magnitude skills are precursors to later symbolic magnitude skills, scaffolding arithmetic development (Halberda et al., 2008; Libertus et al., 2011). This position alludes to non-symbolic rather than symbolic skill as the more robust predictor of later mathematics achievement (Barnes & Raghubar, 2017). Others have explored whether ANS training can improve arithmetic skills (Au et al., 2018). Rittle-Johnson et al., (2017) early maths trajectories model suggests that preschool non-symbolic skills predict first-grade symbolic skills and together predict later maths achievement.

However, others suggest that symbolic and non-symbolic skills contribute equally to the development of maths skills (Nosworthy et al., 2013). Longitudinal early years research (Toll et al., 2015), showed an inter-relationship between non-symbolic and symbolic numerical skills and maths achievement. However, early symbolic skills were the greater predictor of later maths achievement. Similarly, van ‘t Noordende et al. (2021) reported that symbolic and non-symbolic skills at age 3½ years were related to children's early maths skills at age 5.

Despite both contributing to maths skills, debate over the relationship between the two systems persists. Mastery of symbolic numerical magnitude skills may affect the development of non-symbolic numerical magnitude skills more than proficiency in non-symbolic numerical magnitude skills affects symbolic skills (Goffin & Ansari, 2019). Tikhomirova et al. (2017) reported that Russian children's preschool symbolic skills predicted Grade 1 non-symbolic skills; Grade 2 non-symbolic skills related to Grade 4 symbolic skills. These results suggest that children can mentally manipulate the two different representations of number. However, the effect of non-symbolic accuracy on symbolic skills may only emerge after mastery of basic arithmetic skills. Thus, the exact relationship between the symbolic and non-symbolic systems remains unclear. Rather than symbolic processing replacing innate non-symbolic numerical skills, the two seem intertwined. Most early numeracy research focuses on higher SES families. Indeed, given the purported innate nature of non-symbolic number skills, Sepúlveda et al. (2020) expected to find no SES differences in children's non-symbolic skills. Higher SES children's abilities overall were better than lower SES, and symbolic skills were greater than non-symbolic skills. Increased exposure to symbolic numerical stimuli in the high SES home environment may have facilitated this difference (Fischer & Thierry, 2021).

Symbolic number understanding may be developed by mapping symbols onto innate and universal ANS (Brankaer et al., 2014; Gilmore et al., 2007). However, some evidence fails to find links between symbolic number representations and non-symbolic quantities (Matejko & Ansari, 2016). Others suggest that symbolic numerical abilities improve non-symbolic numerical representation skills (Mussolin et al., 2014) with the ability to move between the two representations of number influencing developing maths skills.

Numerical mapping

Numerical mapping occurs when children mentally translate between symbolic and non-symbolic representations of number (Brankaer et al., 2014; Mundy & Gilmore, 2009). Efficient estimation of the number of items in a set arguably indicates the quality of the numerical mapping between the numerosity of a dot array group with its symbolic Arabic numeral equivalent (Yeo & Price, 2021).

Early mapping studies examined children's ability to map in one direction. Preschool children could map symbolic number words onto non-symbolic representations of number after mastering the counting sequence (Lipton & Spelke, 2005). The first study to examine mapping in both directions found 6- and 8-year-olds could map from symbolic to non-symbolic, and from non-symbolic to symbolic representations of number, although non-symbolic to symbolic accuracy was greater (Mundy & Gilmore, 2009). Mundy and Gilmore also reported that mapping abilities were associated with individual differences in maths achievement. However, Brankaer et al. (2014) found that first- and second-grade children could map equally well between symbolic and non-symbolic representations in both directions. Children's accuracy improved with age and was related to maths ability. They suggest that the bidirectional transformation of non-symbolic quantities into symbolic numerals creates links that support understanding the relationship between the two.

