Received: 2 November 2021 | Revised: 22 April 2022 | Accepted: 6 June 2022
DOI: 10.1002/icd.2356

REPORT

WILEY

The impact of theory of mind and executive function on math and reading abilities: A longitudinal study

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Funding information
Deutsche Forschungsgemeinschaft, Grant/Award Number: SO213/27-1,2

Handling Editor: Emily K. Farran

Abstract

Both theory of mind (ToM) and executive functioning have been related to children's academic abilities. In a longitudinal study with 112 children, we investigated the influence of these two abilities on children's math and reading performance at 7 years of age. We found that math performance was predicted by concurrent working memory as well as by preschool numerical abilities and ToM. Reading performance was predicted by concurrent working memory and verbal IQ at 6 years. This corroborates earlier research demonstrating the importance of executive functioning (working memory) and ToM for later academic abilities. We argue that ToM may be an important developmental precursor of math performance because both require an understanding of representations.

KEYWORDS
longitudinal, math abilities, reading abilities, school achievement, theory of mind, working memory

1 | INTRODUCTION

Two important domains in children's cognitive development are theory of mind (ToM) and executive functions. Executive functions refer to cognitive self-regulatory processes, which enable the conscious control of actions, thoughts, and emotions. In the literature on adults, there is consensus that there are three core executive functions: inhibitory control, working memory, and set-shifting (Miyake et al., 2000). Executive functions are primarily associated with prefrontal regions; they emerge in the first year of life, grow rapidly during the preschool years, but do not reach full maturity until early adulthood (see, e.g., Diamond, 1990; Garon et al., 2008). The second domain, ToM, denotes our ability to ascribe mental states ('mentalize') to oneself and other people (Premack & Woodruff, 1978) and, like executive functioning, undergoes a substantial developmental shift in the preschool years (see, e.g., Sodian et al., 2020, for a recent review).

Furthermore, preschool children's ToM and executive functioning are important developmental achievements supporting later academic growth. A large body of research shows that early executive functioning, in particular working memory, is related to children's academic performance (e.g., Becker et al., 2014; Best et al., 2011; Cortés Pascual et al., 2019; Finders et al., 2021). For example, attention span persistence in preschool, as rated by parents, predicts math and reading achievement at 21 years of age (McClelland et al., 2013). Also, Röthlisberger et al. (2013) showed that executive functioning in preschool predicts mathematical, reading, and spelling performance 2 years later. When focusing on mathematics performance, executive functions have been found to be of particular importance. For example, Mazzocco and Kover (2007) showed that executive function performance at 6–7 years of age is related to concurrent and later mathematics ability. And Clark et al. (2010) found that executive functioning at 4 years predicts mathematical achievement at 6 years even after controlling for general cognitive ability and reading achievement.

Research on the impact of ToM on children's later academic achievement, in contrast, is less extensive. In a recent paper, Lecce and Devine (2021) review evidence suggesting that ToM understanding influences children's academic success, in particular, reading comprehension and scientific reasoning. They suggest that ToM may enhance academic outcomes by enhancing social competence, metacognition, or linguistic abilities (e.g., mental state language). However, there are still only a few empirical studies specifically investigating relations between ToM understanding and school achievement.

In an Italian sample comprising 60 children, individual differences in preschool ToM at 5 years have been found to predict children's academic achievement in mathematics, reading, and text comprehension at 7 years (Lecce et al., 2011) and 10 years (Lecce et al., 2014). In addition, this effect was partially mediated by children's sensitivity to criticism at 6 years of age.

