Designing and Evaluating a Novel Board Game to Improve Early Numerical Skills

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Executive Summary

Early numeracy predicts future math achievement, which impacts health, income, and quality of life. Supporting numerical skill development is crucial, especially for children from low socioeconomic backgrounds who risk falling behind. Previous studies show the positive impact of linear number board games and counting forward and backwards on early numeracy. We created a fun board game for children to place number cards in order, engaging them in small group play in the classroom under adult supervision. We evaluated the game's effectiveness in four- to five-year-olds from low socioeconomic areas. Children played the number game in the forward-only condition (e.g., from 1 to 10), the bidirectional condition (e.g., from 1 to 10 and 10 to 1), or an alphabet game (n = 85). After eight sessions over five weeks, all children improved their numerical and letter-sound knowledge. While children enjoyed playing, the game it did not yield any benefit beyond the learning already happening at school.

Background

Early numeracy skills are vital for advanced mathematics, and are strong indicators of mathematical achievement throughout education. Proficiency in mathematics is linked to various life outcomes, such as health, income, and quality of life. However, in the UK, one in four adults lacks the numeracy skills needed for daily life, with an estimated annual cost of £765 million to the UK government. Disparities in mathematical skills appear early, with children from lower socioeconomic status families less likely to reach the recommended skill level by age five, putting them at risk of further falling behind in school.

To tackle this issue, it is crucial to support the development of early numerical skills in children, particularly those at higher risk of falling behind. In this project, a linear number board game was designed, and its effectiveness in improving early numeracy among children from low socioeconomic backgrounds was examined.

Number lines, visually representing numbers ordered from left to right, have proven to be effective tools for representing numerical information. They are widely used in educational settings to introduce arithmetic and other numerical concepts. Accuracy in placing numbers on a number line has been associated with various numerical skills, such as number recall, number comparison, arithmetic, and overall mathematical achievement. Linear board games have also proven effective in enhancing various numerical skills in preschool children from diverse socioeconomic backgrounds. Moreover, recent studies have highlighted the benefits of counting forward and backward on numerical skill development.

Project Aims

In this project, a game was developed where children placed number cards in order forward and backwards to construct a number line. Through a randomised controlled trial, the effects of playing the number game in the forward or bidirectional condition (i.e., forward and backwards) compared to an alphabet game were examined. It was hypothesised that children in the bidirectional condition would show greater improvement in numerical skills than those in the forward condition. Additionally, it was predicted that children playing the number game, in either the forward or bidirectional condition, would exhibit greater improvement in numerical skills compared to those playing the alphabet game. Lastly, it was expected that children playing the alphabet game would demonstrate greater improvement in letter-sound knowledge compared to those playing the forward or bidirectional number line game.

Methods

A total of 272 children were recruited from the Reception year of primary schools in Nottinghamshire and South Yorkshire, with a focus on schools with a high percentage of low socioeconomic status (SES) students. After exclusions, a final sample of 249 children was used for statistical analyses. Schools were recruited between February and April 2022, and the intervention took place between May and June 2022.

Children were assigned to one of three conditions: Number game - Forward, Number game - Bidirectional, or Alphabet Lotto (active control). A within-school stratified blocked approach was implemented for randomisation to ensure a balanced number of participants in each condition within each school and overall. This method aimed to increase the likelihood of a good match in numerical knowledge between the three conditions before the intervention. There were no significant differences among the three conditions in terms of age or gender distribution. All groups played their respective game twice weekly over four weeks. The post-test was conducted in the two weeks following the intervention with the majority of children tested within a week of the intervention finishing.

During the intervention, children played the allocated game in a quiet corner of the classroom for approximately ten minutes. The game actively encouraged children to identify the number before or after in the sequence. The Number Game aimed to help children build a number line progressively by placing cards in ascending or descending order in the intervals from 1 to 10 and 6 to 15. By doing so, children practised determining the successive or preceding number in the sequence and recognising the number to be placed among the other cards. The game targeted counting, number recognition and reading, symbolic number ordering, and the spatial arrangement of numbers on the number line, while also promoting social interaction.

Each child participated in a 10-minute individual session for the pre-test and post-test assessments. These sessions took place either in a quiet corner of the classroom or a separate room, depending on the school's availability. The tasks were administered in a specific order, which remained consistent for both the pre-test and post-test assessments. The assessments included counting, number naming, number order, number line, number comparison, WIAT-

III Numeracy subtest, YARC Letter-Sound knowledge subtest, and game preference questions. Data collection and intervention delivery were carried out by four experimenters. To ensure blinding, the experimenters who delivered the intervention did not conduct the post-test assessment for the children they interacted with during the intervention phase.

Key Findings

- The study showed no significant differences in the improvement of numerical and letter-sound knowledge skills between the forward and bidirectional number games and the alphabet game. This implies that these game-based interventions did not provide additional benefits beyond regular classroom learning in the case of this particular study, contradicting prior research that showed linear number board games improving early numeracy skills.
- Low attrition, high engagement and enjoyment were observed among the children during the game sessions, demonstrating the game's potential in terms of usability. This indicates that the game could keep children's attention and engagement, but requires further refinement to maximise its educational impact.
- Short game-based interventions may not always improve numerical skills beyond the learning already happening in the classroom. However, we note that children who played the number game showed small (though not statistically significant) improvements in their numerical skills. More frequent and longer interventions and individualised playing sessions where children’s learning is guided depending on their current knowledge may be necessary to observe a beneficial effect of the game on early numeracy.