Mapping ability is a valuable predictor of later maths skills because it appears to indicate children's later competency in manipulating specific numerical information. However, it is unclear whether mapping occurs through schooling or is age-related. For example, Hutchison et al. (2020) reported a bidirectional relationship between symbolic and non-symbolic number acquisition in Canadian kindergarteners, but this was only observed for numbers of 5 and lower. Thus, Hutchinson et al.'s findings may reflect subtilizing which is the ability to perceive a small number of items in a group, without counting (Kaufman et al., 1949, p. 520). Outwith the subitizing range, a unidirectional relationship from symbolic to non-symbolic number representation emerged, suggesting children demonstrate mapping ability but only for small numbers. Kindergarteners' early symbolic and non-symbolic skills also showed a bidirectional relationship (Toll et al., 2015), with symbolic comparison skills being the greater predictor of numerical mapping abilities and maths achievement. Mundy and Gilmore (2009) found that mapping skills improved with age, but their study was not longitudinal. In addition to mapping between symbolic and non-symbolic representations of number, the distance between the to-be-compared numerosities affects performance. Participants are slower and less accurate when the distance between numbers is small (e.g. ratio 4:3 so 8 vs. 6) than when it is larger (e.g. ratio 4:1 so 8 vs. 2). This is termed the numerical distance effect (Dehaene et al., 1990; Moyer & Landauer, 1967).

Although numerical mapping performance seems to predict later maths achievement (Brankaer et al., 2014; Kolkman et al., 2013; Li et al., 2018), there are some inconsistencies. For example, Lyons et al. (2014) found no link between children's symbolic and non-symbolic number comparison skills and maths abilities. Nevertheless, numerical mapping may play an important role as children master the relationship between non-symbolic quantities and their symbolic counterparts.

Evidence for the directional relationship between the systems is inconclusive (Goffin & Ansari, 2019), but research supports a positive relationship between non-symbolic and symbolic abilities, alongside mapping skills, linked to attainment (Toll et al., 2015; van 't Noordende et al., 2021; Vasilyeva et al., 2018). However, the mapping abilities of 4½ to 5-year-old children in formal schooling remain unknown. Previous research has explored mapping abilities in informal preschool contexts rather than the formal education environment of the current study. For example, Hurst et al. (2017) found preschool children could map in both directions between symbolic and non-symbolic representations of number, with greater accuracy on the symbolic to non-symbolic version of their task. However, since they used numerosities 1–5, the children were likely to be counting dot arrays rather than mentally translating between the two representations of number. Mapping research with younger participants in formal education settings and using numbers outwith the subitizing range is lacking. Therefore, the current study can add to the literature by examining how the abilities of 4- to 5-year-old children in formal schooling relate to their maths attainment.

Moreover, whilst many studies consider single cohorts, the current study utilizes a cohort sequential design to ensure that the results found are not an artefact of a single cohort. Both cohorts were recruited from the same schools and comprise both lower and higher SES populations.

Present study

The present study examined how high- and low-SES children's ability to map between symbolic (Arabic numerals) and non-symbolic (dot arrays) at two difficulty ratios (1:2 and 2:3) related to their math performance.

In Scotland, formal education begins the year of a child's fifth birthday. Other research that has considered the abilities of children of this age recruited children from preschool environments rather than formal education where they receive symbolic numeric instruction (Mazzocco et al., 2011; Toll et al., 2015). Thus, the Scottish context allows for a novel examination of similar-aged children in a school environment.

Following previous findings, we predict that children will be more accurate on symbolic to non-symbolic mapping tasks than non-symbolic to symbolic tasks (Hypothesis 1) and more accurate on 1:2 than 2:3 ratio stimuli tasks (Hypothesis 2). Furthermore, as SES differences have previously affected performance, we predict that high-SES children will have greater accuracy on all tasks than low-SES children (Hypothesis 3). Finally, we predict a correlation between mapping task accuracy and maths task scores (Hypothesis 4).

METHOD

Ethics

The University Ethics Committee, council education Department and school headteachers, approved the study. The first author attended parents' events to recruit families and obtain parental consent. The children provided written and oral consent.

