

An Embodiment Perspective on Number–Space Mapping in 3.5-Year-Old Dutch Children

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Previous research suggests that block adding, subtracting and counting direction are early forms of number–space mapping. In this study, an embodiment perspective on these skills was taken. Embodiment theory assumes that cognition emerges through sensory–motor interaction with the environment. In line with this assumption, it was investigated if counting and adding/subtracting direction in young children is related to the hand they use during task performance. Forty-eight 3.5-year-old children completed a block adding, subtracting and counting task. They had to add and remove a block from a row of three blocks and count a row of five blocks. Adding, subtracting and counting direction were related to the hand the children used for task performance. Most children who used their right hand added, removed and started counting the blocks at the right side of the row. Most children who used their left hand added, removed and started counting the blocks at the left side of the row. It can be concluded that number–space mapping, as measured by direction of adding, subtracting and counting blocks, in young children is embodied: It is not fixed, but is related to the situation. © 2016 The Authors *Infant and Child Development* Published by John Wiley & Sons, Ltd.

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Recent research has shown that young children already show number–space mapping skills (Hoffmann, Hornung, Martin, & Schiltz, 2013; Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer, Thompson, & Furlong, 2010; Patro & Haman, 2012). Number–space mapping refers to the ability to link numbers to space. There

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are different types of number–space mapping. Patro, Nuerk, Cress, and Haman (2014) classified them into four categories: (i) cross-dimensional magnitude processing; (ii) associations between spatial and numerical intervals; (iii) associations between cardinalities and spatial directions; and (iv) associations between ordinalities and spatial directions. The current study will focus on associations between ordinalities and spatial directions. This type of number–space mapping can be found in young children in the form of adding, subtracting and counting objects. It has been found in previous studies that these skills are highly influenced by cultural and educational experiences, especially after children enter formal schooling (Shaki, Fischer, & Goebel, 2012). A critical question is how number–space mapping develops before educational experiences mold it in a particular cultural form. However, not much is known yet about the development of these skills before children enter school. The present study aims to fill this gap by studying block adding, subtracting and counting direction in 3.5-year-old Dutch children who did not yet enter kindergarten.

One of the most investigated types of number–space mapping is the ‘spatial numerical association of response codes’ (SNARC) effect, measuring associations between cardinalities and spatial directions. The SNARC effect shows that people respond faster to small numbers with the left hand and respond faster to larger numbers with the right hand (refer to Wood, Willmes, Nuerk, & Fischer 2008 for a review). It is assumed that this effect is caused by mapping of numbers from left to right on a horizontal axis. The SNARC effect is already present in preschool/kindergarten children (Hoffmann et al., 2013; Patro & Haman, 2012). A recent habituation study suggests that even 7-month-old infants prefer magnitudes *increasing* from left to right over magnitudes *decreasing* from left to right (De Hevia, Girelli, Addabbo, & Macchi Cassia, 2014). This could point to an early predisposition for left-to-right number–space mapping. However, in a baseline experiment without habituation, De Hevia et al. (2014) also showed that the infants did not look longer to left-to-right increasing magnitudes if they had seen left-to-right decreasing magnitudes first. This suggests that early number–space associations are not fixed. It is likely that there is an early predisposition to associate numbers and space, but specific directional biases are shaped by situated and cultural influences (McCrink & Opfer, 2014; Nuerk et al., 2015)

Many studies on influences on number–space mapping in adults have focused on reading direction and found that people map numbers to space in the same direction as they read text (Fischer, Mills, & Shaki, 2010; Fischer, Shaki, & Cruise, 2009; Hung, Hung, Tzeng, & Wu, 2008; Shaki, Fischer, & Petrusic, 2009). Other researchers have suggested that in preliterate children, adding/subtracting and counting direction influence number–space mapping (Opfer & Furlong, 2011; Opfer et al., 2010; Shaki et al., 2012). Most preschoolers already add, subtract and count objects from left to right. When they have to add an object to a linear array of objects, most preschoolers add the object at the right side. When they have to take away an object from the array, most preschoolers take the object from the right side. This is consistent with left-to-right number–space mapping (Opfer & Furlong, 2011; Rinaldi, Gallucci, & Girelli, 2016). Percentages of 2.5 to 6-year-old children counting from left to right range between 60 and 98% in cultures where reading direction is left to right (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Patro, Nuerk, & Cress, 2015; Rinaldi et al., 2016; Shaki et al., 2012), although other studies did not find a significant preference for left-to-right counting direction under age 6 (Knudsen, Fischer, & Aschersleben, 2015; Patro, Fischer, Nuerk, & Cress, 2016). Opfer and Furlong (2011) found a relation between adding, subtracting and counting direction and number–space mapping