Further evidence for a link between ToM and school achievement comes from Lockl et al. (2017). They found that ToM (false belief [FB] and knowledge access understanding) at the age of 4 years was related to arithmetic skills and numeracy as well as to teacher ratings of literacy, mathematics, attention, and socio-emotional aspects in Grade 1 (6 years), but only to numeracy in Grade 2 (7 years). Numeracy included skills like counting, identifying numbers, comparing quantities, understanding numbers as symbols, and verbally presenting arithmetic problems. That is, in this study, ToM was not related to reading abilities as measured with the 'ELFE 1–6' (Lenhard & Schneider, 2006) in the first 2 years of elementary school; this may be due to the fact that 'theory-of-mind abilities may be more relevant later on when children begin to read for meaning and when it becomes important to comprehend the action of stories and the mental states of the protagonists' (Lockl et al., 2017, p. 99). However, ToM was related to numeracy, possibly 'because the tasks in both areas require operating with different mental representations' (Lockl et al., 2017, p. 99f).

This argument has been elaborated by Perner et al. (2021). They claim that mentalizing is necessary when we encounter different perspectives and have to understand that the same thing can be described differently under different perspectives. This is required in FB tasks but also in many mathematical concepts and operations. For example, when counting a number of objects, children need to understand that the last word uttered refers to the last item in the set and also denotes the number of objects in the set (cardinality principle). Understanding that a single number can refer to two entities (the last item counted and the size of the set) requires an understanding of homonyms; and homonym tasks are related to FB tasks (Doherty, 2000). Furthermore, Sarnecka and Wright (2013) showed that at around 4 years of age (when children begin to understand FBs) children master the counting principles of cardinality and equinumerosity (one-to-one correspondence). Therefore, children's understanding of mental representations may underlie both their growing ToM and the acquisition of mathematical concepts.

Interestingly, Arora et al. (2020) showed that the meta-cognitive function of identity processing activates the same brain areas (left inferior parietal lobe, precuneus, and posterior cingulate) in linguistic identity tasks as well as in numerical identity tasks (equations). Given the fact that identity understanding codevelops with FB understanding (Perner et al., 2011) and that the left inferior parietal lobe is also consistently activated in FB tasks and visual perspective-taking tasks (Schurz et al., 2013), these data suggest that understanding that the same thing can be described differently under different perspectives may be a central cognitive function, which is relevant for both ToM understanding and mathematical computation.

There is also an established relationship between developmental improvements in ToM and executive functioning (see Devine & Hughes, 2014, for review). Therefore, Blair and Razza (2007) investigated interrelations among ToM, executive functioning, and academic abilities. In a cross-sectional study with 141 three- to five-year-old children from low-income homes, they measured FB understanding, executive functions, effortful control (the ability to inhibit a prepotent response; Rothbart & Ahadi, 1994), math and literacy ability. They found that inhibitory control in preschool (and to a moderate degree also FB understanding) predicted mathematics ability in kindergarten. In addition, FB understanding and teacher-reported effortful control in preschool predicted letter knowledge in kindergarten.

1.1 | Present study

Given the paucity of longitudinal studies focusing on the relation between ToM and later academic performance, the primary goal of this study was to evaluate the role of early ToM in preschool as a precursor to math and literacy ability in primary school (Grade 2). Furthermore, as executive functioning is known to be an important predictor of academic achievement and is also related to ToM understanding, we aimed at further elucidating the role of early executive functioning, specifically in relation to early ToM.

Apart from these two domain-general factors, domain-specific competencies may also play an important predictive role. For example, Stock et al. (2010) (see also Martin et al., 2014) showed that early counting skills predict later mathematical competencies. Therefore, children were also given a counting game (Bornstein & Putnick, 2019) as a measure of their understanding of number concepts. Also, we controlled for verbal intellectual ability, because the verbal ability is related to ToM (for a meta-analysis, see Milligan et al., 2007) and school achievement (Hohm et al., 2007).

As an outcome measure, we used two standardized achievement tests of math and reading abilities, because teacher ratings may be influenced by children's general behaviour in the classroom setting. Math performance was assessed with the DEMAT 2 (Deutscher Mathematiktest für 2. Klassen; Krajewski et al., 2004), a curriculum-based test for second graders including arithmetic (addition, subtraction, and division), applied arithmetic (e.g., calculating with money), and geometry. And the reading performance was assessed with the ELFE 1–6 (Lenhard & Schneider, 2006), a standardized German reading test for Grades 1–6 measuring reading comprehension at the word, sentence, and text level.

