



# Spontaneous focusing on numerical order and numerical skills of 3- to 4-year-old children

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Accepted: 28 April 2024  
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## Abstract

Recent studies have highlighted the importance of ordinality skills in early numerical development. Here, we investigate individual differences in ordering sets of items and suggest that children might also differ in their tendency to spontaneously recognize and use numerical order in everyday situations. This study investigated the individual differences in 3- to 4-year-old children's tendency to spontaneously focus on numerical order (SFONO), and their association with early numerical skills. One hundred fifty children were presented with three SFONO tasks designed as play-like activities, where numerical order was one aspect that could be focused on. In addition, the children were administered tasks addressing spontaneous focusing on numerosity (SFON), numerical ordering, cardinality recognition, and number sequence production. Our results showed that children had substantial individual differences in all measures, including SFONO tendency. Children's SFONO tendency was associated with their early numerical skills. To further investigate the association between SFONO tendency and numerical ordering skills, a hierarchical regression was conducted for a group of children who could successfully order sets from one to three at a minimum and were regarded as likely having the requisite skills to spontaneously focus on numerical order. The findings reveal that SFONO tendency had a unique contribution to children's numerical ordering skills, even after controlling for age, cardinality recognition, and number sequence production. The results suggest that SFONO tendency potentially plays a relevant role in children's numerical development.

**Keywords** Early numerical skills · Spontaneous focusing on numerical order · Spontaneous focusing on numerosity · Ordinality · Children

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## 1 Introduction

Strong foundations for mathematical competence are built from a young age. Growing evidence suggests that numerical skills prior to school entry play a crucial role in later mathematical achievement (Duncan et al., 2007; Foster et al., 2015). Importantly, children who have lower numerical skills during preschool years often continue to struggle or even fall further behind their peers (Aunola et al., 2004; Jordan et al., 2009). Thus, it is highly important to investigate children's early numerical skills. Major milestones in numerical skills are achieved already around the age of three years, such as using counting to tell how many items there are in a set. These cardinality skills have been thoroughly investigated (Bermejo et al., 2004; Fuson, 1988; Mix et al., 2012; Wynn, 1992), while another important early milestone, understanding the ordinality of numbers (e.g., six comes one after five and one before seven), has gotten much less attention (Lyons et al., 2016).

Studies have highlighted the importance of cardinality and ordinality skills for later mathematical achievement (Liang et al., 2023; Lyons et al., 2014; Malone et al., 2021; Sasanguie & Vos, 2018; Xu & LeFevre, 2021), and they are suggested to be separate constructs of early numeracy (for a review, see Devlin et al., 2022). Already from the age of 5 years, ordinality skills seem to be a stronger predictor of later mathematical skills than cardinality (Liang et al., 2023; Lyons et al., 2014; Sasanguie & Vos, 2018). Although cardinality certainly remains important as a foundational skill, ordinality may play a crucial role in understanding how numbers are related to each other and how they form a coherent system (Fuson, 1988; Gattas et al., 2021; Lyons et al., 2016).

However, it is not only the learning of numerical skills in adult-guided situations that play a role in children's numerical development. Some children tend to focus on and use numerical information in mathematically non-explicit situations spontaneously (i.e., in a self-initiated way) more than others, which has been associated with better concurrent and later mathematical skills (Hannula & Lehtinen, 2005; McMullen et al., 2019; Verschaffel et al., 2020). Especially relevant in young children's numerical development is their spontaneous focusing on numerosity (SFON), which develops reciprocally with cardinality and counting skills (Hannula & Lehtinen, 2005; Poltz et al., 2022). However, there is little knowledge about when and how children focus spontaneously on numerical information concerning ordinality of numbers, such as numerical order. Given the importance of ordinality understanding, it may be assumed that children's tendency to spontaneously focus on numerical order may also play a crucial role in their mathematical development. Thus, the aim of the present study is to investigate individual differences in children's spontaneous focusing on numerical order (SFONO) and how these differences relate to numerical skills.

### 1.1 The role of ordinality skills in numerical development

While cardinality skills refer to being able to define how many items there are in a set, there are three aspects to ordinality skills: understanding numerical relations, numerical ordering, and using ordinal number words (Fuson, 1988). The three aspects to ordinality skills are distinguishable, yet intertwined: the repeated use of numerical relations (e.g., seven is more than five/seven comes after five) results in numerical ordering, where ordinal number words can be used to tell the relative position of one item with respect to the other items (Fuson, 1988). Put together, situations where ordinality skills are used might be more complex than those involving cardinality skills, as they require considering items

in relation to one another within a set (Fuson, 1988), and thus a complete understanding of ordinality goes beyond mere recitation of the number sequence.

Recent studies on ordinality skills have mainly focused on numerical ordering of number symbols by measuring participants' ability to judge whether number symbols are in numerical order (Gattas et al., 2021; Goffin & Ansari, 2016; Hutchison et al., 2022; Lyons & Beilock, 2009, 2011; Malone et al., 2021; Turconi et al., 2006), or on their ability to order visually presented number symbols (O'Connor et al., 2018; Xu et al., 2023; Xu & LeFevre, 2021). For example, Liang et al. (2023) observed that the ability to order number symbols predicted the growth of mathematical competence over cardinality skills already from the age of 4 to the age of 5 years, whereas from the age of 3 to 4 years, they observed the opposite. It is suggested that more advanced numerical skills, such as arithmetical skills, might rely more on ordinal information of numbers instead of cardinal information (Liang et al., 2023; Lyons et al., 2014, 2016).

Understanding the ordinality of numbers may be crucial for understanding the logic of the number system (Gattas et al., 2021; Geary, 2013; Lyons et al., 2016). This induction does not automatically follow from learning to recite the number sequence and recognize cardinal values, since studies suggest that after acquiring these skills, children still lack the knowledge of how the number sequence and cardinal values are connected (Cheung et al., 2017; Davidson et al., 2012; Spaepen et al., 2018). According to Geary (2013), one of the first indications of a coherent understanding of the number system is learning that magnitudes can be systematically ordered by their cardinal values. It may be, that non-symbolic numerical ordering requires children to consider the exact relations between cardinal values (Spaepen et al., 2018), which could contribute in understanding the link between number sequence and cardinal values. Considering this, it is surprising that fewer studies have investigated ordinality skills from the aspect of non-symbolic numerical ordering, which involves arranging sets of pictures or dots in numerical order (Berteletti et al., 2010; Purpura & Lonigan, 2013; Spaepen et al., 2018). Nonetheless, non-symbolic numerical ordering has been positively associated with various early numerical skills, for example, estimation accuracy in a number line task among children aged from 3.5 to 6.5 years (Berteletti et al., 2010), as well as with symbolic number ordering, addition, and subtraction in 3- to 6-year-old children (Purpura & Lonigan, 2013). However, non-symbolic numerical ordering was not the main variable of interest in these studies, and the results are correlational.