Participants

Participants were Scottish children who began formal schooling, during the year of their fifth birthday. Data were collected from two cohorts of children. Low- and high-SES children were included in both cohorts which were recruited from four schools the year they commenced formal education. A cohort sequential design was used to recruit entire year groups from schools that responded to an invitation to participate in the project ($N = 4$). This design allowed an analysis to check that the findings were not specific to a single cohort. Cohort 1 ($n = 202$) started school in 2018 and cohort 2 ($n = 196$) in 2019. Participants were aged 53–70 months ($M = 60$ months, $SD = 4$). SES was determined by the Scottish Index of Multiple Deprivations (Scottish Government, 2020). Most early years of maths research focuses on high-SES populations. To address this gap in the literature, the current study focused on low-SES children; consequently, 72.5% of the participants came from homes within low-SES areas, with 27.5% high-SES participants included as a control group. Recognizing the differences in the sizes of the groups, and to increase our confidence in the results, two consecutive cohorts were recruited from the same four schools, located in the same city. Consistent results between the two groups will support the findings.

Exclusion criteria

Data from nine participants who failed to attempt at least 50% of mapping trials were removed. Table 1 shows the descriptive statistics for 389 children included in the analyses.

Materials and procedures

Participants were individually tested over two sessions, each lasting 30 min, in a quiet area of the school, approximately 12 weeks apart.

Session 1: Numerical mapping task

Participants completed two numerical mapping tasks: symbolic to non-symbolic (SNS) and non-symbolic to symbolic (NSS). The presentation order was counterbalanced to avoid order effects.

The materials were adapted from Mundy and Gilmore (2009). Target numbers varied from 5 to 20, and the answer options included the correct answer and a distractor answer. Both versions of the task used the same numbers. The ratio between target and correct answers varied. The difficulty was manipulated by varying the ratio of the stimuli presented. For half of the trials, the ratio was 1:2; for the remainder, the ratio was 2:3 (see Table 2). The correct answer was the larger or smaller of the answer options an equal number of times, and the larger number option was presented on the left or right of the screen an equal number of times. As the distractor and answer options appeared at the same time, the presentation (e.g. 1:2 or 2:1; 2:3 or 3:2) was assessing the same skill, matching the target to one of two answer options, with the numerical distance between the two consistent. The dot array stimuli were organized following Pica et al. (2004) to ensure dot size and magnitude did not influence participants' answers. Screen luminosity was also calibrated.

TABLE 1 Study participants

	Gender		
SES group	**Male**	**Female**	**Total**
High SES	56	51	107
Low SES	139	143	282

TABLE 2 Numerosities for SNS and NSS numerical mapping trials

	Stimuli type	
Ratio	Target	Distractor
1:2	5	10
	7	14
	10	5
	10	20
	14	7
	20	10
2:3	6	9
	9	6
	9	12
	12	18
	12	9
	18	12

Stimuli were presented on laptop computer using PsychoPy2 (Peirce et al., 2019). For each version, the children completed four practice trials followed by 24 randomly presented experimental trials. On all trials, a target quantity was displayed in the centre of the laptop screen for 1.5 s. This was followed by two choices, placed to the left and right of the screen, for 1.5 s. Finally, a screen with a question mark in the centre was displayed. Participants selected which option they thought matched the target quantity. Participants indicated their choice by pressing the M key (to select the right side) or the C key (to select the left side). After a response or a maximum of 10 s, the programme moved onto the subsequent trial. During the practice trials, the children were reminded of the rules and informed if each response was correct.

SNS mapping

On SNS trials, the target quantity was an Arabic symbol, and the numeral it represented was spoken by the experimenter. The two choices were dot arrays, and children selected which choice they thought represented the Arabic numeral.

NSS mapping

In NSS trials, the target quantity was a dot array. The two choices were Arabic numerals also spoken by the experimenter. After the question mark, children chose which numeral represented the dot array.

Session 2: Maths numeracy and problem-solving

Participants individually completed the Wechsler Individual Achievement Test-3rd UK Edition (WIAT-iii UK) numeracy and problem-solving subscales (Wechsler, 2017), administered following published guidelines. Both the numeracy (.81) and problem-solving (.84) subscales have very good test re-test reliability.