Based on previous research and theoretical frameworks, we expected the following specific, significant correlations: Math performance should be related to first-order FB understanding (Lockl et al., 2017; Perner et al., 2021), working memory (e.g., Cortés Pascual et al., 2019), counting skills (e.g., Stock et al., 2010), verbal IQ (e.g., Hohm et al., 2007), and reading performance. And reading performance should be related to working memory (e.g., Cortés Pascual et al., 2019) and verbal IQ (e.g., Hohm et al., 2007), but not to FB understanding (Lockl et al., 2017).

2 | METHOD

2.1 | Participants

The present study is part of a longitudinal project on the development of social and cognitive abilities (e.g., Sodian & Kristen-Antonow, 2015). The full sample of this longitudinal study included 155 children (68 girls). Children came from predominantly white middle-class families in an urban area of Germany. The current study is based on the 112 children (50 girls) who completed the key outcome variables, a math and a reading comprehension test at 7 years of age. The mean ages of this sample at the different time points were: 4;0 (years; months, $SD = 0.3$ months) at Time 1, 5;0 ($SD = 0.6$ months) at Time 2, 5;10 ($SD = 0.5$ months) at Time 3, and 7;10 ($SD = 0.5$ months) at Time 4.

2.2 | Procedure

At each time point, children were tested individually by a trained experimenter in a child-friendly University laboratory. Participation was voluntary and addresses were obtained through local birth records. Parents received full information about the study. Informed parental consent was obtained for all children who participated. Families received a small age-appropriate gift and a travel reimbursement at each measurement point. The study was approved by the ethics committee of the university.

2.3 | Measures

Our outcome measures at 7;10 years of age (Time 4) were the DEMAT 2 (Deutscher Mathematiktest für 2. Klassen; Krajewski et al., 2004), a German mathematics test, and the ELFE 1–6 (Ein Leseverständnistest für Erst- bis Sechstklässler; Lenhard & Schneider, 2006), a German reading comprehension test. At 7;10 years, children also received a working memory test. In addition, ToM and inhibition were measured at 5;0 years of age (Time 2). A test of verbal intelligence was given at 5;10 years of age (Time 3). And basic numerical abilities were assessed at 4;0 years of age (Time 1).

2.3.1 | Mathematics test (7,10 years)

Children's arithmetic skills were assessed with a standardized German math competence test for second graders (DEMAT 2; Deutscher Mathematiktest für 2. Klassen; Krajewski et al., 2004). The DEMAT 2 is a curriculum-based test including arithmetic (addition, subtraction, and division), applied arithmetic (e.g., calculating with money), and geometry. The test comprises nine tasks and has a good reliability (Cronbach's $\alpha = 0.93$). We use the T-score for analysis.

2.3.2 | Reading test (7;10 years)

Reading comprehension was assessed with a standardized German reading test for Grades 1 to 6 (ELFE 1–6; Ein Leseverständnistest für Erst- bis Sechstklässler; Lenhard & Schneider, 2006). This test measures reading comprehension at the word, sentence, and text level (Cronbach's $\alpha = 0.91$ to 0.97 for the three different subtests). For analysis, we use the T-score for children's overall reading comprehension score.

2.3.3 | First-order FB (5;0 years)

First-order FB understanding was measured with three tasks from the German version of the ToM Scale (Kristen et al., 2006; Wellman & Liu, 2004; see Hofer & Aschersleben, 2007, for the full German version). In the *contents FB* task, children were shown a Smarties tube and were asked, 'What do you think is inside the Smarties box?' After the expected answer ('Smarties'), the experimenter opened the box and revealed that the box actually contained a toy piglet. The tube was closed again, and a control question was asked ('Okay, what is in the box?'). Then, a Playmobil figure called Lukas, who has never ever seen what is inside this box, was introduced. Children were asked a test question ('So, what does Lukas think is in the box?') and a memory control question ('Did Lukas look inside this box?').