in 4-year-old children. They presented two boxes to the children, each separated into seven ‘rooms’ labelled one to seven from right to left or from left to right. The children were more accurate in matching a room from the sample box with the room that had the same number in the matching box when the rooms were labelled from left to right, especially when they also displayed a consistent left-to-right adding, subtracting and counting direction. This suggests that children who show a left-to-right adding, subtracting and counting bias are more likely to expect numbers to be ordered from left to right in the spatial search task.

In the current study, adding, subtracting and counting objects in young children will be studied using an embodiment perspective. Embodiment theory assumes that cognition emerges through interaction of a person with his or her environment as a result of sensory–motor activity (Smith, 2005; Smith & Gasser, 2005; Wilson, 2002). When children are adding or subtracting blocks, they are using space to ‘make more’ or ‘make less’, and when they are counting objects, they are labelling space by using numbers. Through this sensory–motor interaction with the environment, associations between ordinalities and spatial directions emerge in real time, at the moment the child is acting on the objects. This implies that number–space mapping can vary between situations and can change over time, depending on the real-time interaction between the body and the characteristics of the setting. Consistency in adding, subtracting and counting direction is indeed quite low in preschoolers, ranging from 20 to 43% (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Rinaldi et al., 2016). However, it is not known if this inconsistency in number–space mapping direction is caused by situation characteristics. A possible task-related influence on adding, subtracting and counting direction is reaching behaviour. In previous studies on adding, subtracting and counting blocks, the blocks were presented in such a way (in a horizontal array) that it will elicit horizontal (left-to-right or right-to-left) responses (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Shaki et al., 2012). Whether the response will be left-to-right or right-to-left could be related to reaching behaviour, which is the interaction between the position of the blocks relative to the child and the hand used for task performance.

It has been found in studies on reaching behaviour that people prefer ipsilateral reaching; they mostly use the right hand to reach for objects on the right side of their body midline and the left hand to reach for objects on the left side of their body midline (Bryden, Mayer, & Roy, 2011; Souza, De Azevedo Neto, Tudella, & Teixeira, 2012), probably because of the lower effort in reaching to an object at the same side as your hand. A preference for ipsilateral reaching could influence the results on adding, subtracting and counting tasks. This might especially be the case in preschool aged children, because hand preference is still variable at this age (Bruckner, Kastner-Koller, Deimann, & Voracek, 2011; Sacrey, Arnold, Whishaw, & Gonzalez, 2013), especially on unimanual tasks (Fagard & Marks, 2000). Moreover, ipsilateral reaching is stronger in young children and children with no fixed hand preference (Carlier, Doyen, & Lamard, 2006; Leconte & Fagard, 2004). Patro et al. (2015) studied the influence of hand use on counting direction. They found a preference for ipsilateral counting in both spontaneous and forced hand use. If children were forced to count objects with the left hand, they were more likely to count from left to right, and if they were forced to count with the right hand, they were more likely to count from right to left. When the children were free in choosing the hand they used, 67.5% of the children spontaneously started counting on the same side as the hand they used. Moreover, the relation between hand use and counting direction even holds after a non-numerical visuo-motor training where children had to move a frog leftwards or rightwards on a

screen, suggesting strong situated influences (Patro et al., 2016). To gain further insight in the early development of embodied number–space mapping, in the current study, spontaneous hand use will be studied not only in relation to counting direction but also in relation to adding and subtracting direction (cf. Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010). This enables us to examine the consistency in spontaneous hand use and number–space mapping direction across tasks. It is expected that there is a preference for ipsilateral reaching in all tasks. If the children already have a strong bias for culturally consistent left-to-right number–space mapping, it would be expected that their number–space mapping direction is consistent across the tasks, but hand use will change to enable ipsilateral reaching. Left-to-right number–space mapping refers to an increase in number from left to right, thus adding at the right side of the sequence with the right hand. Similarly, right-to-left number–space mapping refers to a decrease in number from right to left, thus subtracting from the right side with the right hand. Left-to-right counting will start at the left side with the left hand. However, to prevent large cultural educational influences, the age group used in the current study will be 3.5-year-olds. At this age, children are able to count objects (Wynn, 1990), but educational experiences that could mold number–space mapping in a certain direction are limited because they have not entered kindergarten or primary school yet. It is expected that sensory–motor preferences like ipsilateral reaching influence number–space mapping instead of educational experiences at this age. In line with embodiment theory, it is hypothesized that both number–space mapping direction and hand use can vary between adding, subtracting and counting, but that the ipsilateral hand is used on all tasks.