Preliminary analyses revealed no significant differences in performance by cohort. All analyses were performed using R version 3.6.3 (2020-02-29). Data and analyses are available at https://osf.io/3t894/.

RESULTS

Numerical mapping tasks: Hypothesis 1, 2 & 3

Data from 384 participants were included in the analysis. Accuracy scores for SNS and NSS numerical mapping at two difficulty ratios (1:2; 2:3) on numerosities 5–20, demonstrated novel findings. Participants from age 4 years, could map in both directions with larger numerosities than previously reported. Accuracy was highest on SNS 1:2 ratio trials and lowest on 2:3 ratio NSS trials, on numerosities outwith the subitizing range. High SES participants scored higher than low SES participants on all mapping tasks. We report another novel finding that performance on the two types of mapping tasks was positively correlated (Figure 1).

A 2(Mapping Task Type: SNS vs. NSS) × 2(Ratio: 1:2 vs. 2:3) × 2(SES: low SES vs. High SES) mixed design ANOVA conducted on mapping task accuracy scores yielded a significant main effect of Mapping Task Type, $F(3, 382) = 17.27$, $MSE = .58$ $p < .001$, $d = .3$ with children performing better on SNS than NSS mapping. There was also a main effect of ratio, $F(1, 382) = 9.6$, $MSE = .58$, $p < .001$, $d = .3$, with better performance in the 1:2 ratio trials, and a main effect of SES, $F(1, 382) = 23.97$, $MSE = .63$, $p < .001$, $d = .3$ with better performance in the high-SES children. There were no significant interactions (ratio: mapping task, $F[1, 382] = 1.74$, $p = .19$, ratio: SES, $F[1, 382] = .14$, $p = .71$, ratio: mapping task: SES, $F[1, 382] = .24$, $p = .62$).

As shown in Figure 2, there appeared to be a positive relationship between SNS and NSS accuracy for high SES participants, SNS accuracy ($M = 55.12$, $SD = 12.47$) and NSS accuracy ($M = 52.54$, $SD = 11.64$). A Pearson correlation found a significant, small positive correlation between the two variables, $r(105) = .19$, $p = .049$. A positive relationship between SNS and NSS accuracy was also shown for low SES participants, SNS accuracy ($M = 50.86$, $SD = 17.96$) and NSS accuracy ($M = 46.08$, $SD = 13.9$). A Pearson correlation found a significant, medium positive correlation between the two variables, $r(285) = .31$, $p < .001$.

Problem-solving and numeracy WIAT-iii [UK]

Figure 3 shows the performance in problem-solving and numeracy by the SES group. Independent t-tests revealed that high-SES children performed better than their low-SES peers in problem-solving, $t(205) = -15.47$, $p < .001$, $d = .7$; M = 99.7 vs. 89.7 and numeracy, $t(205) = -13.15$, $p < .001$, $d = .8$; M = 101.12 vs. 89.81.

Figure 4 shows the relationship between the numeracy and problem-solving subscales of the WIAT-iii [UK]. A Pearson correlation revealed a significant positive correlation between the numeracy scores and the problem-solving task scores, $r(388) = .69$, $p < .001$, and this was the case for both high, $r(105) = .7$, $p < .001$ and low SES, $r(274) = .62$, $p < .001$ participants.