In the *location FB task*, children were told a story about a Playmobil figure called Paul, who wants to find his mittens. His mittens might be either in the closet or in his backpack. Children were told, 'Really, Paul's mittens are in his backpack. But Paul thinks that his mittens are in the closet.' Then, they were asked a test question ('So, where will Paul look for his mittens?') and a memory control question ('Where are Paul's mittens really?'). In each task, one point was given when children answered correctly to both questions (possible range on each task = 0–1).

2.3.4 | Real-apparent emotion (5;0 years)

In the *real-apparent emotion* task, children were told a story about Tim (shown as a coloured figure of a boy drawn from the back). Then, children were shown three different faces (a happy, a neutral, and a sad one) in order to check whether they are familiar with these emotional expressions. Children were told that at the end of the story they will be asked about how Tim really feels inside and how he looks on his face. In the story, Tim wants to receive a toy car as a present, but gets a book instead. After the story, children were asked a feel test question ('So, how does Tim really feel, when he gets the book. Does he feel happy, sad, or in-between?') and a look test question ('How will Tim try to look on his face, when he gets the book – happy, sad, or in-between?'). One point was given when children answered correctly to both questions (possible range = 0–1).

2.3.5 | Second-order FB (5;0 years)

Second-order FB understanding was assessed using the '*Birthday Puppy*' story about a boy called Peter whose mom wants to surprise him with a puppy on his birthday (Sullivan et al., 1994). In the story, Peter's mom has hidden the puppy in the basement. Peter says to his mom, 'I really hope to get a puppy for my birthday.' Then, children were reminded, 'Remember, Peter's mom wants to surprise him. So, she tells him that he will get a great toy instead of a puppy.' The story goes on and, by accident, Peter finds the birthday puppy in the basement. He thinks, 'Wow, Mom didn't get me a toy, I will really get a puppy for my birthday.' It was emphasized that Peter's mom did not see him go down to the basement and find the puppy.

Children were asked two control questions ('Does Peter know that he will get a puppy for his birthday?' and 'Does his mom know that Peter found the puppy in the basement?'). Then, the story was continued, 'The telephone rings. Peter's grandmother calls to find out what time the birthday party starts. Grandma asks Peter's mom, "Does Peter know what you really got him for his birthday?"' And children were asked the *second-order ignorance question* ('What does Peter's mom say to Grandma?'; correct answer: 'No, he doesn't know.'). Then, children were told, that Grandma says to Peter's mom, 'What does Peter think you got him for his birthday?' followed by the *second-order FB test question* ('What does Peter's mom say to Grandma?'; correct answer: 'He thinks he will get some toy.'). Children were given one point, if they answered both control and both test questions correctly (possible range = 0–1).

2.3.6 | Strange stories (5;0 years)

As an 'advanced' measure of ToM, we also used two strange stories (from Happé, 1994) depicting social situations. In the 'lie' task, children were told a story about Anna, who accidentally knocks over and breaks a crystal vase. Then, Anna's mother comes home and sees the broken vase. She asks Anna what happened and Anna says, 'It wasn't my fault. The dog knocked the vase over.' In the 'joke/metapher' task, Doris shows Thomas her new dog. The dog jumps up to greet Thomas and he says, 'Doris, you haven't got a dog. You've got an elephant!' Each story was followed by a truth-question ('Has Anna/Thomas told the truth?') and an open-response question ('Why has she/he said that?'). In each story, children received a score of 0 (wrong answer/no answer), 1 (physical explanation), or 2 (mental/psychological explanation). In the 'joke' task, only five children gave a correct answer. Therefore, we used only the 'lie' task for analysis (possible range = 0–2).

2.3.7 | Counting game (4;0 years)

The counting game (Bornstein & Putnick, 2019) focuses on children's understanding of four number concepts: one-to-one correspondence, stable-order principle, cardinality principle, and the integration of number with another dimension (direction). In a training phase, we assessed children's ability to count three and five dots on a die. In Game 1, they moved a game piece step-by-step in one direction on a game board (using a die with one, three, or five dots). In Game 2, a second die was introduced indicating the direction of movement. In each trial, children used both dies and had to coordinate two dimensions (number of moves and direction of movement).