Recommendations

Extend intervention duration and frequency: Our study entailed eight sessions across a five-week intervention with bi-weekly game sessions. It is plausible that the intervention duration was insufficient and the game sessions were not frequent enough to yield significant results. It would be beneficial to lengthen the intervention period and augment the frequency of game sessions, offering students more chances to interact with the game and reinforce their learning.

Individualised instruction: Our study adopted a one-size-fits-all approach, but it is crucial to acknowledge that children might be at varying phases of numerical knowledge acquisition. It is recommended to offer more structured playing for students who are in the initial stages of learning while permitting more autonomous exploration for those who have already solidified their knowledge. Personalising instruction to meet individual needs could boost the efficacy of the game-based intervention.

Game mechanics: The newly developed number game received high ratings from children. Educators and game designers should consider incorporating similar game mechanics, storylines, and visuals that have demonstrated success in engaging children’s attention and interest.

Introduction

Early numeracy skills are critical for developing advanced mathematics and serve as strong predictors of mathematical achievement throughout schooling (Duncan et al., 2007; Watts et al., 2014). Mathematics competency has been linked to various life outcomes, including health, income, and quality of life (National Numeracy, 2015; Wagstaff et al., 2001). However, in the United Kingdom, one in four adults lack the numeracy skills necessary for daily life, costing the government £765 million annually (Organisation for Economic Co-operation and Development, 2013; Every Child a Chance Trust, 2009). Disparities in mathematical skills emerge early, with children from lower socioeconomic status (SES) families less likely to reach the recommended skill level by age five, putting them at risk of further falling behind in school (Blakey et al., 2020; Caro et al., 2009; Department for Education, 2014).

To address this issue, it is crucial to support the development of early numerical skills in children, especially those at higher risk of falling behind. In this project, we designed a linear number board game and examined its effectiveness in improving early numeracy among children from low socioeconomic backgrounds.

Number lines, which visually represent numbers ordered from left to right, have proven to be effective tools for representing numerical information (Sella et al., 2017). They are widely used in educational settings to introduce arithmetic and other numerical concepts (Ernest, 1985; Greenes et al., 2004; Griffin, 2004, 2009; Griffin & Case, 1996; Lewis Presser et al., 2015; Tonizzi et al., 2021). Accuracy in placing numbers on a number line has been associated with various numerical skills, such as number recall, number comparison, arithmetic, and overall mathematical achievement (Ramani & Siegler, 2008; Schneider et al., 2018; Sella et al., 2017, 2018, 2020a; Thompson & Siegler, 2010).

Previous interventions using number lines have shown promise in improving mathematical skills. For example, Siegler and Ramani (2008) found that preschool children from low-income families who played a linear numerical board game displayed greater accuracy in placing numbers on a number line compared to those who played a non-numerical colour board game. Linear board games have also proven effective in enhancing various numerical skills in preschool children from diverse socioeconomic backgrounds (Ramani & Siegler, 2009). Moreover, recent studies have highlighted the benefits of counting forward and backward on numerical skill development (Xu & LeFevre, 2016; Sella et al., 2020b). Training children to indicate successive and preceding numbers has shown improvements in number ordering and number line tasks (Xu & LeFevre, 2016). Encouraging children to explore the number sequence forward and backwards relates to early numerical skill development (Sella et al., 2020b, 2019).

In this project, we developed a game where children placed number cards in order forward and backwards to construct a number line. The game was designed to be suitable for small groups of children to play in school with adult supervision. The game actively encouraged children to identify the number before or after in the sequence. Through a randomised controlled trial, we examined the effects of playing the number game in the forward or bidirectional condition (i.e., forward and backwards) compared to an alphabet game. We hypothesised that children in the bidirectional condition would show greater improvement in numerical skills than those in the forward condition. Additionally, we predicted that children playing the number game, in either the forward or bidirectional condition, would exhibit greater improvement in numerical skills compared to those playing the alphabet game. Lastly, we expected that children playing the alphabet game would demonstrate greater improvement in letter-sound knowledge compared to those playing the forward or bidirectional number line game.

Method

Participants

A total of 272 four- to five-year-olds children were recruited for the study from primary schools in Nottinghamshire and South Yorkshire. We targeted schools with a high percentage of low socioeconomic status (SES) students, identified by at least 30% of children receiving Free School Meals (FSM). Seven schools agreed to participate. These schools had a significant proportion of children eligible for FSM (mean = 44%, SD = 7, range = 31.3%-52.8%), which is approximately double the national average of 22.5% (National Statistics, 2022). A total of 23 children were excluded from the analysis for various reasons (see Figure 1). This resulted in a final sample of 249 children for the statistical analyses. Among the participants, there were 127 females, and the average age was 61 months (*SD* = 4, range = 54-76).