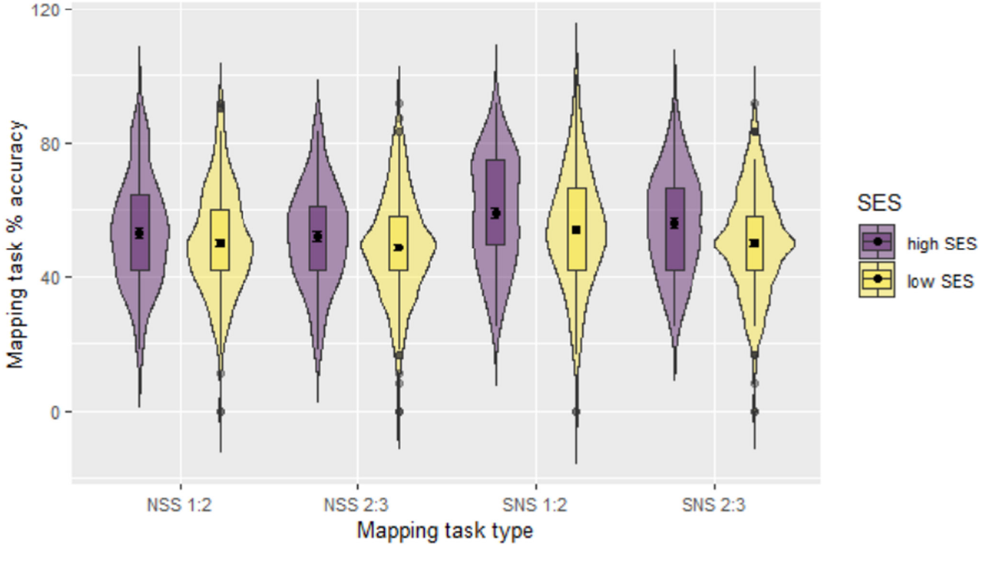

FIGURE 1 A violin plot for the mapping task accuracy scores by mapping direction, ratio and SES group.

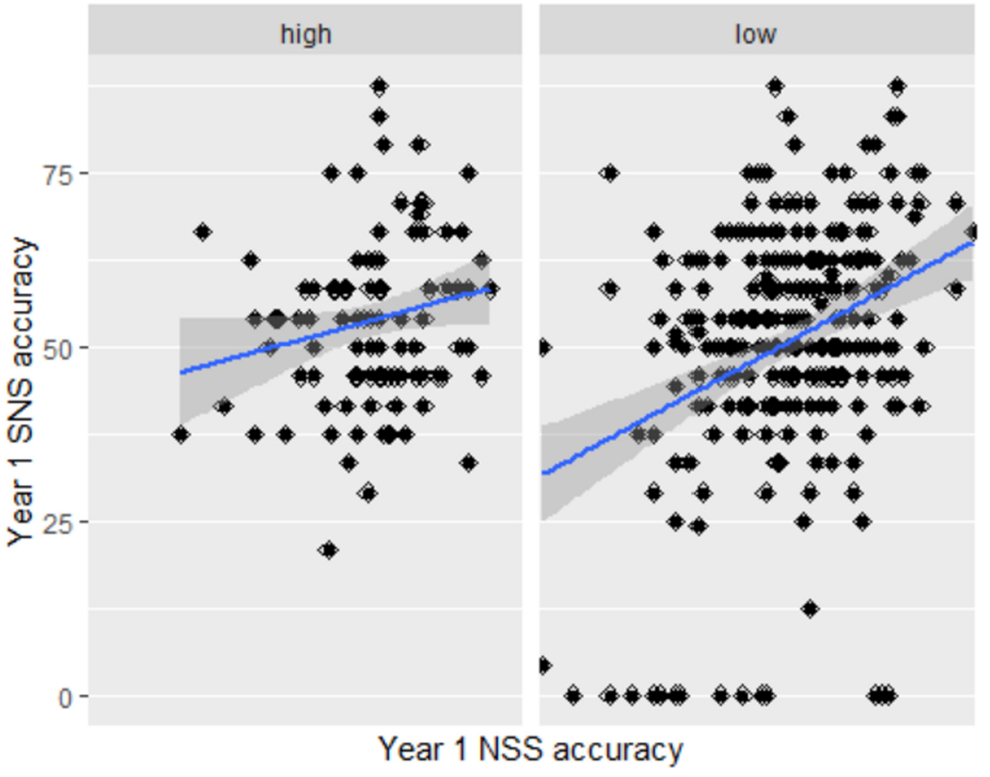

FIGURE 2 Scatterplot showing correlation between accuracy on SNS and NSS mapping tasks for high and low SES participants

Relationship between mapping task accuracy and maths ability (hypothesis 4)

Correlational analyses revealed significant positive correlations between performance on all numerical mapping tasks and problem-solving and numeracy tasks (WIAT- iii UK; see Table 3). These relationships were most robust between SNS mapping tasks for numeracy and problem-solving.