In Game 1, children received one point for the correct number of moves and an additional point for the correct number of squares (due to the fact that sometimes, for example, children jumped twice on the same square). In Game 2, children were given one point for the correct number of squares and one point for the correct direction. In each Game, children received an average score (dividing the sum score across all turns by the number of turns). Finally, a counting game score was computed by averaging the standardized scores ($M = 0$, $SD = 1$) of both games.

2.3.8 | Verbal IQ estimate at 5;10 years

Verbal IQ was assessed using three subtests (*similarities*, *information*, and *vocabulary*) of the German version of the Wechsler Preschool and Primary Scale of Intelligence-III (WPPSI-III; Petermann, 2009). Based on the raw values of each subtest, normalized scores for the given age group were assigned. Based on the sum of these scores, estimated verbal IQ scores were assigned.

2.3.9 | Peter says (5;0 years)

Based on the 'Simon says' task (Strommen, 1973), children were told: 'Now, we are playing a game. I'll do all the exercises. Sometimes you are to do them with me and sometimes you are not. Only if I say "Peter says" you do them. If I don't, you don't do them.' After two practise trials (one Simon- and one non-Simon-trial) with corrective feedback, children received 20 test trials without feedback. In both trial types, the experimenter performed all movements (e.g., 'stamp your feet'). Simon and non-Simon trials were given in a fixed random order with a rule reminder after the first ten trials. On each trial, children were given a score from 0 to 2. A score of 2 was given for a full commanded movement on a Simon trial or for no movement on a non-Simon trial. A score of 1 was given for partial or incorrect movements on both trial types. And a score of 0 was given for a full commanded movement on a non-Simon trial or no movement on a Simon trial. Scores per trial type were summed resulting in a possible range of 0–20 for each trial type (Simon vs. non-Simon). For analysis, we use only non-Simon (non-Peter) trials.

2.3.10 | Backward digit span (7;10 years)

As a measure of working memory, we used the backward digit span test of the Wechsler Intelligence Scale for Children. In this test, children had to repeat progressively longer sequences of orally presented numbers in reverse sequence. Testing was discontinued after two incorrect trials in a row. For analysis, we used the number of correct trials.

3 | RESULTS

Table 1 presents the means and standard deviations of children's performance on the individual tasks.

First, we computed zero-order correlations (two-tailed) and applied post hoc Bonferroni–Holm corrections for the predicted correlations, which turned out to be significant (Table 2). As expected, we found a predictive relation between early FB understanding and later math performance (contents FB: $r = 0.21$, $p = 0.044$; location FB: $r = 0.30$, $p = 0.01$). Furthermore, math performance was significantly related to performance on the counting game ($r = 0.36$, $p = 0.008$), on the backward digit span task ($r = 0.27$, $p = 0.012$), on the Peter says task ($r = 0.22$, $p = 0.034$), on the reading comprehension ($r = 0.40$, $p < 0.008$), and to verbal IQ ($r = 0.26$, $p = 0.018$). Performance on the ELFE was significantly associated with real-apparent emotion understanding ($r = 0.25$, $p = 0.01$), counting game performance ($r = 0.24$, $p = 0.028$), backward digit span ($r = 0.37$, $p < 0.008$), and verbal IQ ($r = 0.22$, $p = 0.044$). Also, replicating previous research, there were significant relations between the different ToM measures (location FB and contents FB: $r = 0.35$, $p < 0.001$; contents FB and strange stories: $r = 0.31$, $p = 0.001$). Furthermore, inhibition as measured with the Peter says task, was significantly related to all ToM measures (except strange stories) with correlations ranging from $r = 0.21$, $p = 0.042$ to $r = 0.29$, $p = 0.004$ and to the counting game ($r = 0.23$, $p = 0.048$). Finally, backward digit span and counting game performance were interrelated ($r = 0.23$, $p = 0.034$).