According to Cheung and Lourenco (2019), numerical ordering tasks with number symbols can be solved by comparing magnitudes between the numbers or by relying on memory of the number sequence (e.g., 2 comes before 3). However, these two strategies can also be applied to numerically order non-symbolic sets (Fuson, 1988). Furthermore, number symbols are embedded with magnitude information. Taken together, symbolic and non-symbolic numerical ordering might be inherently related. In the current study, ordinality skills are examined from the less explored aspect of non-symbolic numerical ordering, which involves arranging sets of items in numerical order. This approach is taken, since it might be more closely related to the conceptual understanding of ordinality among young children (Fuson, 1988).

## 1.2 Spontaneous focusing on numerosity in early numerical development

SFON refers to an attentional process of spontaneously (i.e., in a self-initiated way, not prompted by others) focusing attention on the exact number of a set of items, and using this information in action in situations that are not explicitly mathematical (Hannula et al.,

2010). For example, noticing that there are exactly three apples in a fruit basket and verbalizing that to others. It is not self-evident that children who have the necessary skills to focus on the exact number of items when guided to do so, also do so spontaneously. Studies show that there are substantial individual differences in children's SFON tendency, which are not entirely explained by their existing mathematical or cognitive skills (Batchelor et al., 2015; Bojorque et al., 2017; Gray & Reeve, 2016; Hannula et al., 2010; Hannula & Lehtinen, 2005; McMullen et al., 2015; Rathé et al., 2019).

SFON tendency may support children's acquisition of self-initiated practice in using their numerical skills in their everyday lives (Hannula & Lehtinen, 2005). Children with a higher SFON tendency acquire more practice in their numerical skills, potentially leading to better mathematical skills. Previous studies have shown that individual differences in SFON tendency are positively related to children's early numerical skills (Gray & Reeve, 2016; Hannula et al., 2007; Hannula & Lehtinen, 2005; Poltz et al., 2022; Silver et al., 2020) and predict later mathematical performance (Batchelor et al., 2015; Gloor et al., 2021; Hannula et al., 2010; Hannula-Sormunen et al., 2015; Lepola & Hannula-Sormunen, 2019; McMullen et al., 2015; Nanu et al., 2018). For example, Hannula and Lehtinen (2005) found in their longitudinal study of 3.5- to 6-year-old children, that SFON and early numerical skills developed reciprocally, with each predicting the other over time.

SFON tendency has been shown to be independent of multiple potential requisite skills (Hannula & Lehtinen, 2005; Nanu et al., 2018; Poltz et al., 2022). These skills include domain-specific skills such as cardinality recognition and counting skills, as well as domain-general skills such as general attention and instruction comprehension (Hannula et al., 2010). To ensure that SFON tasks truly capture children's SFON tendency, several principles need to be followed within task design (Hannula, 2005; Hannula & Lehtinen, 2005). First, the tasks should be mathematically unspecified and open for multiple (numerical and non-numerical) interpretations. This means that the task contexts or testers should not provide any hints towards the numerical aspects, the tasks or the material should not be associated with typical numerical activities (e.g., counting money), and there should be multiple options for actions for children in the tasks. This way, it is possible to capture children's spontaneous focusing. Second, the tasks should sustain children's general attention and situational interest and contain only such small numerosities that are possible for all children to enumerate. This ensures that individual differences in SFON tendency are not due to the requisite skills needed in the tasks. Third, using multiple tasks with different task contexts and considering additional numerical behaviors that reveal the numerical focus of the child as indicators of SFON are crucial for a valid assessment of children's SFON tendency.

Over the last decade, research on SFON has been expanded to cover also other mathematical aspects children can focus on spontaneously. These studies have found individual differences in spontaneous focusing on quantitative relations (SFOR) (McMullen et al., 2014), Arabic number symbols (Rathé et al., 2019), and mathematical patterns (SFOP) (Wijns et al., 2020), which are also associated with better mathematical skills. One explanation for the relation between these spontaneous mathematical focusing tendencies and later mathematical skills is, that children with a higher tendency to spontaneously recognize and use mathematical features in non-explicitly mathematical situations, may gain more self-initiated practice with their mathematical skills (for a review, see McMullen et al., 2019). We suggest that there may be similar individual differences in how children focus on another numerical aspect, numerical order, more specifically the ordering of sets of items based on their cardinal values, which might be associated with their ordinality understanding.

### 1.3 Spontaneous focusing on numerical order

To our knowledge, only a few studies have investigated children's focusing on numerical order. Sharir and Mevarech (2022) examined 4- to 6-year-old children's spontaneous recognition of mathematical structures, including "arithmetic series," which included recognizing that sets of items were arranged in numerical order. Their results indicated that children's spontaneous focusing on mathematical structures was associated with better mathematical achievement, but the specific relation between spontaneous focusing on arithmetic series and mathematical achievement was not examined. As well, the numerical order aspect was highly salient in the tasks. Harju et al. (2022) showed that 3- to 6-year-old children had individual differences in focusing on numerical order, and focusing on numerical order at the age of five predicted mathematical achievement at the age of 12 years. However, focusing on numerical order was measured with only one task with some numerical hints, and the sample size was small, so the results were preliminary.

### 1.4 Present study

While previous studies on the role of ordinality in the development of early numerical skills have mainly used tasks which guide children's attention towards numerical order, the present study uses tasks which leave the numerical order aspect for the children to notice. These novel tasks were developed according to the methodological criteria for SFON measures (Hannula, 2005; Hannula & Lehtinen, 2005) and piloted prior to the start of the data gathering.

The aim of the present study was to investigate 3- to 4-year-old children's SFONO tendency and its relation to early numerical skills. To do so, we measured children's early numerical skills, including SFON tendency, numerical ordering skills, cardinality recognition, and number sequence production.

There were two research questions:

1. *What kind of individual differences are there in 3- to 4-year-old children's SFONO tendency?*
2. *How is SFONO tendency related to SFON tendency and early numerical skills?*

## 2 Methods

The current study is part of a larger research project called FONO (focusing on numerical order) following children's numerical development for 1.5 years, and the data presented here is from the first measurement point of the longitudinal study.