DISCUSSION

Key finding

School children from 4 years old, could map in both directions between symbolic and non-symbolic representations of number, on numerosities up to 20. Performances on the two versions of the task were positively correlated, suggesting a bidirectional relationship between symbolic and non-symbolic skills.

Numerical mapping tasks

Our results show that children could map in both directions from age 4 years, younger than suggested previously (Brankaer et al., 2014; Li et al., 2018; Mundy & Gilmore, 2009). Task accuracy was greater on SNS than NSS mapping. Previous findings reported greater accuracy on NSS mapping tasks (Brankaer et al., 2014) or no effect of mapping direction on performance (Mundy & Gilmore, 2009). However, our results with a larger sample and younger participants in formal education showed different results. Participants' accuracy was significantly higher on easier 1:2 ratio for both mapping tasks; with the highest

FIGURE 3 Numeracy & problem-solving scores for high & low SES participants, showing median, range and distribution of scores

FIGURE 4 Scatterplot between scores on problem-solving and numeracy scores for high and low SES participants

TABLE 3 Correlations between numerical mapping tasks and WIAT tasks

WIAT task type	Mapping task	*df*	*r*	*p*
Numeracy	SNS 1:2	379	.28	<.001
	SNS 2:3	379	.24	<.001
	NSS 1:2	380	.13	.001
	NSS 2:3	380	.16	.009
Problem-solving	SNS 1:2	379	.29	<.001
	SNS 2:3	379	.24	<.001
	NSS 1:2	380	.16	.002
	NSS 2:3	380	.11	.02

accuracy on SNS mapping at 1:2 ratio, and lowest accuracy on NSS mapping at 2:3 ratio. The results demonstrated that children had symbolic number knowledge earlier than previously seen and before mastery of non-symbolic quantities beyond the subitizing range emerged.

Additionally, NSS skills and SNS skills were positively correlated, suggesting that performance could be related from an early stage in education. However, since this was only measured once, it is uncertain whether this relationship is bidirectional. However, the current study shows that low-SES children had lower mapping accuracy than high-SES children. Although the numerical mapping literature including SES differences is sparse, and some (Gilmore et al., 2010; Jordan et al., 2009) found no SES differences in mapping performance, Rittle-Johnson et al. (2017) also reported that disadvantaged children had less accurate mapping performance. These results suggest performance on mapping tasks at an early age could identify potential future mathematical difficulties.

Numeracy and problem-solving tasks

The numeracy and problem-solving scores showed a strong positive correlation. However, high-SES children scored in the expected range, while low-SES children had significantly lower performances. This difference was not unexpected; Lower maths achievement was previously associated with economically disadvantaged children (see Davis-Keen, 2005; DeFlorio & Beliakoff, 2015; Ersan & Rodriguez, 2020; Scottish Government, 2019). This study had a Scottish perspective where the children began schooling aged 4½–5 years and demonstrate the academic attainment gap in younger children than reported elsewhere. Our results support previous findings that the education of lower SES children may already be disadvantaged by the time they begin formal schooling. However, we must interpret the results with caution. Although the children were from two consecutive year groups, these results do not necessarily generalize to the Scottish school population. As whole-year groups were recruited from schools in higher or lower SES areas, participants could not be randomly assigned to experimental groups. Nevertheless, we did find significant differences between maths achievement for higher and lower SES groups.