METHOD

Participants

Fifty-two 3.5-year-old children participated in this study. Four children were excluded from the analyses, because they failed to complete the tasks according to the protocol. The mean age of the remaining 48 children was 3.59 years ($SD = 0.08$ years). The sample consisted of 14 (29.2%) boys and 34 (70.8%) girls. Most of the parents completed higher vocational training or university (one missing). Seven children (14.6%) had at least one parent who completed higher vocational training or university, and for 39 children (81.3%), both parents completed higher vocational training or university. Thirty-eight children (79.2%) came from Dutch families; the remaining 10 children (20.8%) had a combined background of Dutch and another ethnicity. All of these children came from cultures where reading direction is left-to-right (just like Dutch), except for one girl with a Dutch–Chinese ethnic background.¹ Forty (83.3%) children received daycare outside their own home (e.g. in a daycare centre or at grandparents' home), with an average of 4.78 half-days ($SD = 1.94$) per week. Fourteen (29.2%) children went to a play group or preschool, with an average of 2.64 half-days ($SD = 1.34$) per week. The children were recruited via letters sent to the home addresses of eligible children in the municipality of Utrecht and via internet forums on parenting.

Procedure

The children came for a 1.5-h visit to our lab at Utrecht University to complete a test battery on early math, number–space mapping, exploration behaviour and

(working) memory. All tests were administered by trained master's students following a fixed protocol. Parents were present during the entire session, but were instructed not to give any help to the child to complete the tasks.

Instruments

The tasks used for this study were similar to the instrument used by Opfer and colleagues (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010). The instrument consisted of three components: (i) block adding; (ii) block subtracting; and (iii) block counting. The blocks were placed on the table at a distance of approximately 15 cm from the edge on the side the child was sitting. The middle block was placed in line with the child's body midline, so no indication of direction was given. The size of the blocks was 3 × 3 cm. The distance between the blocks was about 1.5 cm.

Forty-four children completed all three tasks. One child did not complete the adding task, two children did not complete the subtracting task, and one child did not complete both the adding and subtracting tasks. These children were only included in the analyses on the tasks they did complete.

Adding

A row of three blocks was presented to the child. The experimenter placed the three blocks on the table all at once. The experimenter handed the child another block and said: 'Here are three blocks. Can you add this block? There will be four blocks then'. It was scored which hand the child used and where the block was placed: at the left or right side of the other blocks or somewhere else (e.g. placing the block on top of one of the other blocks). It is assumed that the children who add the block at the *right* side of the row map numbers to space from *left-to-right*, whereas the children who add the block at the *left* side map numbers to space from *right-to-left* (cf. Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010).

Subtracting

The same procedure as in 'adding' was followed, except that the child was told: 'Here are three blocks. Can you remove one block? There will be only two blocks left then'. It was scored which hand the child used and which block the child took: the left, right or middle block. It is assumed that the children who subtract the block at the *right* side of the row map numbers to space from *left-to-right*, whereas the children who subtract the block at the *left* side map numbers to space from *right-to-left* (cf. Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010).

Counting

The child was asked to count (by pointing) a horizontal array of five blocks. The experimenter first placed the middle block on the table in line with the child's body midline and then added the remaining blocks at both ends simultaneously, so no indication of direction was given. The counting direction (from left to right or vice versa) of the child and the hand used for counting were scored.

Statistical Analyses

First, chi-square tests were used to analyse the frequency distributions of adding/subtracting/counting direction*hand use separately. Second, kappas

were calculated for number–space mapping direction * hand use frequency distributions for all pairs of tasks (adding vs subtracting, adding vs counting and subtracting vs counting) to analyse if the children were consistent in their number–space mapping direction and hand use across the tasks.