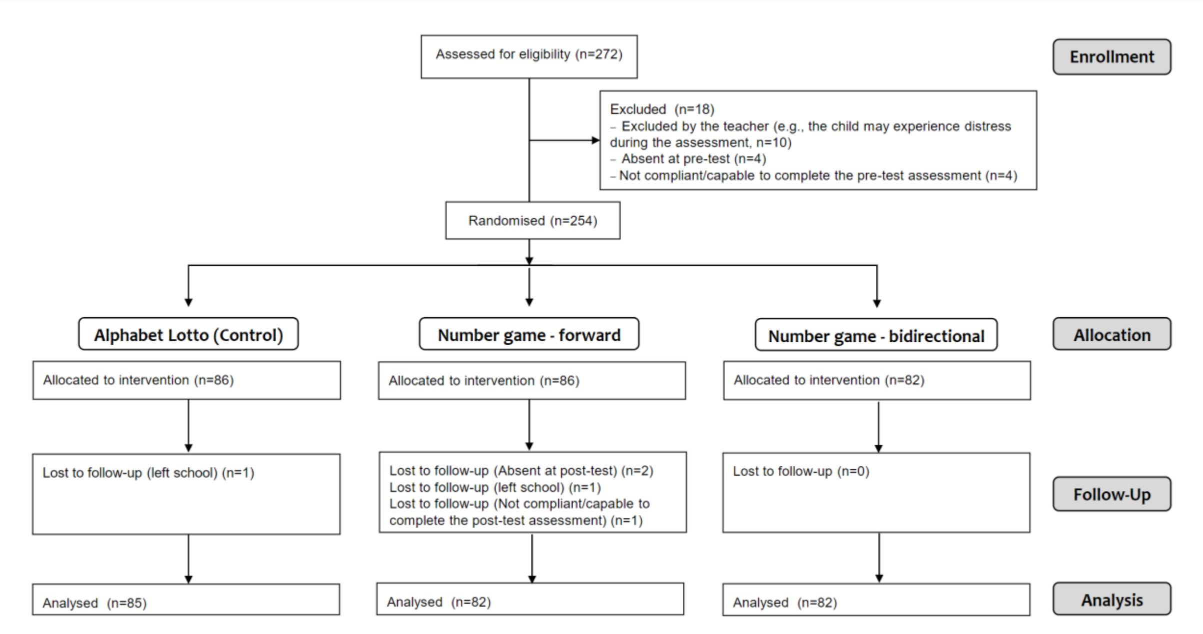

Figure 1. Flow diagram depicting the number of participants excluded and the reasons for exclusion.

Procedure

Recruitment of schools for the study occurred from February to April 2022, while the randomised controlled trial (RCT) was conducted between May and June 2022. Parents were provided with the opportunity to opt-out their child from participating, and children gave verbal assent to participate. Following completion of the pre-test assessment, children were assigned to one of three conditions: Number game - Forward, Number game - Bidirectional, or Alphabet Lotto (active control). Over the course of four weeks, all groups played their respective game twice weekly, with a one-week break due to the school holiday. Children had the option to interrupt or take breaks during the game or assessment sessions. At the end of each session, children received stickers as a reward. The post-test was conducted in the two weeks following the intervention with the majority of children tested within a week of the intervention finishing. Ethical approval for the study was granted by the Loughborough University ethics committee (2022-7658-8320).

Randomisation

For randomisation, a within-school stratified blocked approach was implemented to ensure a balanced number of participants in each condition within each school and overall. This method aimed to increase the likelihood of a good match in numerical knowledge between the three conditions before the intervention. Children's Number Knowledge Index scores (n=254; see below for details) were sorted from lowest to highest within each school. Groups of three children with similar baseline scores represented a stratum, and these strata were ordered from low to high. Children with missing pre-test scores were positioned at the end of the sorted scores within each school. Sampling from the six permutations of the three conditions (Number game - Forward, Number Game - Bidirectional, Alphabet Lotto) occurred a sufficient number of times to match the participant count, generating a sequence of random blocks with the three conditions. There were no significant differences among the three conditions in terms of age ($F(2, 210)=0.726$, $p=0.485$) or gender distribution ($\chi^2(2)=1.18$, $p=0.554$).

The Intervention

During the intervention, a research team member called four children to play in a predetermined random order to avoid clustering. If a child was absent or temporarily unavailable, the next child on the list was called. The allocated game (Number game - Forward, Number Game - Bidirectional, or Alphabet Lotto) was played by two pairs of children in a quiet corner of the classroom for approximately ten minutes. In the number game conditions, children placed nine number cards, while in the alphabet lotto, they placed six letter cards. To ensure an equal number of turns, children in the number game conditions played the game twice per session, while those in the alphabet game played it three times. The experimenter encouraged each pair member to take turns placing cards. The game's order was shuffled to ensure different playing times across conditions.

In the Number Game (see Figure 2 and 3), each pair of children had a laminated tablecloth-like game-playing mat (50cm x 9cm) in front of them to place number cards on. A card depicting one of twelve monsters was randomly chosen and placed at one end of the mat. Forty double-sided number cards were placed on the table. The face-up side of the cards displayed a closed cloche with a number, while the face-down side showed an open cloche with the number and an image of "monster food" or a "monster drink." In the initial three sessions, number cards from one to ten were used, while sessions four to eight involved numbers from six to fifteen to increase difficulty. In the number game forward condition, children played with the number 1 (sessions 1-3) or 6 (sessions 4-8) placed on the left-hand side of the tablecloth, and the monster card was positioned at the end of the right-hand side. Children were instructed to place the number cards in ascending order, starting from the number already on the tablecloth to obtain the monster's food and drinks. In the number game bidirectional condition, children played one game as in the forward condition, and in the second game, the number 10 (sessions 1-4) or 15 (sessions 4-8) was placed on the far right-hand side of the tablecloth, with the monster at the far left-hand side. Children in this condition had to count backward when placing number cards from right to left, going from 10 or 15 to reach the monster. Throughout the game, the experimenter encouraged children to identify the number to be placed by asking questions like "what number comes after n?" or "what number comes before n?". After placing the cards, the experimenter checked if they were in the correct order. If any mistakes were made, the experimenter provided scaffolding by first asking the child if they could identify the error, then pointing out the mistake if needed. If the child was still unable to correct the error, the experimenter made the necessary corrections. Once all the cards were in the correct order, the numbers were read aloud, and the cards were flipped to reveal the monster's food and drinks. Children had a moment to observe the cards before proceeding to another game or returning to classroom activities.