### 2.1 Participants

Participants were 150 children aged 3 years 5 months to 4 years 9 months ( $M = 4$  years 1 month,  $SD = 4$  months, 77 boys) from 13 daycare centers located in urban middle-income areas of south-western Finland. All children had Finnish as their first language and they did not have any diagnosed need for special support. The educational level reported by parents was below upper secondary in mothers 0.8% and in fathers 3.8%, upper secondary in

mothers 16.7% and in fathers 29.0%, and tertiary education in mothers 82.6% and in fathers 66.9%. The educational level of the parents, on average, exceeded that of the corresponding Finnish men and women (Statistics Finland, n.d.).

Ethics approval was obtained from the Ethics Committee for Human Sciences of the University of Turku, and required research permissions were asked from participating cities, daycare centers, and parents. Children gave their verbal assent to participate. All daycare centers were asked for their willingness to participate in the study, and teacher's help was used to find children fulfilling the inclusion criteria (age range, no diagnosed need for special support, native Finnish speaker). The data was gathered during spring (March–May) and autumn (September–October) of 2022.

## 2.2 Procedure

The children were assessed individually in two 30-min video-recorded sessions in a separate room at their own daycare center during the same day. Both sessions included short 2- to 3-min physical break activities between tasks (e.g., jumping like bunnies), and a longer (30-min) break between the sessions. The experimenter wore a face mask. The first session included tasks in the following order: SFON Bird imitation task, SFONO Duck family production task, SFON Postbox imitation task, and SFONO Tower building production task. The second session included measures of SFONO Find the mother reproduction task, numerical ordering, cardinality recognition, and number sequence production. The testing sessions were checked from the video recordings subsequently throughout the testing period by the experimenter and co-authors.

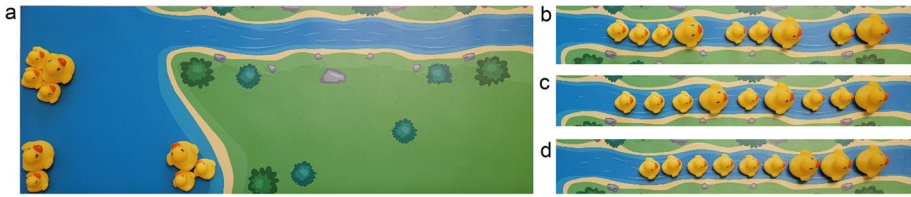
To ensure capturing children's spontaneous focusing on numerical aspects, children should not be aware of the mathematical nature of the tasks when they come to testing (e.g., Hannula & Lehtinen, 2005; Hannula-Sormunen, 2015). To conceal the numerical aspect of the study, the participating daycare centers and the parents were told that the assessments would cover different cognitive skills without specifying mathematics. The daycare center personnel were asked to help to ensure that the children did not talk to each other about the tasks and to guide children's talking about the tasks towards the physical break activities rather than other tasks. In addition, the experimenter made sure that the testing room did not have any numerical displays that could potentially draw the child's attention to numbers or assist them in solving the numerical tasks. The SFON and SFONO tasks were conducted before the explicit numerical tasks. Additionally, the experimenter did not use any phrases before or during the SFON and SFONO tasks that included number, counting, or other mathematical concepts (Hannula & Lehtinen, 2005). No specific feedback was given during the tasks.

## 2.3 Measures

### 2.3.1 SFONO tendency

Children's SFONO tendency was measured with two production tasks, the Duck family task and the Tower building task, and with one reproduction task, the Find the mother task.

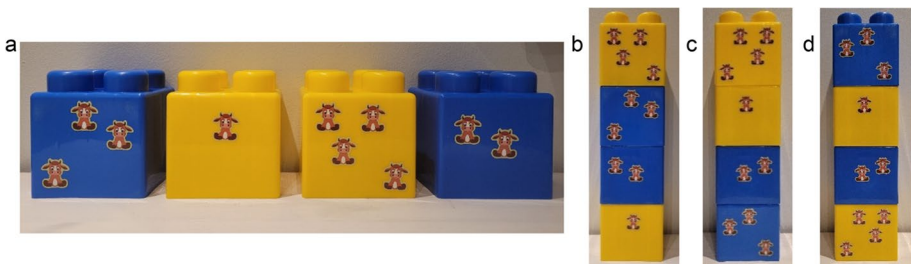
**Duck family task** In the Duck family task, the child was presented with a picture of a pond and a river, and three rubber duck families that were placed on the pond. Each family had a mother duck, and ducklings (see Fig. 1). The number of ducklings was different in each



**Fig. 1** Set up and the material in the Duck family task (a). The children showed several different outcomes in the task, for example, putting the families on the river in numerical order (regarded as SFONO) (b), in a mixed order (c), or in an order based on the size of the ducks (d)

family, and the numbers were consecutive (e.g., families had 1, 2, and 3 ducklings). The experimenter introduced the material to the child by saying: “Here is a pond, and here is a river. Here is this family, mother duck and its ducklings. Here is this family, mother duck and its ducklings. Here is this family.”, and pointed towards the material. After that, the child was told that all the duck families wanted to go swim on the river, and asked to help them out. In addition, the child was told that the ducklings could not swim alone, and they had to swim with their mother, to prevent the child from mixing up the families. The order of the families on the pond was the same for all the children, the families were not in numerical order at the start of the task, and the family with the least ducklings was never closest to the child. The task had three trials, and each trial had different colored rubber ducks. The numbers of ducklings in the first and third trials were 1–3, and 2–4 in the second trial.