RESULTS

Chi-Square Tests

Figure 1 displays the frequency distribution of all three tasks. Forty-six children completed the adding task. It was found that 24 children (52.2%) added the block at the right side of the other blocks, cf. left-to-right number–space mapping. All of them used their right hand. Fifteen children (32.6%) added the block at the left side, cf. right-to-left number–space mapping. Only two of these 15 children used their right hand to do this; the others used their left hand. In line with our expectations, most of the children showed ipsilateral reaching. A total of 37 children (80.4%) added ipsilateral, and only two children (4.3%) added contralateral. Seven children (15.2%) did not add the block either at the left or right side but for example on top of one of the other blocks. Six of these children used their right hand, and one child used both hands. The distribution of the children across the combinations of direction and hand use was unequal: $\chi^2(4) = 42.71, p < .001, \phi = 0.96$.

Forty-five children completed the subtracting task. The same pattern as in the adding task was found. Most children (27 children, 60%) took away the block at the right side of the array, cf. left-to-right number–space mapping, and all of them used their right hand. Fifteen children (33.3%) took the block at the left side, cf. right-to-left number–space mapping. Three of them used their right hand, and 12 children used their left hand. Again, the majority of the children used the ipsilateral hand. A total of 39 children (86.7%) subtracted ipsilateral, and three children (6.7%) subtracted contralateral. Three children (6.7%) took away the middle block, two of them used their right hand, and one child used its left hand. This distribution was also unequal across the combinations of direction and hand use: $\chi^2(2) = 30.07, p < .001, \phi = 0.82$.

Forty-eight children completed the counting task. The number–space mapping direction of the majority of the children was opposite to the most common direc-

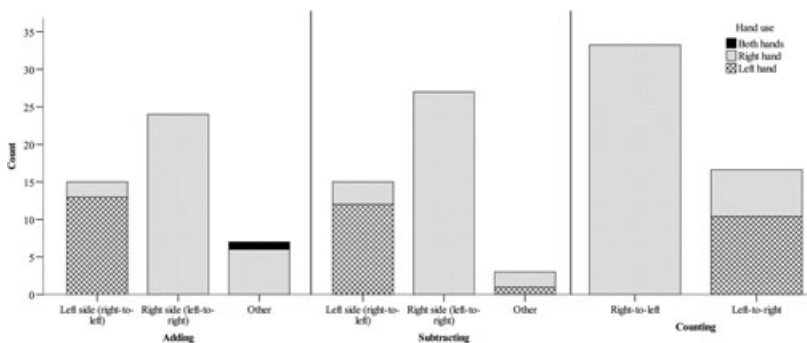


Figure 1. Frequency distributions of the number of children, calculated by the side where they added (left panel) and subtracted (middle panel) blocks and the direction in which they counted blocks (right panel) and the hand they used for task performance.

tion in adding and subtracting. Thirty-two children (66.7%) counted from right to left, and all of them used their right hand. The other children (16 children, 33.3%) counted from left to right. Ten of these 16 children used their left hand, and six children used their right hand. The majority of the children started counting on the ipsilateral side. A total of 42 children (87.5%) showed ipsilateral hand use, and six (12.5%) children showed contralateral hand use. The distribution was unequal across the combinations of direction and hand use: $\chi^2(1) = 25.26, p < .001, \phi = 0.73$.








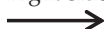
Consistency Analyses

Table 1 shows the frequency distribution of hand use and number–space mapping direction across the adding and subtracting tasks. Most children (29 children, 85.3%) were consistent in hand use and direction across the tasks, $k = .71$. Out of these 29 children, 27 children used the ipsilateral hand. Five children changed both direction and hand use. All of them used the ipsilateral hand on both tasks.


The frequency distribution of hand use and number–space mapping direction across the adding and counting task is shown in Table 2. The consistency of hand use and number–space mapping direction across the adding and counting task was very low, $k = -.08$, suggesting that the children are not influenced by a predetermined directional number–space mapping bias. Only one child (2.6%) used the same hand and the same direction in both tasks. The majority of the children (31 children, 79.5%) changed direction but not hand use. Thirty of these children used the ipsilateral hand on both tasks. Four children (10.3%) changed hand use but not direction. All of them used their ipsilateral hand on both tasks. A change in both hand use and direction was observed in three of the children (7.7%). These children used the contralateral hand.

Table 3 shows the frequency distribution of hand use and number–space mapping direction across the subtracting and counting task. The consistency of hand use and number–space mapping direction between these tasks was very low, $k = -.08$. This again suggests that the children’s performance was not influenced

Table 1. Frequency distribution of consistency hand use and number–space mapping direction across the adding and subtracting tasks ($N = 34$)

Adding	Subtracting			
				
	Left side, left hand	Left side, right hand	Right side, left hand	Right side, right hand
	8 ¹	0	0	3 ¹
Left side, left hand				
	0	2	0	0
Left side, right hand				
	0	0	0	0
Right side, left hand				
	2 ¹	0	0	19 ¹
Right side, right hand				

¹Ipsilateral hand use.