The Number Game aimed to help children build a number line progressively by placing cards in ascending or descending order until they reached the monster at the end of the tablecloth. By doing so, children practised determining the successive or preceding number in the sequence and recognising the number to be placed among the other cards. The game targeted counting, number recognition and reading, symbolic number ordering, and the spatial arrangement of numbers on the number line, while also promoting social interaction.

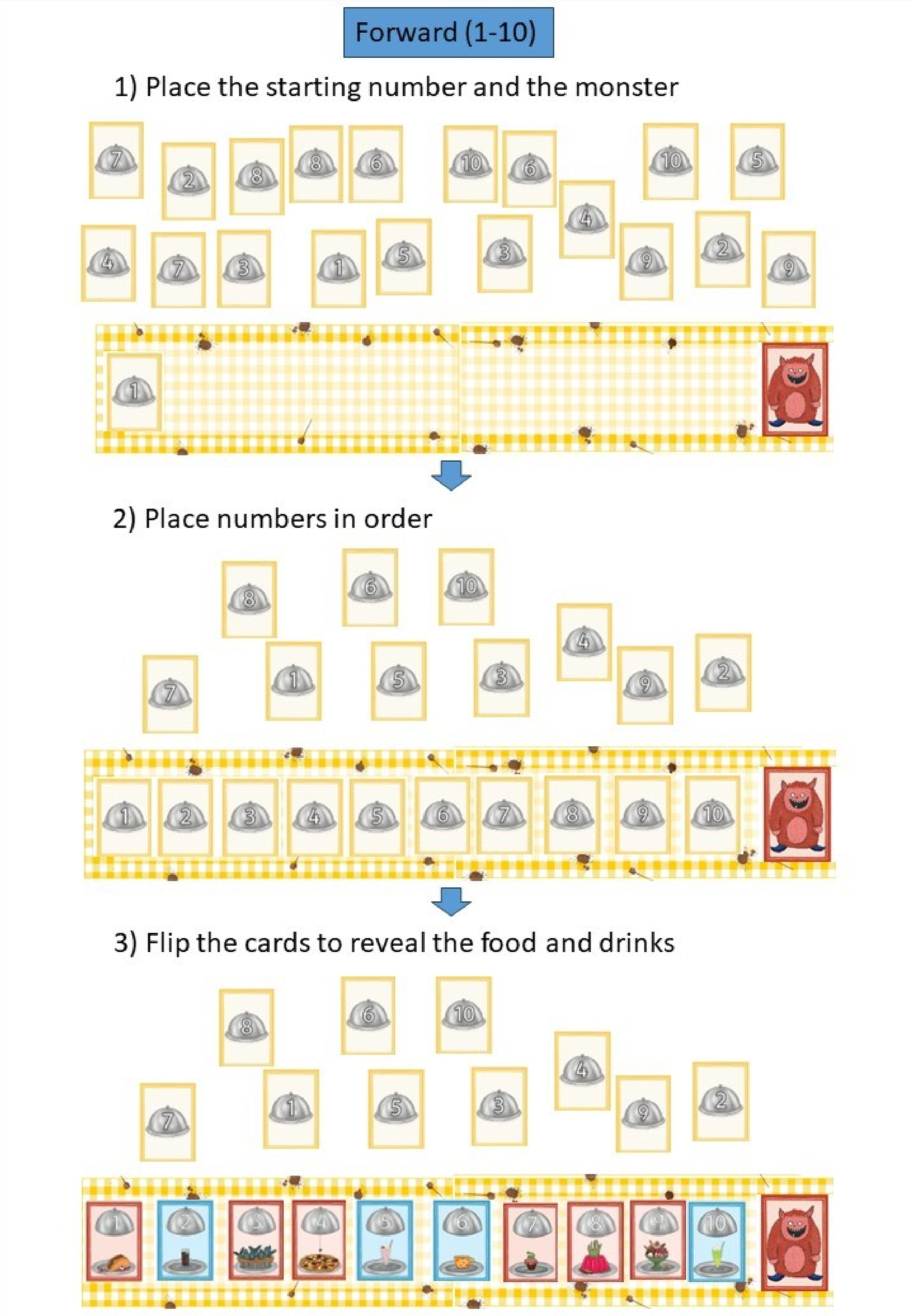

Figure 2. Children placed number cards to bring food and drinks to the monster. In the Forward condition, children placed cards in ascending order from left to right two times per session. After being ordered, the cards were flipped to reveal the food and drinks to feed the monster.