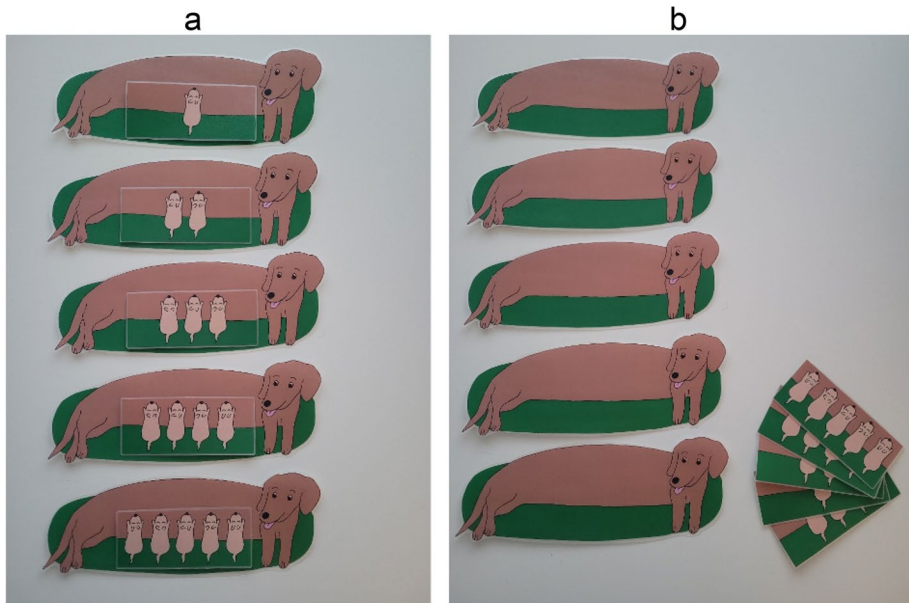
**Tower building task** The Tower building task was an adaptation of the Wijns et al. (2020) construction task. In this task, the child was shown four blocks with a unique number of animal stickers on one side (see Fig. 2). All the trials had blocks of two different colors. The experimenter began the task by showing each block individually to the child by saying for each block “Here is this block, it has cows.” The blocks were put on the table in a row in front of the child, with the sticker sides facing the child. After this, the child was asked to build a tower going straight up, using all the blocks. The first trial had two yellow and two blue blocks with 1–4 cow stickers, the second trial had red and blue blocks with 2–5 horse stickers, and the third trial had red and yellow blocks with 1–4 lamb stickers. The blocks were never put on the table in numerical order, and the block with the least or the



**Fig. 2** Set up and the material in the Tower building task (a). Children showed several different outcomes in the task, for example, building the tower in numerical order based on the number of stickers (regarded as SFONO) (b), by putting together the blocks with the same color (c), or by making a pattern from the colors (d)

most stickers was never on either edge of the block arrangement on the table. The stickers on the blocks were not arranged in the same patterns as in a dice, to avoid hinting towards the numerical nature of the task.

**Find the mother task** In the Find the mother task (adapted from Harju et al., 2022), the child was first presented with five similar mother dogs, that each had a unique number of puppies. The task material was five laminated dog figures, and five puppy cards that each had a set of 1–5 similar puppies on a horizontal row, that fit on top of the mother figures (see Fig. 3a). The task started by placing the mother dog figures in a vertical line on the table in front of the child. Then the child was told that the dogs had puppies, and each set of puppies was placed on its own place by saying: “These puppies are this mother dog’s puppies.” When all sets of puppies were with their own mothers, the puppies formed a numerical order from the set of one puppy on top, to the set of five puppies on the bottom. The sets of puppies were placed with their mothers in a mixed order, and the numerical order was left for the child to notice. After placing all the puppies with their mothers, the experimenter told the child to: “Look carefully, so that you will soon remember which mother dog the puppies belong to.”, and pointed at each mother from top to bottom. After this, the child was told that the puppies go to play, and the puppy cards were collected in a pile in a mixed order. The experimenter took the puppies in their lap, and mixed the puppy cards while making playful sounds. After this, the child was told that “the puppies want to go to their own mother,” and was asked to help them out. The pile of puppy cards was spread like a fan, and it was placed in front of the child, on the right side of mother dogs (see Fig. 3b). The next trials included pigs with 2–6 piglets, and cats with 1–5 kittens.



**Fig. 3** The material for the first trial of the Find the mother task, the placement of the puppy cards shown to the child during the task instruction (a), and the final setup of the task (b)

**Scoring** Video recordings of the three SFONO tasks were analyzed in order to determine the children's different behavioral manifestations of SFONO. Based on previous research (Hannula & Lehtinen, 2005), we propose children may show the following manifestations of SFONO: (1) arranging sets of items in ascending/descending numerical order without any additional numerical behavior, (2) arranging sets of items in ascending/descending numerical order with indications of numerical behavior, or (3) not arranging sets of items in numerical order, but showing other indications of noticing the numerical order aspect in the task. The analysis of the video recordings involved coding children's:

- Outcomes (the order produced)
- Numerical behavior such as the use of number words, signs of counting (e.g., showing numbers with fingers, whispered number sequence and pointing acts, interpreting the goal of the task as quantitative)
- Indications of recognizing the numerical order in the task, such as the following:
  - a. Verbal and/or behavioral indications of recognition of numerical order (e.g., “*Hey, there is one, two, three!* (while pointing at the sets of items in numerical order)”)
  - b. Comments referring to the number sequence (e.g., “*After two comes three.*”).
  - c. Interpreting of the goal of the task as numerical ordering (e.g., “*These should be in the same order as numbers.*”)

Each of these numerical behaviors and indications of recognizing the numerical order in the task was coded as 1 if it occurred in a trial and as 0 if it did not occur.

Each task had three trials. The maximum SFONO score from each trial was 1, which was given if children produced an ascending or descending numerical order in the task, or showed any of the above-mentioned indications (a-c) of recognition of the numerical order in the task. In addition, we found two task-related behaviors that were included in the criteria for SFONO score. In the Duck family task, it was possible for children to take the sets of items in numerical order without producing a numerical order in the task; these children were also given a SFONO score of 1 from the trial. In the Find the mother task, there were five sets of items to order. Some children could start by correctly ordering the smallest numbers but ended up making a mistake with the larger numbers. Children who ordered correctly a minimum of three consecutive sets of items with the smallest numbers in the task were also given a SFONO score.

To get an indicator of children's SFONO tendency, a sum score of all the items was calculated. However, it was observed that the first item of the Duck family task did not correlate well with other items (inter-item correlations  $< .19$ ). A qualitative look at the first item of the Duck family task revealed that children had exceptionally many SFONO answers in the first item compared to the two other items in the Duck family task. In addition, it was observed that almost all produced numerical orders in the first item were descending (i.e., 3-2-1) rather than ascending (i.e., 1-2-3), which might be a result of the family of three ducklings being closest to the child in the starting position. Because of these quantitative and qualitative issues, the first item of the Duck family task was not further used. This resulted in a maximum score of 8, with Cronbach's alpha of .75 for the eight items. Two researchers independently analyzed 20 children's task videos for all variables that were coded from the SFONO tasks. Inter-rater reliabilities for the three tasks were .98, .98, and .96, respectively, indicating high inter-rater reliability.