 Right-to-left number–space mapping.


 Left-to-right number–space mapping.

Table 2. Frequency distribution of consistency hand use and number–space mapping direction across the adding and counting tasks (N = 39)

	Counting			
	←	←	→	→
Adding	Start right, left hand	Start right, right hand	Start left, left hand	Start left, right hand
← Left side, left hand	0	3 ¹	8 ¹	2
← Left side, right hand	0	0	1	1
→ Right side, left hand	0	0	0	0
→ Right side, right hand	0	22 ¹	1 ¹	1

¹Ipsilateral hand use.

← Right-to-left number–space mapping.

→ Left-to-right number–space mapping.

by a predetermined directional number–space mapping bias. Three children (7.1%) used the same hand and the same direction in both tasks. A change in direction but not hand use was observed in 27 children (64.3%). Twenty-six of them used the ipsilateral hand on both task. Eight children (19.0%) changed hand use, but not direction. All of them used their ipsilateral hand on both tasks. Four children (9.5%) were inconsistent in both hand use and direction across the tasks. These children used the contralateral hand.

To summarize, the results show that number–space mapping direction was consistent across the adding versus subtracting task, but inconsistent across the

Table 3. Frequency distribution of consistency hand use and number–space mapping direction across the subtracting and counting tasks (N = 42)

	Counting			
	←	←	→	→
Subtracting	Start right, left hand	Start right, right hand	Start left, left hand	Start left, right hand
← Left side, left hand	0	5 ¹	4 ¹	3
← Left side, right hand	0	1	1	1
→ Right side, left hand	0	0	0	0
→ Right side, right hand	0	22 ¹	3 ¹	2

¹Ipsilateral hand use.

← Right-to-left number–space mapping.

→ Left-to-right number–space mapping.

adding versus counting and subtracting versus counting task. However, hand use was consistent across all three tasks, and in most cases, ipsilateral. It is likely that the consistent ipsilateral hand preference is related to the change in number–space mapping direction. Remember that the side at which the children added or subtracted is not the same as the direction in the adding and subtracting tasks. Adding or subtracting at the *left* side of the row is interpreted as *right-to-left* number–space mapping, and adding or subtracting at the *right* side of the row is interpreted as *left-to-right* number–space mapping. This means that if the children consistently prefer ipsilateral reaching with the left hand, their number–space mapping direction would be right-to-left on the adding and subtracting task and left-to-right on the counting task. Similarly, if the children consistently prefer ipsilateral reaching with the right hand, their number–space mapping direction would be left-to-right on the adding and subtracting task and right-to-left on the counting task. This would lead to a low consistency in number–space mapping direction, while in fact, there is a high consistency in the starting side. Therefore, additional kappas were calculated to analyse the consistency of starting point* hand use on adding versus counting and subtracting versus counting.

The consistency of starting point* hand use across the adding and counting task was indeed high, $k = .60$. Thirty-one children (79.5%) used the same hand and the same starting point on both tasks. Only one of these children did not use the ipsilateral hand on both tasks. One child (2.6%) changed starting point, but not hand use. This child did not use the ipsilateral hand on both tasks. A change in hand use, but not starting point, was observed in three children (7.7%) who did not use the ipsilateral hand on both tasks. Four children (10.3%) changed both hand use and starting point. They all used the ipsilateral hand on both tasks.

The consistency of starting point between the subtracting and counting task was lower than the consistency between the adding and counting task, $k = .30$, although still substantial. Moreover, most children were indeed consistent in hand use and starting point: 27 children out of 42 (64.3%). Twenty-six of these children used the ipsilateral hand on both tasks. Three children (7.1%) changed starting point, but not hand use, and did not use the ipsilateral hand on both tasks. Four children (9.5%) used the same starting point, but not hand on both tasks. All of these children did not use the ipsilateral hand on both tasks. A change in both hand use and starting point was observed in eight children (19.0%), who all used the ipsilateral hand on both tasks.

DISCUSSION

Previous research suggested that number–space mapping might be influenced by block adding/subtracting and counting direction. In most Western cultures, the predominant direction of number–space mapping is from left to right. Preschoolers in these countries already order and count in this direction (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Patro et al., 2015; Shaki et al., 2012). Following embodiment theory, it was hypothesized in the current study that block adding, subtracting and counting direction are early forms of number–space mapping itself, and that this early number–space mapping is related to the children’s hand use. This hypothesis was confirmed by the results, which show that children’s adding, subtracting and counting direction is related to a preference for ipsilateral reaching.