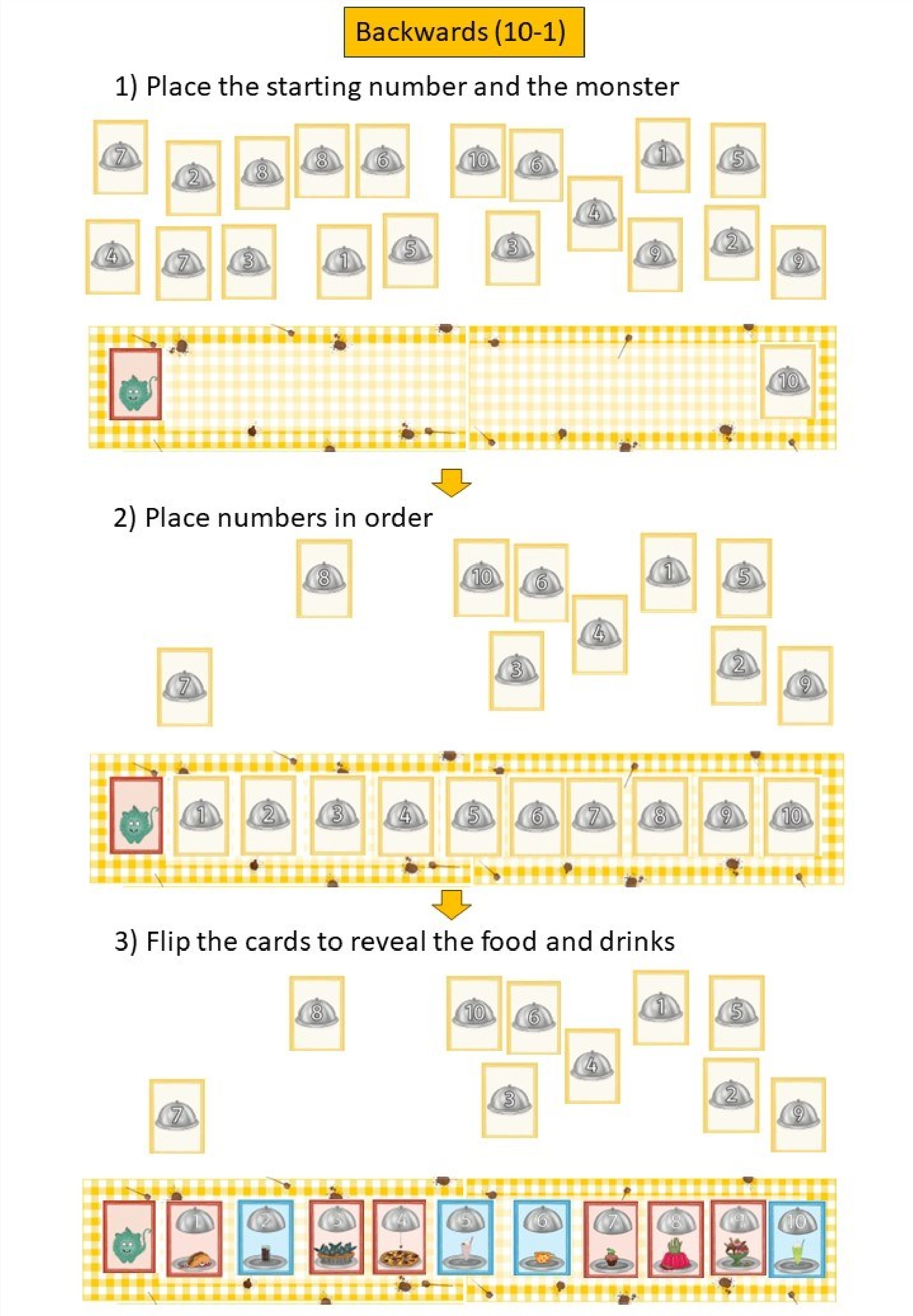

Figure 3. In the Bidirectional condition, children placed cards in ascending order from left to right (Forward, as in Figure 2) and, then, in descending order from right to left (Backward, this figure). After being ordered, the cards were flipped to reveal the food and drinks to feed the monster.

As for the active control group, children played the Alphabet Lotto (Orchard Toys; Figure 4), a commercially available game suitable for children aged three- to six- years. This game was chosen as an active control condition because it focused on a non-numerical skill, specifically letter-sound knowledge, while having a similar structure to the number game, where cards were selected and placed on a board. Each pair of children received one of five lotto boards, each displaying six pictures with the corresponding word written beneath them (e.g., apple, fish, penguin, moon, violin, cheese). Thirty letter cards (e.g., a, f, p, m, v, ch) were placed on the table, and children had to match the letter cards to the pictures on the lotto board. After each game, the lotto boards were rotated in a predetermined random order to ensure that children had similar experiences with all the boards and letters in the game.

Figure 4. An example of one of the Alphabet Lotto boards, where children have to match the letter cards to the corresponding image.

Pre- and post-test measures

Each child participated in a 10-minute individual session for the pre-test and post-test assessments. These sessions took place either in a quiet corner of the classroom or a separate room, depending on the school's availability. The tasks were administered in a specific order, which remained consistent for both the pre-test and post-test assessments. The assessments included counting, number naming, number order, number line, number comparison, WIAT-III Numeracy subtest, YARC Letter-Sound knowledge subtest, and game preference questions.

The tasks were presented on a computer laptop, except for the WIAT-III Numeracy subtest, which was administered on paper as it required children to write their responses. Data collection and intervention delivery were carried out by four experimenters. To ensure blinding, the experimenters who delivered the intervention did not conduct the post-test assessment for the children they interacted with during the intervention phase.

Counting: Children were asked to count forward from 1 to 15 and backward from 15 to 1 aloud, and the experimenter recorded the number at which they stopped or made an error. The proportion of correct responses was calculated for each child in both the forward and backward counting conditions.

Number naming: Children read aloud eleven numbers between 1 and 15 presented on the screen, and the proportion of correct responses was calculated.

Number order: Children were shown three squares on the screen, with two squares containing consecutive numbers and one square left empty, which could be the left-most or the right-most of the three squares. Children were asked to identify the number that comes before or after the number in the central square. Children answer which number comes after 2, before 2, after 5, before 9, after 15, before 15, after 7, before 7, after 10, before 12, after 13, and before 13, in this order. The proportion of correct responses was calculated.

Number line: Children saw a horizontal line representing the numerical interval from 1 to 15. Using a mouse, they moved a red target number on the line and marked its position by clicking. Children placed five target numbers 2, 4, 6, 7, and 13 presented in a random order. The accuracy of their placement was calculated based on the absolute error between the estimated position and the target number.

Number comparison: Children selected the largest and smallest numbers among four visually presented numbers. Following this, the experimenter read aloud four numbers and asked the child to indicate the largest and the smallest number in four trials. The proportion of correct responses was calculated.