### 2.3.2 SFON tendency

Two imitation tasks, the Bird task and the Postbox task (Hannula & Lehtinen, 2005), were used to measure children's SFON tendency.

**Bird imitation task** The Bird imitation task material included a blue toy parrot and three boxes of ten glass berries in three different colors. The toy parrot was sitting on a table in front of the child, and a box of ten yellow berries was placed in front of the bird. The experimenter introduced the task material to the child and asked the child to "Look carefully what I do, and then you do just as I did." Then the experimenter inserted two berries, one at a time, with a large hand movement into the parrot's mouth, from which the berries fell, bumping into the parrot's stomach, where they could not be seen. Then the child was given instruction "Now, you do just as I did." The following trials included three blue and two green berries.

**Postbox imitation task** In the Postbox imitation task, the material was a yellow postbox, and six piles of ten blank closed envelopes, each in a different color. The postbox was sitting on the table in front of the child, and in each trial, two piles of envelopes, orange and green in the first trial, were placed in front of the postbox. The experimenter introduced the task material to the child and told the child to "Look carefully what I do, and then you do just as I did." Then the experimenter took one orange letter and two green letters, one at a time, and put them into the postbox with a large hand movement. Then the child was told to do exactly as the experimenter had done. Two brown and three yellow envelopes, and three blue and two pink envelopes were used in the following trials.

**Scoring** As in Hannula and Lehtinen (2005), the analysis of the video recordings of the tasks involved identifying

all the child's (a) utterances including number words (e.g., "I'll give him two berries"), (b) use of fingers to express numerosities, (c) counting acts such as a whispered number word sequence and indicating acts by fingers, (d) other comments referring to either exact quantities or counting (e.g., "Oh, I miscounted them"), and (e) interpretations of the task's goal as quantitative (e.g., "I gave an exactly accurate number of them"). (pp. 240–241)

The maximum score in one trial was 1, which was given if children produced the same numerosity in the task as the experimenter and/or presented any of the quantifying acts (a-e) (Hannula & Lehtinen, 2005). To get an indicator of children's SFON tendency, a sum score of all the items was calculated. This resulted in a maximum sum score of 6, with Cronbach's alpha of .69. The inter-rater reliability based on 20 children's data were 1.00 and .99.

### 2.3.3 Numerical skills

**Numerical ordering skills** Children's numerical ordering was assessed with an adaptation from the "Ordering task" (Spaepen et al., 2018). In the task, children were presented with a set of cards, each representing a different number of red dots. The cards were put on the table in a randomized order, so that the child could see all the cards in the set. The child was then told to look at the cards with different numbers of dots on the table and asked to

put the cards in order of magnitude. Then the experimenter indicated that the card with the least dots should go to the child's left, then the next cards to the right side of the previous card, the last card being the one with the most dots, forming a line of cards.

The trials were with sets of cards of 1–3, 1–5, 1–7, and 2–5 dots in this order. If the child could not place the card with the least dots first, the trial was repeated with the help of the experimenter showing the place of the first card. If the child could not correctly order cards with 1–3 or 1–5 dots, or the only correct answer in these two trials was in the first trial with the help of the experimenter, the task was stopped. Otherwise, the child was presented with the last two trials. Children were given a score from each trial equal to the highest number up to which they placed the cards in the correct numerical order. If all the cards in the trial were correctly ordered, the maximum score of the trial was the number of cards minus one (e.g., in trial with 1–3 cards, the maximum score was 2 instead of 3, since correctly ordering the cards 1–2 results in correctly placing the last card). For analysis, the sum score was calculated. The maximum score in the task was 15. Cronbach's alpha for the four trials was .83.

**Cardinality skills** Children's cardinality recognition was measured with a "Give-a-number" task (Wynn, 1990). In the task, the child was asked to take a specific number of items from a box and put them on the table. The numbers in the trials were 2, 3, 5, 7, 9, 13, 19, and 23. The task material included eight different sets of wooden figures, one for every trial. If the child put the wrong number of items on the table, the trial was repeated once. The task was discontinued after two failed attempts in one number. Correctly produced number in the first or second attempt was given a score of 1. For analysis, a sum score was calculated, resulting in a maximum score of 8. Cronbach's alpha of the task was .83.

**Number sequence production** To assess number word sequence production, children were asked to count as far as they could (Salonen et al., 1994). The highest number up to which the child could correctly count aloud in one of two trials determined the score in the task. The counting was stopped at 50, which was the maximum score of the task.

## 2.4 Data analysis

A descriptive analysis was run to investigate the individual differences (IBM SPSS Statistics Version 28). Since the normality assumption of the variables was not met, the Spearman correlations were conducted to examine the relations between variables. Partial correlations controlling for age were conducted to see whether the correlations remained significant after controlling for age. To look at how SFONO tendency is uniquely associated with numerical ordering skills, a hierarchical regression analysis was conducted.

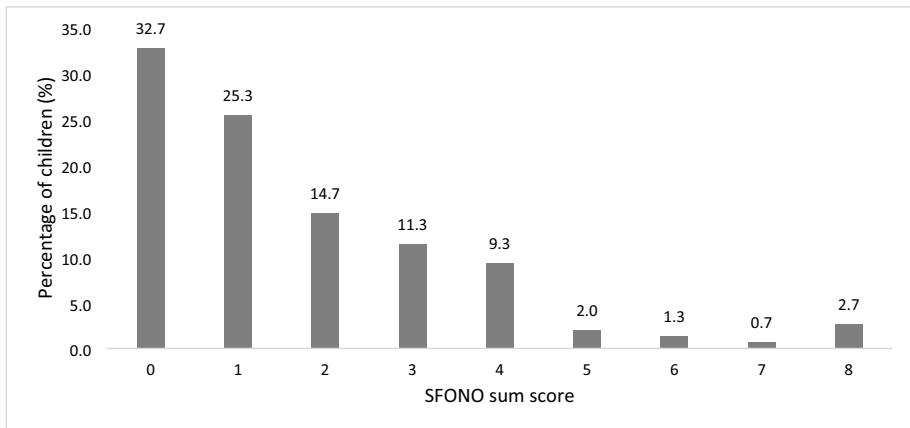
## 3 Results

### 3.1 Descriptive analyses

Frequencies of children's SFONO scores (Table 1) and SFONO tendency (Fig. 4), showed substantial individual differences in children's SFONO. The most SFONO was found in the Find the mother task (Table 1). Less SFONO was observed in the Duck family task and in

**Table 1** Frequencies (and percentages of the sample) of Spontaneous Focusing On Numerical Order in the SFONO tasks ( $N = 150$ )

SFONO score	Duck family task	Tower building task	Find the mother task
0	124 (82.7%)	117 (78.0%)	60 (40%)
1	22 (14.7%)	16 (10.7%)	40 (26.7%)
2	4 (2.7%)	8 (5.3%)	24 (16.0%)
3		9 (6.0%)	26 (17.3%)

**Fig. 4** Frequencies of children's SFONO tendency

the Tower building task. As seen from Table 2, children also had large individual differences in their other measured numerical skills.