In the current study, it was found that when Dutch toddlers were asked to add or remove an object from a horizontal array, most of them added or took the

object at the right side of the array. It is assumed that adding and subtracting the block at the right side of the sequence conforms to left-to-right number-space mapping. Left-to-right number-space mapping implies that the amount of blocks increases from left to right, thus adding the block at the right side of the sequence. Similarly, left-to-right number-space mapping implies that the amount of blocks decreases from right to left, thus subtracting the block at the right side of the row. In line with previous research from Western cultures, this result may lead to the conclusion that block adding and subtracting direction in Dutch toddlers is already influenced by cultural practices. However, it was found that the children's counting direction in the current study does not conform to cultural practices. They counted in the opposite direction: from right to left instead of left to right. This confirms previous research showing that preschoolers are quite inconsistent in adding, subtracting and counting direction (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Rinaldi et al., 2016). The difference in direction between the adding/subtracting versus counting task shows that early number-space mapping can vary between situations and cannot be completely explained by the influence of culture or education.

In line with embodiment theory, the variation in number-space mapping direction across the tasks in the current study is related to low-effort reaching behaviour. Children preferred ipsilateral reaching on all tasks. Consistency analyses across the tasks show that number-space mapping direction changes, but starting point and hand use do not change substantially. Although the correlational design of the current study does not allow us to draw definitive conclusions about the causal nature of the found relations, the consistency analyses suggest that the used hand affects number-space mapping direction instead of the other way around. Remember that the same starting point leads to opposite number-space mapping directions in the adding/subtracting versus counting task. If a predetermined number-space mapping direction affects the hand used, it would be expected that the children show the same number-space mapping direction on all tasks and varied in hand use to reach ipsilateral to the starting point. In contrast, this study shows that the majority of the children used the same hand on all tasks and started at the corresponding side of the array to add, subtract or count, resulting in a change in number-space mapping direction. This is in line with experimental results from previous research, which showed that a forced change in hand use resulted in a change in counting direction (Patro et al., 2015). An alternative explanation would be that the starting point plays a causal role instead of either number-space mapping direction or used hand. It is possible that children prefer a certain side of space to start adding/subtracting/counting, which influences both the used (ipsilateral) hand and number-space mapping direction. Further research varying in (forced) starting point and hand use is needed to examine this.

Although the current study did not analyse the development of number-space mapping over time, the fact that number-space mapping can vary between situations suggests that it is not fixed. It is possible that early number-space mapping is strongly related to the body in space and can be reordered upon cultural and educational practices later in life. This is supported by Crollen, Dormal, Seron, Lepore, and Collignon (2013), who found that the SNARC effect is hand-based in early blind individuals and externally based in sighted and late blind individuals. These authors propose a developmental model, in which number-space mapping direction is body-centered early in life but becomes externally based later on as a result of environmental factors and cultural habits like reading direction. A few studies already showed the influence of education on early number-space

mapping. Shaki et al. (2012) found that the percentage of children counting from left to right is higher in school children than in preschool children. Moreover, Patro et al. (2016) did not find a directional bias in number–space mapping in 3 to 4-year-old children, and Knudsen et al. (2015) showed that there is no significant preference for left-to-right counting direction until age 6 in German children. Longitudinal studies are needed to examine if number–space mapping indeed develops from embodied to culturally determined.

The influence of educational practices on number–space mapping could also explain why only 33.3% of the children in the current study count objects from left to right, which is far below the 60–80% or even 98% reported in some previous studies (Opfer & Furlong, 2011; Opfer & Thompson, 2006; Opfer et al., 2010; Shaki et al., 2012). Most previous research included children who attended preschool or kindergarten or used a mixed sample of both children who did and did not attend preschool/kindergarten. In the current study, only 29% of the children attended a play group/preschool. Moreover, quantity of math activities in Dutch childcare and preschools is low (Slot, 2014). It is likely that the influence of hand use is not yet overruled by cultural practices in these children. This probably also caused the higher percentage of ipsilateral counting in our study compared to Patro et al. (2015): 87.5 versus 67.5%. The participants in the study of Patro et al. (2015) attended preschool and were older than the participants in the current study. This could have resulted in a stronger bias to count from left to right regardless of preferred hand use, induced by cultural learning practices.