Number Knowledge index: The mean accuracy across the counting, number naming, number order, number line, and number comparison tasks was calculated to create a Number Knowledge index, summarising children's number knowledge.

Numeracy subtest of the WIAT-III (WIAT-III; Wechsler, 2017): Children completed a paper-and-pencil test with 61 items assessing various numerical skills, such as counting and arithmetic. The proportion of correct responses was calculated.

Letter Sound knowledge subtest of the YARC (YARC; Hulme et al., 2009): Children produced the sound of 17 letters and digraphs presented sequentially on the screen. The proportion of correct responses was calculated.

Game preference: At the end of the pre-test assessment, children expressed their preference for either the number or the letter game by pointing to a picture shown on the tablet screen.

Game playing: Children in the number game conditions completed two games per session, while those in the Alphabet Lotto completed three games. The proportion of completed games was calculated for each child across the eight playing sessions.

Game engagement: The experimenter rated each child's engagement during the game session on a 5-point Likert scale, assessing the amount of time the child remained focused and engaged with the game.

Game enjoyment: At the end of the post-test assessment, children responded to two questions about their enjoyment of the game using a 5-point Likert scale with smiley faces indicating increasing levels of happiness. The mean of their responses was calculated as an index of game enjoyment.

Primary and secondary outcome measures

The primary outcome measures were the Number Knowledge index, Numeracy subtest of WIAT-III, and Letter Sound knowledge subtest of YARC. The Number Knowledge index assessed specific numerical knowledge related to the number game interventions (near transfer). The Numeracy subtest of WIAT-III provided a standardised measure of mathematical achievement that partially related to the number game interventions (far transfer). The Letter Sound knowledge subtest of YARC aimed to detect any improvement related to the Alphabet Lotto intervention. The combination of ad-hoc tasks and standardised tests provides a complete assessment of children's numerical skills, intending to capture both near and far transfer effects of the intervention.

Results

Game preference, attendance, engagement, and enjoyment

At the end of the pre-test assessment, children were asked to indicate their preference for playing a number game or a letter game. The majority of children expressed a preference for the number game, and this preference did not significantly differ between the conditions. It is speculated that the number-related questions in the pre-test assessment influenced their preference for the number game. Children had high attendance rates, as they completed an average of 7.41 out of eight game sessions. The number of completed sessions did not significantly differ between the conditions. The experimenters rated the engagement of each child during the game sessions. Children displayed high levels of engagement throughout the sessions, with an average score of 4.5 out of 5. At the end of the post-test assessment, children reported high levels of enjoyment for the game with an average score of 4.17 out of 5, with no significant differences between the conditions. Overall, children expressed a preference for the number game, had high attendance rates, consistently showed high engagement, and reported enjoying the game. These positive attitudes were consistent across the different game conditions.

Effect of the intervention

The descriptive statistics for the assessed measures at pre-test and post-test are presented in Table 1.

Measure	Condition	Pre-test *M*(*SD*)	Post-test *M*(*SD*)	Gain *M*(*SD*)
Counting	Alphabet Game	0.54(0.23)	0.65(0.25)	0.1(0.22)
	Number game - Forward	0.55(0.21)	0.66(0.24)	0.11(0.2)
	Number game - Bidirectional	0.58(0.25)	0.69(0.25)	0.11(0.25)
Number naming	Alphabet Game	0.8(0.21)	0.89(0.16)	0.08(0.16)
	Number game - Forward	0.82(0.21)	0.9(0.16)	0.08(0.13)
	Number game - Bidirectional	0.81(0.21)	0.88(0.18)	0.07(0.13)
Number order	Alphabet Game	0.59(0.3)	0.71(0.28)	0.13(0.22)
	Number game - Forward	0.59(0.29)	0.72(0.26)	0.13(0.21)
	Number game - Bidirectional	0.57(0.27)	0.72(0.25)	0.15(0.21)
Number line	Alphabet Game	0.71(0.2)	0.72(0.18)	0.02(0.16)
	Number game - Forward	0.69(0.18)	0.72(0.17)	0.03(0.18)
	Number game - Bidirectional	0.69(0.17)	0.72(0.19)	0.03(0.2)
Number comparison	Alphabet Game	0.53(0.28)	0.6(0.26)	0.07(0.22)
	Number game - Forward	0.54(0.28)	0.62(0.27)	0.08(0.21)
	Number game - Bidirectional	0.49(0.28)	0.61(0.29)	0.11(0.23)
Number Knowledge index	Alphabet Game	0.63(0.18)	0.71(0.17)	0.08(0.1)
	Number game - Forward	0.64(0.17)	0.72(0.16)	0.09(0.08)
	Number game - Bidirectional	0.63(0.17)	0.72(0.17)	0.1(0.1)
Numeracy (WIAT-III)	Alphabet Game	0.12(0.06)	0.14(0.07)	0.02(0.05)
	Number game - Forward	0.12(0.06)	0.14(0.06)	0.02(0.05)
	Number game - Bidirectional	0.12(0.07)	0.14(0.07)	0.02(0.05)
Letter sound knowledge (YARC)	Alphabet Game	0.77(0.2)	0.85(0.16)	0.08(0.11)
	Number game - Forward	0.78(0.2)	0.84(0.17)	0.06(0.1)
	Number game - Bidirectional	0.77(0.2)	0.84(0.17)	0.07(0.1)

Table 1. Mean and standard deviation of assessed measures at pre-and post-test, and gaining scores separately for each condition.

ANCOVA analyses were conducted for each primary outcome measure, with post-test scores as the dependent variable and pre-test scores and conditions as predictors. Specifically, we evaluated the effect of the condition; meaning that at least one condition differed at the post-test after controlling for pre-test scores. The effect of the condition was never statistically significant (Figure 5).