To investigate how children showed SFONO in their behavior, we counted the frequencies of their different numerical behavioral manifestations in each of the SFONO tasks (Table 3). Results show that even though there were trials when children arranged sets of items in numerical order without giving any additional information about their thoughts during the task, there were also several trials including numerical behavior (e.g., used counting in the task, or said number words related to the task) in addition to arranging sets of items in numerical order in the task. Additionally, there were several trials where children did not arrange the sets in numerical order but showed verbally or with gestures that they had focused spontaneously on the numerical order in the task.

**Table 2** Descriptive statistics of the variables

	<i>N</i>	<i>M</i>	<i>SD</i>	<i>Skewness</i>	<i>Kurtosis</i>	<i>Range</i>
Age in months	150	49.32	3.76	0.23	-0.86	41.10–57.07
SFONO tendency	150	1.70	1.87	1.42	2.07	0–8
SFON tendency	150	1.48	1.62	0.79	-0.49	0–6
Numerical ordering	148	6.10	5.41	0.52	-1.18	0–15
Cardinality recognition	150	3.57	2.07	0.17	-0.85	0–8
Number sequence production	149	14.10	7.72	1.27	2.82	2–50

**Table 3** Frequencies of observed behavioral manifestations of SFONO in trials and number of children showing them (in parenthesis)

	Duck family task	Tower building task	Find the mother task
<b>Arranging sets of items in numerical order without any additional numerical behavior</b>	<b>3 (3)</b>	<b>8 (4)</b>	<b>53 (44)</b>
<b>Arranging sets of items in numerical order with indications of numerical behavior</b>	<b>10 (4)</b>	<b>83 (22)</b>	<b>162 (50)</b>
Recognition of numerical order	0	1 (1)	3 (3)
Verbalizing numerical ordering as the goal of the task	0	7 (6)	3 (3)
Referring to number sequence	1 (1)	9 (8)	16 (14)
Saying cardinal number words	5 (4)	38 (21)	84 (48)
Showing signs of counting	3 (3)	27 (17)	53 (36)
Saying ordinal number words	0	0	2 (2)
Comparing numerosities	1 (1)	1 (1)	1 (1)
<b>Not arranging in numerical order, but other indications of noticing the numerical order</b>	<b>24 (18)</b>	<b>14 (9)</b>	<b>28 (24)</b>
Recognition of numerical order	8 (6)	10 (9)	2 (2)
Verbalizing numerical ordering as the goal of the task	1 (1)	3 (1)	1 (1)
Referring to number sequence	3 (2)	1 (1)	10 (10)
Taking subsets in numerical order <sup>1</sup>	4 (4)		
End result is a numerical order <sup>1</sup>	8 (8)		
Begins with numerical order <sup>2</sup>			15 (15)

<sup>1</sup>Only in the Duck family task

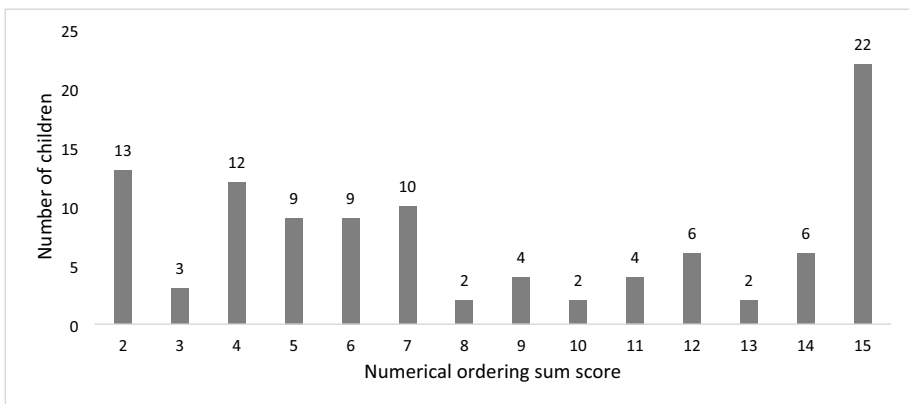
<sup>2</sup>Only in the Find the mother task

### 3.2 Associations between SFONO, SFON, and numerical skills

To ensure that the individual differences measured with the SFONO tasks were due to individual differences in SFONO tendency and not the requisite skills needed to spontaneously focus on numerical order in the tasks, we conducted subsequent analyses on a subset of children who demonstrated the skills to successfully order sets of one to three dots numerically. In this sample ( $n = 105$ ), children had large individual differences in their numerical ordering skills, from 15% of the children only being able to order cards from one to three to 21% of the children completing the task with a maximum sum score (see Fig. 5).

The Spearman correlations (Table 4) show that SFONO tendency was positively correlated with numerical ordering, cardinality recognition, and number sequence production in the subsample. Importantly, the correlations remained significant even after controlling for age. The correlation between SFONO and SFON tendencies was not significant. However, with the full sample, SFON tendency correlated positively with SFONO tendency and all numerical skills (see Appendix Tables 6 and 7 for the results with the whole sample). All measured numerical skills correlated with each other, and all variables were positively correlated with age.

Since it was hypothesized that SFONO tendency might be closely associated with numerical ordering skills, a hierarchical regression analysis was performed with numerical ordering as the dependent variable. Since age was highly correlated with all the numerical skill measures, we controlled for age by entering it first. Next, we added children's number sequence production and cardinality recognition as control variables in the first step to separate variation explained by SFONO tendency from that of numerical skills. Since previous research has consistently demonstrated a positive association between SFON and numerical skills, we included SFON as a predictor in the second step. Lastly, SFONO tendency was entered in the third step. As shown in Table 5, SFONO tendency had a unique contribution to numerical ordering skills, explaining 2% of the variance in children's numerical ordering performance. SFON tendency was not a significant contributor in children's performance in numerical ordering.