The current study analysed one specific type of number–space mapping: associations between ordinalities and spatial directions (Patro et al., 2014). It is assumed that associations between number and space arise from real-time sensory–motor interaction with the environment. This implies that the results from this study can only tell something about this specific type of number–space mapping in this specific situation. It is not known yet if this type of number–space mapping is related to mental number–space concepts or other forms of number–space mapping. Rinaldi et al. (2016) found that consistency in mapping ordinalities to space is related to more accurate mapping of numerical intervals to space, suggesting intertwined development of different types of number–space mapping. Future research is recommended to further explore the developmental relations between different types of number–space mapping.

When interpreting the results of the current study, it should be taken into account that the sample was relatively small, and most children came from higher socioeconomic status families. Nevertheless, this study sheds a light on the early characteristics of number–space mapping. The findings of this study are in line with embodiment theory; 3.5-year-old children in the Netherlands add, subtract and count objects in accordance with characteristics of the task at hand and in relation to their body and not always consistent with left-to-right cultural directional biases. Further experiments are needed to strengthen this conclusion. An interesting starting point for future research would be to manipulate the position of the blocks relative to the position of the child towards the left or right side of the body midline, to examine whether this changes block adding/subtracting and counting direction.

Note

1. No substantial changes in the results were observed if the Dutch–Chinese girl was excluded from the analyses.

REFERENCES

- Bruckner, J., Kastner-Koller, U., Deimann, P. & Voracek, M. (2011). Drawing and handedness of preschoolers: A repeated-measurement approach to hand preference. *Perceptual and Motor Skills*, *112*, 258–266. DOI:10.2466/04.10.PMS.112.1.258-266.
- Bryden, P. J., Mayer, M. & Roy, E. A. (2011). Influences of task complexity, object location, and object type on hand selection in reaching in left and right-handed children and adults. *Developmental Psychobiology*, *53*, 47–58. DOI:10.1002/dev.20486.
- Carlier, M., Doyen, A.-L. & Lamard, C. (2006). Midline crossing: Developmental trend from 3 to 10 years of age in a preferential card-reaching task. *Brain and Cognition*, *61*, 255–261. DOI:10.1016/j.bandc.2006.01.007.
- Crollen, V., Dormal, G., Seron, X., Lepore, F. & Collignon, O. (2013). Embodied numbers: The role of vision in the development of number–space interactions. *Cortex*, *49*, 276–283. DOI:10.1016/j.cortex.2011.11.006.
- De Hevia, M. D., Girelli, L., Addabbo, M. & Macchi Cassia, V. (2014). Human infants' preference for left-to-right oriented increasing numerical sequences. *Plos One*, *9*(5), e96412. DOI:10.1371/journal.pone.0096412.
- Fagard, J. & Marks, A. (2000). Unimanual and bimanual tasks and the assessment of handedness in toddlers. *Developmental Science*, *3*, 137–147. DOI:10.1111/1467-7687.00107.
- Fischer, M. H., Mills, R. A. & Shaki, S. (2010). How to cook a SNARC: Number placement in text rapidly changes spatial–numerical associations. *Brain and Cognition*, *72*, 333–336. DOI:10.1016/j.bandc.2009.10.010.
- Fischer, M. H., Shaki, S. & Cruise, A. (2009). It takes just one word to quash a SNARC. *Experimental Psychology*, *56*, 361–366. DOI:10.1027/1618-3169.56.5.361.
- Hoffmann, D., Hornung, C., Martin, R. & Schiltz, C. (2013). Developing number–space associations: SNARC effects using a color discrimination task in 5-year-olds. *Journal of Experimental Child Psychology*, *116*, 775–791. DOI:10.1016/j.jecp.2013.07.013.
- Hung, Y., Hung, D. L., Tzeng, O. J.-L. & Wu, D. H. (2008). Flexible spatial mapping of different notations of numbers in Chinese readers. *Cognition*, *106*, 1441–1450. DOI:10.1016/j.cognition.2007.04.017.
- Knudsen, B., Fischer, M. H. & Aschersleben, G. (2015). Development of spatial preferences for counting and picture naming. *Psychological Research*, *79*, 939–949. DOI:10.1007/s00426-014-0623-z.
- Leconte, P. & Fagard, J. (2004). Influence of object spatial location and task complexity on children's use of their preferred hand depending on their handedness consistency. *Developmental Psychobiology*, *45*, 51–58. DOI:10.1002/dev.20019.
- McCrink, K. & Opfer, J. E. (2014). Development of spatial–numerical associations. *Current Directions in Psychological Science*, *23*, 439–445. DOI:10.1177/0963721414549751.
- Nuerk, H.-C., Patro, K., Cress, U., Schild, U., Friedrich, C. K. & Goebel, S. M. (2015). How space–number associations may be created in preliterate children: Six distinct mechanisms. *Frontiers in Psychology*, *6*, 215. DOI:10.3389/fpsyg.2015.00215.
- Opfer, J. E. & Furlong, E. E. (2011). How numbers bias preschoolers' spatial search. *Journal of Cross-Cultural Psychology*, *42*, 682–695. DOI:10.1177/0022022111406098.
- Opfer, J. E., & Thompson, C. A. (2006). Even early representations of numerical magnitude are spatially organized: Evidence for a directional magnitude bias in pre-reading preschoolers. In R. Sun, & N. Miyake (Eds.), *Proceedings of the 28th annual cognitive science society* (pp. 639–644). Mahwah, NJ: Erlbaum.
- Opfer, J. E., Thompson, C. A. & Furlong, E. E. (2010). Early development of spatial–numeric associations: Evidence from spatial and quantitative performance of preschoolers. *Developmental Science*, *13*, 761–771. DOI:10.1111/j.1467-7687.2009.00934.x.
- Patro, K., Fischer, U., Nuerk, H.-C. & Cress, U. (2016). How to rapidly construct a spatial–numerical representation in preliterate children (at least temporarily). *Developmental Science*, *1*, 126–144. DOI:10.1111/desc.12296.
- Patro, K. & Haman, M. (2012). The spatial–numerical congruity effect in preschoolers. *Journal of Experimental Child Psychology*, *111*, 534–542. DOI:10.1016/j.jecp.2011.09.006.