Second, for the significant raw correlations, we computed partial correlations (one-tailed) controlling for verbal ability at 5;10 (see Table 2). Math performance remained significantly related to location FB ($r = 0.25$, $p = 0.009$) as well as to performance on the ELFE ($r = 0.37$, $p < 0.001$), on the counting game ($r = 0.34$, $p = 0.001$), and on the backward digit span task ($r = 0.28$, $p = 0.002$). Performance on the ELFE remained significantly correlated with real-apparent emotion understanding ($r = 0.25$, $p = 0.006$), counting game performance ($r = 0.22$, $p = 0.025$), and backward digit span ($r = 0.37$, $p < 0.001$). Also, there were still significant relations between different ToM measures (location FB and contents FB: $r = 0.30$, $p = 0.001$; contents FB and strange stories: $r = 0.27$, $p = 0.003$). Performance on the Peter says task remained significantly related to three ToM measures (contents FB: $r = 0.22$, $p = 0.018$; real-apparent emotion understanding: $r = 0.27$, $p = 0.006$; second-order FB: $r = 0.19$, $p = 0.033$) and to

TABLE 1 Descriptive statistics of performance on all measures

Measure	*M* (*SD*)	Range	*n* (task)
DEMAT (T value) 7;10 years	51.87 (8.14)	31–65	112
ELFE (T value) 7;10 years	55.41 (8.61)	29–73	112
Contents FB 5;0 years	0.80 (0.40)	0–1	107
Location FB 5;0 years	0.78 (0.42)	0–1	108
Real-apparent emotion 5;0 years	0.40 (0.49)	0–1	101
Second-order FB 5;0 years	0.20 (0.40)	0–1	108
Strange stories 5;0 years	1.28 (0.83)	0–2	104
Counting game 4;0 years	−0.03 (0.90)	−1.82 to 1.37	84
Verbal IQ 5;10 years	105.66 (10.03)	77–131	107
Peter says 5;0 years	7.7 (6.27)	0–19	94
Backward digit 7;10 years	6.05 (1.41)	2–10	110

Abbreviation: FB, false belief.

TABLE 2 Zero-order and partial correlations controlling for IQ (below the main diagonal)

Measure	2	3	4	5	6	7	8	9	10	11
1. Verbal IQ 6 years	0.27*	0.22*	0.31**	0.26**	0.03	0.18	0.19	0.12	0.31**	0.02
2. DEMAT (T value) 7 years	–	0.40**	0.21*	0.30*	0.11	0.17	−0.12	0.36**	0.22*	0.28*
3. ELFE (T value) 7 years	0.37**	–	−0.04	0.06	0.25*	−0.05	−0.06	0.24*	0.10	0.37**
4. Contents FB 5 years	0.14	−0.12	–	0.35**	−0.02	0.13	0.31**	0.15	0.29**	−0.08
5. Location FB 5 years	0.25**	0.01	0.30**	–	0.13	0.16	0.17	0.15	0.21*	0.09
6. Real-apparent emotion 5 years	0.10	0.25**	−0.03	0.13	–	−0.08	0.14	0.20	0.26*	0.19
7. Second-order FB 5 years	0.13	−0.10	0.08	0.12	−0.09	–	0.02	0.08	0.24*	0.08
8. Strange stories 5 years	−0.18*	−0.11	0.27**	0.13	0.14	−0.01	–	0.08	0.03	−0.15
9. Counting game 4 years	0.34**	0.22*	0.12.	0.12	0.20*	0.06	0.06	–	0.23*	0.23*
10. Peter says 5 years	0.15	0.03	0.22*	0.14	0.27**	0.19*	−0.03	0.21*	–	0.15
11. Backward digit span 7 years	0.28**	0.37**	−0.10	0.08	0.19*	0.08	−0.16	0.23*	0.15	–

Abbreviation: FB, false belief.