**Fig. 5** Distribution of total scores in children who could successfully arrange sets of one to three dots ( $n = 105$ )

**Table 4** The Spearman correlations (below diagonal) and partial Spearman correlations controlling for age (above diagonal) between the variables ( $n = 105$ )<sup>1</sup>

Variable	<i>M</i>	<i>SD</i>	1.	2.	3.	4.	5.	6.
1. Age in months	50.17	3.72	-	-	-	-	-	-
2. SFONO tendency	2.02	1.96	.35***	-	.00	.42***	.39***	.39***
3. SFON tendency	1.64	1.71	.22*	.10	-	.07	.14	.05
4. Numerical ordering	8.46	4.75	.41***	.51***	.16	-	.57***	.53***
5. Cardinality recognition	4.15	1.96	.38***	.47***	.22*	.64***	-	.74***
6. Number sequence production	15.75	7.91	.40***	.49***	.15	.61***	.77***	-

\* $p < 0.05$ ; \*\*\* $p < 0.001$ <sup>1</sup>Missing data in numerical ordering ( $n = 1$ ), and in number sequence production ( $n = 1$ )**Table 5** Hierarchical regression analysis examining the unique relation of SFONO sum score to children's numerical ordering skills ( $n = 103$ )

	$\beta$	$\Delta R^2$
Step 1		.45***
Age	.23**	
Number sequence production	.18	
Cardinality recognition	.41***	
Step 2		.00
Age	.23**	
Number sequence production	.18	
Cardinality recognition	.41***	
SFON tendency	-.03	
Step 3		.02*
Age	.20*	
Number sequence production	.12	
Cardinality recognition	.38**	
SFON tendency	-.02	
SFONO tendency	.18*	
	$F(5,97) = 17.73***, R^2 = .48$	

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ 

## 4 Discussion

The aim of the present study was to examine children's spontaneous focusing on numerical order and how it relates to early numerical skills. Our findings show that there are substantial individual differences in children's spontaneous focusing on numerical order in situations that are not explicitly mathematical, which we refer to as SFONO tendency. Furthermore, our results suggest that these individual differences relate to early numerical skills, especially numerical ordering skills.

Similar to previous studies on SFON (Hannula & Lehtinen, 2005) and other spontaneous mathematical focusing tendencies (McMullen et al., 2019; Verschaffel et al., 2020), we found large individual differences in children's SFONO tendency. We consider that

the individual differences found in performance on the SFONO tasks were highly likely due to individual differences in SFONO tendency, even though there are some requisite skills (i.e., recognizing small cardinal values, counting skills, ordering numerically small sets of items) involved in the process of spontaneously focusing on numerical order. We have several reasons to support this interpretation. First, the SFONO tasks did not have any indications towards the numerical aspects and were open for several numerical and non-numerical interpretations. Second, the tasks only included sets of items that had numerosities within the children's numerical ordering competencies, especially when taking into consideration that the children could receive SFONO scores even by only ordering the first three sets correctly. As well, there remained substantial individual differences in children's SFONO tendency within the subsample of children who had the necessary skills to order at least the sets of one to three numerically when guided to do so. Third, in addition to producing numerical order in the SFONO tasks, children's other behavioral indications of noticing the numerical order aspect in the tasks were regarded as indications of SFONO. In conclusion, our results indicate that we were able to separately measure children's SFONO tendency.

As hypothesized, we found strong associations between SFONO tendency and all early numerical skills, even after controlling for age. Importantly, our results indicated that SFONO tendency was uniquely associated with children's numerical ordering skills after controlling for age, number sequence production, cardinality recognition, and SFON tendency. It is probable it was the individual differences in SFONO tendency that accounted for the unique association, since only a subsample of children who had the requisite numerical ordering skills were included in the analysis. This result indicates that SFONO tendency might be especially important in children's developing ordinality skills, analogous to the role of SFON in the development of cardinality skills (Hannula & Lehtinen, 2005; Poltz et al., 2022). However, our findings are cross-sectional, and therefore future research should examine the development of SFONO tendency and its role in numerical development.

SFONO tendency had stronger associations with numerical ordering, number sequence production, and even cardinality recognition than SFON tendency. This might indicate that SFONO requires more advanced numerical skills than SFON, such as understanding that numbers can be ordered based on their cardinal value and reasoning about exact numerical relations between sets of items. In fact, some studies suggest that children have to develop adequate cardinality skills in order to begin to understand how numbers can be ordered based on their magnitudes (Cheung et al., 2017; Davidson et al., 2012; Spaepen et al., 2018). Our findings align with this suggestion, as they demonstrated that cardinality skills explained the majority of the variance in children's numerical ordering performance. Children who spontaneously focused on numerical order in the SFONO tasks could be seen as engaging with more complex numerical aspects beyond exact number. Thus, we hypothesize that children with higher SFONO tendency may be more inclined to recognize and use numerical order in everyday situations after acquiring the requisite basic numerical ordering skills, and thereby gain self-initiated practice with more advanced numerical skills. This might explain why children who spontaneously focused more on numerical order also had better numerical skills.

The association between SFONO and SFON tendencies was rather low in the whole sample. However, the association was non-significant in the analysis with the subsample.

This could be considered as preliminary evidence that the SFONO tasks are measuring a separate numerical focusing tendency than the SFON tasks. However, the results need to be treated with caution for several reasons. First, SFON tendency had weaker correlations with numerical skills within the whole sample (see Appendix Table 6) in our study than previous studies on SFON (e.g., Hannula & Lehtinen, 2005; Nanu et al., 2018; Silver et al., 2020). One potential reason for this could be limited variation in our measures. This study is a part of a longitudinal research project and the first measurement point was planned to catch the start of the development of children's emerging ordinality skills, potentially limiting the variation in the tasks. Second, the low association between SFONO and SFON tendencies might be due to having different set sizes in the tasks. Third, it is possible that some children used approximation in the SFONO tasks to create a quantitative order (i.e., least, more, most), or mixed exact enumeration and quantitative strategies in order to create a numerical order out of the sets. Our tasks did not control for the surface areas of the sets, which might lead to children using them as a cue to order the sets instead of recognizing the exact number of items of each set. However, we observed that many children showed numerical behavior (e.g., said number words, used counting) during the SFONO tasks, thus the sole use of the approximate strategy does not seem highly likely. Furthermore, SFONO and SFON tendencies are inherently connected as SFON is needed in order to spontaneously focus on numerical order. A similar suggestion has been made regarding the relation between SFON and SFOR tendencies (e.g., McMullen et al., 2014). Thus, further research is needed to examine the relation between SFONO and SFON tendencies.