Mixed ANOVA analyses were conducted for each outcome measure, with Session (Pre-test, Post-test) as the within-subject factor and Condition (Number game – Forward, Number game – Bidirectional, Alphabet Lotto) as the between-subjects factor. The presence of a significant interaction was evaluated between Session and Condition, meaning that the change in scores between pre-test and post-test differed in at least one of the three conditions. The presence of a significant effect of Session was also evaluated, expecting children to improve their scores between pre-test and post-test. The interaction between Session and

Condition was never statistically significant, indicating that the change in scores between pre-test and post-test did not differ between the conditions. However, the effect of Session was always significant, indicating that children improved their scores in the primary outcome measures from pre-test to post-test.

Measure	**Model**	**Effect**	***F***	***df***	***p***	η^2_p
Number Knowledge index	ANCOVA	Pre-test score	666.814	1, 245	< 0.001	0.731
		Condition	0.54	2, 245	0.58	0.004
	ANOVA	Condition	0.038	2, 246	0.96	0.0003
		Session	222.925	1, 246	< 0.001	0.475
		Condition*Session	0.588	2, 246	0.56	0.005
Numeracy (WIAT-III)	ANCOVA	Pre-test score	280.078	1, 245	< 0.001	0.533
		Condition	0.131	2, 245	0.88	0.001
	ANOVA	Condition	0.011	2, 246	0.99	0.0001
		Session	51.01	1, 246	< 0.001	0.172
		Condition*Session	0.141	2, 246	0.87	0.001
Letter Sound knowledge (YARC)	ANCOVA	Pre-test score	674.546	1, 245	< 0.001	0.734
		Condition	0.584	2, 245	0.56	0.005
	ANOVA	Condition	0.01	2, 246	0.99	0.0001
		Session	117.198	1, 246	< 0.001	0.323
		Condition*Session	0.531	2, 246	0.59	0.004

Table 2. ANCOVA and ANOVA table on the primary outcome measures.

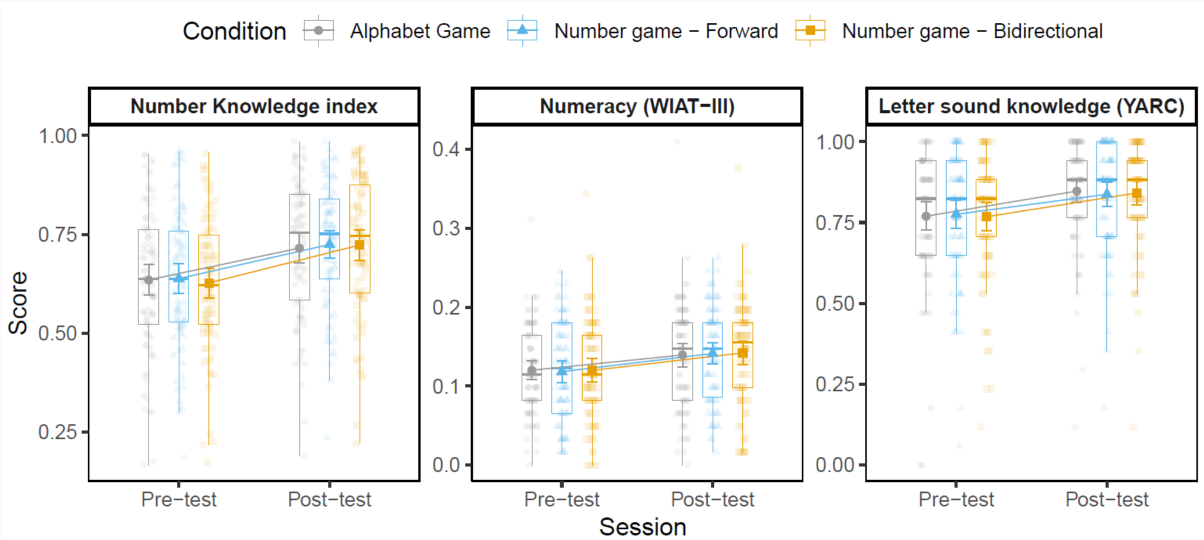

Figure 5. Scores (y-axis) in the primary outcome variables (i.e., Number Knowledge index, Numeracy, Letter sound knowledge) at pre- and post-test (x-axis) separately for the three conditions. Boxplots represent the distribution of scores. Solid shapes represent the mean and error bars represent 95% confidence intervals. Transparent jittered dots represent individual scores.

Conclusions

We developed a number game in which children placed number cards in order on a line. The game had two versions: forward and bidirectional, and we compared the effects of these number games to an alphabet game in a randomised controlled trial (RCT). Both games involved similar actions of locating and placing cards correctly. The study included children with similar baseline numerical and letter-sound knowledge skills and preferences for playing a numeracy or literacy game. The children participated in two game sessions per week for four weeks, with a one-week break in the middle. Attendance was high, attrition was low, and children displayed high engagement and enjoyment regardless of the game played. However, there were no significant differences in the improvement of numerical and letter-sound knowledge skills between the conditions. Neither the forward nor bidirectional condition of the number game, nor the alphabet game, provided additional benefits beyond regular classroom learning.