Relationship between numerical mapping and WIAT-iii UK tasks

The performance of participants varied by SES, but positive correlations existed between mapping and maths performance for both SES groups. Although weak (.2 to .3), the strongest correlations were between SNS mapping tasks and numeracy and problem-solving scores, supporting other findings (Kolkman et al., 2013; Li et al., 2018). We did not find support for non-symbolic skills scaffolding the development of later symbolic skills (Halberda et al., 2008; Libertus et al., 2011). Instead, the results demonstrate that symbolic number knowledge is becoming established in children from age four, related to their numerical mapping abilities, and may predict arithmetic skills (Honoré & Noël, 2016; Inglis et al., 2017; Lyons et al., 2014).

SES and maths attainment

This study showed that children from low SES families perform at a lower level on tasks that tap into early mathematical knowledge, as well as standardized maths tests. This finding supports the literature that family background affects educational outcomes. A sizeable poverty-related attainment gap persists between children from poor and affluent homes (Lyu et al., 2019), resulting in fewer low-SES children reaching the expected levels in maths. However, the effect of family SES on academic attainment varies by culture and has less effect in countries such as China than in Western societies like Germany (Lyu et al., 2019). In the current study, not all low-SES children had low attainment, possibly due to increased opportunities provided by some parents regardless of their low-SES status. This finding suggests that SES differences may be due to attitudes and expectations of caregivers towards education, supporting the expectancy-value theory (Eccles, 1983). From a theoretical perspective, this knowledge informs developmental theory, highlighting that individual differences and specific factors in children's environments relate to early maths development.

Due to the younger school starting age, the influence of the home environment on preschool academic skills might be less, but this was not the case. Differences appear early; consequently, some children begin school already at a disadvantage. However, awareness of early differences may guide early maths interventions and facilitate appropriate support for all children (Plucker & Peters, 2018).

Identifying children early is important because early mathematics abilities predict later academic attainment (Jordan et al., 2009; Rittle-Johnson et al., 2017; Watts et al., 2014). The current study reported significant differences in performance between children of different SES groups already exist when children start school. As much of the research emphasizes the importance of non-symbolic skills and highlights their absence in many preschool settings, more activities supporting non-symbolic development should be encouraged., with a focus on early years maths teaching, particularly in areas of high deprivation.

Challenges, limitations and future directions

This study had several limitations. First, although similar to some published work, the relatively small sample size, single study, and population mean the results should be interpreted with caution as they may not generalize to future studies, current, or different populations. Second, while this study collected data from schools that cross-socioeconomic areas and schools were classified as high or low SES, this may not represent individual families; there are variations between families attending each school. Furthermore, cultural differences and parental expectations can influence children's attainment; therefore, SES may be too crude a measure of the quality of home (Huntsinger et al., 2016). Future studies should include a more direct measure of family SES, cultural background, and parental education.

CONCLUSION

Children from lower SES backgrounds typically have lower academic achievement than their higher SES peers. Our results present novel findings and show that this academic achievement gap is already present when children begin formal schooling in Scotland. Furthermore, children could map between non-symbolic and symbolic representations of number in both directions, at two difficulty ratios, and with larger numerosities than previously reported; this ability was related to maths achievement. The results suggest that mapping tasks could be useful in identifying children at risk of low maths attainment. Similar preschool assessments may highlight children who are more likely to find maths challenging. Therefore, future research should consider whether earlier mapping ability predicts later maths performance.

AUTHOR CONTRIBUTIONS

Dawn S. Short: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualization; writing – original draft; writing – review and editing. **Janet F. McLean:** Resources; supervision; writing – review and editing.

ACKNOWLEDGEMENTS

The authors are grateful to the schools for allowing us access to their educational spaces and to the children for their enthusiastic participation.

CONFLICTS OF INTEREST

None.

OPEN RESEARCH BADGES

This article has earned an Open Data badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. The data is available at https://osf.io/3t894/.

DATA AVAILABILITY STATEMENT

The data and analyses are available at https://osf.io/3t894/.

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How to cite this article: Short, D. S., & McLean, J. F. (2023). The relationship between numerical mapping abilities, maths achievement and socioeconomic status in 4- and 5-year-old children. *British Journal of Educational Psychology*, *00*, 1–17. https://doi.org/10.1111/bjep.12582