The current study expanded the repertoire of spontaneous mathematical focusing assessments by showing that it was possible to capture individual differences in children's SFONO with the three tasks included in this study. In addition, our results showed that similarly to previous spontaneous mathematical focusing tendency studies (Hannula & Lehtinen, 2005; McMullen et al., 2014), different behavioral indications of SFONO could be observed beyond children ordering the sets numerically. This finding suggests that it is important to not only consider the correct outcome in tasks that measure children's spontaneous focusing on mathematical aspects; children might make a mistake during the task or focus on numerical aspects but then decide to do something else.

It should be noted that numerical order may have been more salient in the Find the mother task (Mazzocco et al., 2020) than in the other SFONO tasks, as the tester matched the puppy groups with their respective mothers, which resulted in the groups of puppies forming a numerical order. Because the puppies were arranged in the cards with even gaps in horizontal rows, the numerical order of the groups of puppies resembled an increasing pattern that could have hinted towards a quantitative logic in the task. However, the task instruction did not have any indications towards the numerical aspects, and the children could focus also on various other aspects in the task, such as to the appearance of the mothers and puppies (e.g., "Do these puppies look like this mother's puppies?").

To ensure that it was the individual differences in SFONO tendency, not the requisite skills needed in the SFONO tasks, that were related to numerical skills, our analyses on the associations between SFONO tendency and early numerical skills included only those children who were expected to have the adequate skills to spontaneously focus on numerical order. However, previous studies on spontaneous mathematical focusing tendencies have used guided focusing task versions to make this distinction (e.g., Hannula & Lehtinen, 2005; McMullen et al., 2014). The guided task versions are similar to the spontaneous

focusing tasks, with an exception that in these tasks the children's attention is explicitly guided towards the targeted numerical aspect, numerical order in our instance. If children could identify the numerical order in tasks with explicit guidance, it would further validate SFONO as a distinct attentional process separate from ordinality skills. We could not include guided task versions in our study because of its longitudinal setting: if given the guided tasks in the first measurement point of the study, it would be probable that the children would remember them at the second measurement point. This could prevent further measurement of spontaneous behavior in the SFONO tasks. An important issue in further research on SFONO would be to administer both spontaneous and guided task versions to validate SFONO as a separate construct. Another line for further research might be to investigate the relation between SFONO and SFOP tendencies. Wijns et al. (2020) found better patterning skills in children who spontaneously created a pattern with building blocks (SFOP). Considering that numerical order with consecutive numbers could be seen as a specific type of a growing pattern where each set adds one more to the previous set, a relation can be expected between SFOP and numerical ordering. Since we found a correlation between numerical ordering and SFONO, it is possible that children's SFONO and SFOP tendencies are related.

To conclude, the current study showed some children appeared more likely to spontaneously recognize and use numerical order information in tasks when they were not explicitly asked to do so, while others did not pay attention to the numerical order. In addition, our study was able to show partial dissociation of SFONO from the requisite skills, but further studies are still needed to validate SFONO as a separate attentional process. Our results suggest that the individual differences in children's SFONO tendency are associated with early numerical skills, especially numerical ordering skills, indicating that SFONO tendency might be a relevant construct of early numeracy worth further research. It may be that children who have a higher SFONO tendency might acquire more self-initiated practice in the relevant numerical skills, especially in numerical ordering skills. Thus, SFONO tendency might have a supporting role in the development of important ordinality skills. These studies could have important educational implications in supporting the development of early numerical skills and designing learning environments that foster mathematics learning.

## Appendix. Correlations and regression with the full sample

**Table 6** The Spearman correlations (below diagonal) and partial Spearman correlations controlling for age (above diagonal) between the variables ( $N = 150$ )<sup>1</sup>

Variable	1.	2.	3.	4.	5.	6.
1. Age	-	-	-	-	-	-
2. SFONO tendency	.38***	-	.15	.35***	.38***	.45***
3. SFON tendency	.17*	.23**	-	.12	.20*	.14
4. Numerical ordering	.48***	.47***	.19*	-	.55***	.49***
5. Cardinality recognition	.41***	.49***	.26**	.64***	-	.69***
6. Number sequence production	.40***	.55***	.22**	.59***	.74***	-

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$

<sup>1</sup>Missing data in numerical ordering ( $n = 2$ ), and in number sequence production ( $n = 1$ )

**Table 7** Hierarchical regression analysis examining the unique relation of SFONO sum score to children's numerical ordering skills ( $N = 147$ )

	$\beta$	$\Delta R^2$
Step 1		.51***
Age	.28***	
Number sequence production	.17	
Cardinality recognition	.41***	
Step 2		.00
Age	.28***	
Number sequence production	.17	
Cardinality recognition	.42***	
SFON tendency	-.03	
Step 3		.01
Age	.26***	
Number sequence production	.12	
Cardinality recognition	.40***	
SFON tendency	-.03	
SFONO tendency	.12	
	$F(5,141) = 30.28***, R^2 = .52$	

\*\*\* $p < 0.001$ 

**Acknowledgements** The authors would like to warmly thank the participating daycare centers, parents, and the children who took part in the project.

**Author contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed mainly by Heidi Harju, but other co-authors actively contributed. The first draft of the manuscript was written by Heidi Harju, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Funding for the project was acquired by Minna Hannula-Sormunen.

**Funding** Open Access funding provided by University of Turku (including Turku University Central Hospital). The research was supported by funding from the Research Council of Finland, awarded to MH-S (331772) and a Jacobs Foundation Research Fellowship awarded to JM.

**Data availability** Data are not publicly available due to restrictions in the consent forms and as communicated with/agreed upon by the ethical board approving the project; however, the data that support the findings of this study are available on request from the corresponding author. Access to an archived form of the data can be provided for reviewing research analyses.

## Declarations

**Ethics approval and consent to participate** We confirm that this work, which obtained ethical approval from the University of Turku Ethical Review Board, has been carried out in accordance with their ethical principles and standards. Permissions from the cities and daycare centers, parental consents, and children's assents were collected before data collection.

**Competing interests** The authors declare no competing interests.

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