This pre-registered study failed to conceptually replicate previous studies that showed linear number board games improving early numeracy (Siegler & Ramani, 2008; Ramani & Siegler, 2008; Siegler & Ramani, 2008, 2011; Ramani et al., 2012). Our sample size was larger than most previous studies in this age group, and we implemented an appropriate design and methodology. We used individual randomisation and randomised playing pairs to reduce clustering effects. The order of the games was also randomised to ensure even distribution across the school day. The baseline skills were similar between groups, ruling out group differences as a potential confound. Children displayed similar enthusiasm toward playing a numeracy or literacy game, reducing expectation biases. We included both ad-hoc measures and reliable standardized tests for numerical and literacy skills. Moreover, we observed high correlations between pre-test and post-test scores, indicating the reliability of the tests. Blinding is challenging in educational studies, but we reduced bias by having experimenters who did not interact during the intervention conduct the post-test assessment.

Several factors may explain the lack of intervention effect in our study compared to previous ones. First, the control group in our study showed improvements between pre-test and post-test, whereas previous studies often had stable control group performance, making it easier to detect differences. Second, our game partially resembled previous linear number board games but had some differences in gameplay. For instance, our game lacked a spinner and differences like these could have reduced the effect of the game on numerical skills. Third, our one-size-fits-all approach, where the experimenter provided a similar level of support for all children, may not have been equally beneficial for children at different stages of numerical knowledge acquisition. For instance, some children may require an adult to support them in reading the numbers already on the tablecloth forward or backward to determine the number to be placed. Further assessment is required to determine the proper support necessary to maximise learning during the game. Fourth, the intervention duration and frequency may have been insufficient to produce significant effects. Increasing the intervention length, frequency, and sample size could yield different results. Fifth, using a task specifically measuring the ordering of number cards may have provided clearer evidence of the game's effect. While our tasks assessed ordering and number-space association, a task directly mimicking the intervention would have provided a more direct transfer measure.

Sixth, it is possible that contamination occurred as children may have discussed their game experiences with each other. However, we believe any contamination was minimal, as simply talking about the game does not fully replicate the experience of playing it. Finally, we acknowledge that giving stickers to children at the end of each session may have influenced their attitude toward the games positively.

In summary, our study did not find significant evidence to support the effectiveness of the newly designed number game in improving numerical skills beyond regular classroom teaching. The game showed promise in terms of engagement and usability but may require further refinement and adaptation to maximise its impact. Future research should explore alternative strategies, longer intervention periods, and potential moderators (e.g., language, executive functions) to enhance the effectiveness of game-based interventions in promoting early numeracy skills.

Recommendations

Based on the findings of our study, we would like to provide the following recommendations for educators and policymakers:

Extend intervention duration and frequency: Our study entailed eight sessions across a five-week intervention with bi-weekly game sessions. It is plausible that the intervention duration was insufficient and the game sessions were not frequent enough to yield significant results. It would be beneficial to lengthen the intervention period and augment the frequency of game sessions, offering students more chances to interact with the game and reinforce their learning.

Individualised instruction: Our study adopted a one-size-fits-all approach, but it is crucial to acknowledge that children might be at varying phases of numerical knowledge acquisition. It is recommended to offer more structured playing for students in the initial stages of learning while permitting more autonomous exploration for those who have already solidified their knowledge. Personalising instruction to meet individual needs could boost the efficacy of the game-based intervention.

Game mechanics: The newly developed number game received high ratings from children. Educators and game designers should consider incorporating similar game mechanics, storylines, and visuals that have successfully engaged children’s attention and interest.

Future directions

We are currently engaged in a qualitative analysis of video recordings focusing on children playing a novel version of the game, specifically targeting the interval from 1 to 10. In the novel version, there is a direct connection between the symbolic number and the number of food elements on the card. For example, the card with the number 2 shows two tacos. This correspondence allows the experimenter to prompt children to count the number of foods on the card to boost their counting routine and cardinality understanding beyond the ability to count forward and backwards.

As we delve into the process of analysing 19 videos recorded so far, we present preliminary insights derived from ten videos: five featuring Reception Year children and five with nursery children. We aim to further explore the playability of a number board game by gaining insights into children's play dynamics. Reception-year children played 13 games both in the forward and bidirectional condition with intervals 1-10 and 1-20, whereas the nursery group played six games all in the interval 1-10 in the forward condition. We recorded the game session focusing on mathematical events such as counting, numeral recognition, and sequencing, in addition to moments where children supported their peers or requested support from the experimenter. From our initial review of the ten videos, we noticed that Reception year children frequently recognised digits, used number words spontaneously, determined the subsequent and preceding numbers, and benefitted significantly from peer assistance. In contrast, nursery children were more familiar with number words than actual digits and relied substantially on external guidance, mainly from the experimenter, for tasks involving numeral recognition and sequencing. Based on these preliminary observations, we plan to introduce different game levels, adjusting difficulty based on a child's prior knowledge of numbers. For beginners, such as many of the nursery children, it might be necessary to reduce the initial interval to numbers from one to five. Moreover, we may introduce tutorials for adults to best scaffold children's learning and progression throughout the game.

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Further information

- The game and instructions are available for download here: https://illuminateearlymaths.co.uk/wp-content/uploads/2023/06/INSTRUCTION-OF-FEED-THE-MONSTER.pdf and here https://illuminateearlymaths.co.uk/wp-content/uploads/2023/07/Feed-The-Monster-cards.pdf
- A blog post describing the project can be found here: https://blog.lboro.ac.uk/cmc/2022/01/18/why-might-number-board-games-boost-childrens-early-number-skills/
- A blog post describing the results of the randomised controlled trial can be found here: https://blog.lboro.ac.uk/cmc/2023/07/28/playing-along-the-line-evaluating-a-novel-number-board-game/
- The results from this project have been submitted for publication. A pre-print version of the manuscript can be found here: https://osf.io/sdztv/?view_only=d126cf89906e4d1c8ecd2040aaac7b82.

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