TABLE 3 Predictors of math performance in a linear regression analysis

Variable	*B*	SE of *B*	*β*	*t*	*p*
Backward digit span	1.85	0.62	0.32	3.00	0.004
Counting game	2.94	1.01	0.31	2.92	0.005
FB location	5.89	2.54	0.26	2.32	0.023

Note: $n = 69$.
Abbreviation: FB, false belief.

TABLE 4 Predictors of Reading performance in a linear regression analysis

Variable	*B*	SE of *B*	*β*	*t*	*p*
Backward digit span	1.91	0.62	0.33	3.08	0.003
Verbal IQ	0.22	0.09	0.23	2.30	0.024

Note: $n = 77$.

the counting game ($r = 0.21$, $p = 0.04$). Furthermore, performance on the counting game remained significantly associated with backward digit span ($r = 0.23$, $p = 0.019$).

Finally, we conducted two linear regression analyses with math and reading performance as dependent variables and all significant correlates as possible predictors (inclusion method). When using math performance as the dependent variable, backward digit span, counting game, and FB location remained as significant predictors explaining 37% of variance, $F(6, 63) = 6.12$, $p < 0.001$ (see Table 3). A subsequent hierarchical regression analysis showed that backward digit span and counting game explain 21% of variance of math performance. Performance on the FB location task significantly explained an additional 7% of variance, $p = 0.005$. When using reading performance as the dependent variable, this yielded backward digit span and verbal IQ as significant predictors explaining 26% of variance, $F(4, 73) = 6.55$, $p < 0.001$ (see Table 4).

4 | DISCUSSION

In this study, we corroborated and extended previous research showing that preschool executive functioning and ToM abilities are important predictors of children's later academic achievement. Using regression analysis, we found that FB understanding at 5 years of age, performance on a counting game at 4 years of age, and concurrent working memory capacity significantly predict children's math performance (as measured with the DEMAT 2) at 7 years of age. Reading performance (as measured with a standardized German reading comprehension test; ELFE 1–6) at 7 years of age was significantly predicted by concurrent working memory and verbal IQ at 6 years of age.

As in the study by Lockl et al. (2017), a regression analysis showed no relation between early FB understanding and later reading performance. Reading performance was measured with the ELFE, which taps reading comprehension at the word, sentence, and text level. Finding no association between early ToM and later reading performance may be due to the fact that reading for meaning emerges later, and ToM abilities may be mainly related to later reading abilities, when children begin to read for story comprehension (see also Astington & Pelletier, 2005; Lockl et al., 2017). Also, Lecce and Devine (2021) argue that ToM understanding is important for high-level reading comprehension, because ToM understanding enables children to understand the intentions and perspectives of story characters (see also Dore et al., 2018). In line with this, Lecce et al. (2021) found associations between ToM and reading comprehension in older (9-year-old) children. However, other studies indicate that ToM is also related to basic reading skills, like word reading (e.g., Wilson et al., 2021) or letter knowledge (Blair & Razza, 2007). In our sample, at 5 years of age, only a minority of children understood second-order FBs, whereas the majority performed well on first-order FB tasks. This may explain why first- and second-order FB understanding were not intercorrelated, and it also suggests that further research is necessary investigating the relation between second-order FB understanding and reading in older children. Furthermore, in our correlational analyses, but not in the regression analysis, reading performance was significantly related to children's understanding of real versus apparent emotions (even when controlling for verbal IQ). In sum, this suggests that the developmental link between ToM and reading performance is multi-faceted and that further research is necessary in order to elucidate this relationship. Replicating previous research, reading performance was related to executive functioning, in particular, working memory (e.g., Cain et al., 2004; Cantin et al., 2016; Sesma et al., 2009).

With regard to the link between executive functioning and school achievement, our results are mixed. When controlling for verbal IQ, inhibition at 5 years of age was not related to later school success, but concurrent working memory abilities were significantly related both to reading and math performance at 7 years of age. Though executive functioning, in general, has been shown to predict later academic achievement (e.g., Morgan et al., 2019), in the present study only working memory, but not inhibition, was significantly related to academic abilities. This is in line with a recent meta-analysis (Cortés Pascual et al., 2019) showing that (among the three main executive functions) working memory is the strongest predictor of academic performance in primary school.