- Patro, K., Nuerk, H. & Cress, U. (2015). Does your body count? Embodied influences on the preferred counting direction of preschoolers. *Journal of Cognitive Psychology*, 27, 413–425. DOI:10.1080/20445911.2015.1008005.
- Patro, K., Nuerk, H., Cress, U. & Haman, M. (2014). How number–space relationships are assessed before formal schooling: A taxonomy proposal. *Frontiers in Psychology*, 5, 419. DOI:10.3389/fpsyg.2014.00419.
- Rinaldi, L., Gallucci, M. & Girelli, L. (2016). Spatial–numerical consistency impacts on preschoolers' numerical representation: Children can count on both peripersonal and personal space. *Cognitive Development*, 37, 9–17. DOI:10.1016/j.cogdev.2015.10.006.
- Sacrey, L. R., Arnold, B., Whishaw, I. Q. & Gonzalez, C. L. R. (2013). Precocious hand use preference in reach-to-eat behavior versus manual construction in 1-to 5-year-old children. *Developmental Psychobiology*, 55, 902–911. DOI:10.1002/dev.21083.
- Shaki, S., Fischer, M. H. & Goebel, S. M. (2012). Direction counts: A comparative study of spatially directional counting biases in cultures with different reading directions. *Journal of Experimental Child Psychology*, 112, 275–281. DOI:10.1016/j.jecp.2011.12.005.
- Shaki, S., Fischer, M. H. & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, 16, 328–331. DOI:10.3758/PBR.16.2.328.
- Slot, P. L. (2014). Early childhood education and care in the Netherlands (Doctoral thesis, Utrecht University, Utrecht, the Netherlands).
- Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review*, 25, 278–298. DOI:10.1016/j.dr.2005.11.001.
- Smith, L. B. & Gasser, M. (2005). The development of embodied cognition: Six lessons from babies. *Artificial Life*, 11, 13–29. DOI:10.1162/1064546053278973.
- Souza, R. M., De Azevedo Neto, R. M., Tudella, E. & Teixeira, L. A. (2012). Is early manual preference in infants defined by intermanual performance asymmetry in reaching? *Infant Behavior & Development*, 35, 742–750. DOI:10.1016/j.infbeh.2012.06.007.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9, 625–636. DOI:10.3758/BF03196322.
- Wood, G., Willmes, K., Nuerk, H.-C. & Fischer, M. H. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. *Psychology Science Quarterly*, 50, 489–525.
- Wynn, K. (1990). Children's understanding of counting. *Cognition*, 36, 155–193. DOI:10.1016/0010-0277(90)90003-3.