Using linear regression analyses, we identified three variables predicting math abilities. First, concurrent working memory capacity emerged as a significant domain-general predictor. This fits a host of research showing that working memory (in particular, verbal updating) is significantly related to mathematics in primary school (for a review, see Friso-Van den Bos et al., 2013).

Second, performance on the counting game at 4 years of age was a significant within-domain predictor of later math abilities. This is in line with findings showing that early counting skills predict later mathematical skills (e.g., Martin et al., 2014; Stock et al., 2010). Also, Sasanguie et al. (2012) showed that basic number processing skills (estimating quantities of dots and comparing symbolic numbers) in 5–7-year-old-children predict math achievement 1 year later.

Third, first-order FB understanding at 5 years of age turned out to be a significant cross-domain predictor. However, second-order FB understanding and understanding of strange stories at 5 years of age were not significantly related to later math performance; though this may be due to floor effects on these tasks at this early age.

Our finding confirms previous results by Lockl et al. (2017) indicating a significant relation between preschool ToM and numeracy skills in Grade 2. Furthermore, in our study, FB understanding remained as a significant predictor of math performance even when counting skills and working memory were taken into account. ToM and math performance may be related, because they involve a similar understanding of mental representations (Lockl et al., 2017). Also, in a cross-sectional study focusing on the data from Time 1, we (Osterhaus et al., 2020) found that social intelligence as measured by FB understanding and mothers' reports of social skills was significantly related to verbal as well as to numerate-spatial intelligence in 4-year-old children. In this study, numerate-spatial intelligence was assessed with the arithmetic, block design, and picture completion subtests of the German version of the WPPSI-III (Petermann, 2009) in addition to the counting game used in the present study.

Our finding is also in line with brain imaging data (see Perner et al., 2021, for a review) suggesting a link between FB tasks and arithmetic equations. Unfortunately, our outcome measure, the DEMAT, does not allow a clear distinction between tasks involving equations or not. Therefore, future, controlled studies are necessary in order to investigate whether FB understanding is specifically related to understanding arithmetic equations or to mathematical understanding in a more general sense.

Though math and reading abilities are complex skills comprising a variety of subcomponents, we decided to use these curriculum-based, standardized measures, because our primary aim was to investigate whether or not children's school achievement in math and reading is influenced by ToM and executive function. Clearly, further research is necessary in order to understand the specific link between different ToM and executive functioning components and different reading and mathematical subskills.

In sum, the present study confirms and extends previous research on the importance of ToM and executive functioning for later academic achievement. In particular, understanding perspectives may be an important contributor to understanding mathematical concepts. This also has practical implications. In the past decades, a host of studies have investigated executive function trainings as a tool for improving children's school achievement (see, e.g., Takacs & Kassai, 2019, for a recent meta-analysis). In contrast, research on ToM training as a tool for fostering academic abilities is limited. Given our results, a training integrating ToM/perspective and executive function training may be particularly useful (see, e.g., Schonert-Reichl et al., 2015).

AUTHOR CONTRIBUTIONS

Daniela Kloo: Conceptualization; data curation; formal analysis; writing – original draft. **Christopher Osterhaus:** Data curation; formal analysis; writing – review and editing. **Susanne Kristen-Antonow:** Conceptualization; data curation; investigation; project administration. **Beate Sodian:** Conceptualization; formal analysis; funding acquisition; writing – review and editing.

ACKNOWLEDGEMENT

This work was supported the German Research Council (Grant number SO213/27-1,2). Open Access funding enabled and organized by Projekt DEAL.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/icd.2356.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study was approved by the ethics committee of the university.

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How to cite this article: Kloo, D., Osterhaus, C., Kristen-Antonow, S., & Sodian, B. (2022). The impact of theory of mind and executive function on math and reading abilities: A longitudinal study. *Infant and Child Development*, *31*(6), e2356. https://doi.org/10.1002/icd.2356