UNIVERSITY OF PADOVA

Department of General Psychology

Bachelor's Degree Course in Psychological Science

Final Dissertation

SPATIAL NUMERICAL ASSOCIATION: A STUDY ON PRESCHOOL CHILDREN

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Academic Years 2021/2022

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1. INTRODUCTION

An association between space and numbers has been described since the 19th century (Galton, 1880). More in particular, humans have shown to represent numbers on a mental line (Mental Number Line) where smaller numbers are associated to the left side and bigger numbers to the right side. The bases of this relation have been attributed to culture, which was thought to be the one and only influence. However, more recent evidence reveals that non-human species and non-verbal infants also show an association between space and numbers. This Spatial Numerical Association (SNA) moves culture to a secondary role, and a new biological basis is explored.

The present work, which aims at investigating SNA in a new age-range of subjects (3 to 5 years old children), is divided into three sections. The first section gives a theoretical framework, starting with a description of the Mental Number Line, i.e., MNL, focusing on the cultural basis, and then discussing the Spatial Numerical Association, i.e., SNA, investigating the new biological basis. The second section focuses on the new study conducted on preschool children (i.e., the Card Game), reporting the game setting, the methods and the procedure used for gathering the data. Finally, the third section discusses data analysis, and then concludes taking into consideration the strengths and limitations of the present study and offering insights for future research.

The study conducted is important because it brings attention to the area of research focusing on the association between space and numbers and its development. Furthermore, it represents a starting point for the consideration of preschool children as subjects of studies on the SNA, in this way overcoming age-related issues observed in previous studies.

2. NUMBER AND SPACE RELATION

The relation between space and numbers will be the focus of this section. I will begin by introducing the concept of Mental Number Line and SNARC effect, reporting evidence and discussing cultural influences. Then, I will move to the concept of the Spatial Numerical Association, mentioning recently investigated biological influences.

2.1 Mental Number Line

2.1.1 MNL and SNARC effect

A characteristic peculiar to humans is that of associating numbers and space in our mind. More in particular, small numbers appear to be associated with our left-space while large numbers appear to be associated with our right-space. This concept was first descripted by Sir Francis Galton in 1880, who reported that humans describe and think of numbers as being represented along an imaginary and continuous line oriented from left to right. Small numbers are located on the left side of the line, and larger ones on the right side. This concept was defined as the “Mental Number Line”, i.e., MNL (Galton, 1880; also, Restle, 1970).

The first experimental demonstration of the MNL was conducted by Dehaene, Bossini, and Giraux more than a hundred of years later (1993) on adult humans. In this research study, it was observed that small numbers (e.g., 0 or 1) were associated with faster left-hand responses, and larger numbers (e.g., 8 or 9) with faster right-hand responses, when making parity judgements. This tendency was not affected by handedness, in fact, left-handed participants displayed the same responses, and even when the subjects’ hands were crossed, with the right hand activating the left response key and vice versa, responses did not change. This behavior is a prominent manifestation of the number-space interaction discussed previously, and it is called

SNARC (Spatial-Numerical Association of Response Codes) effect (Dehaene et al., 1993).

2.1.2 Cultural Influences

It was generally believed that the existence of the above explained number-space association was due to cultural influences, thus that it was a learned behavior. More in particular, reading and writing habits were thought to play a significant role in its development. Research focusing on groups of people with different cultural conventions for reading and writing direction showed that in individuals who used the right-to-left reading and writing system, the SNARC effect was reversed (small numbers were associated with right-space and large numbers with left-space). Furthermore, this reversed association was weaker in biliterates (people with both right-to-left and left-to-right reading and writing habits), and inexistent in illiterates (people who could not read nor write) (Shaki and Fischer, 2008; Shaki et al., 2009; Zebian, 2005).

These results provided support to the hypothesis that the association between space and numbers is dictated by experience, and so it is a result of cultural influences.

2.2 Spatial Numerical Association

2.2.1 SNA

Although the orientation of the SNARC effect varies with culture, its presence across multiple, different cultures supports the idea that spatial mapping of numbers is a universal cognitive strategy (Göbel et al., 2011).

In order to focus on the origins of the spatial-numerical association (i.e., SNA) and questioning the importance of cultural influences such as reading and writing direction, studies began to focus also on subjects that cannot read nor write. In fact, research had by far only implemented adult humans as participants, in whom it is not possible to distinguish biological influences from cultural influences characterizing a behavior. Thus, experiments on subjects such as non-human animal species and young children started being conducted.

Rugani and colleagues (2015) found evidence for the existence of a mental number line in 3-day-old domestic chicks. In this study, two experiments were carried out. In the first one, chicks first familiarized with the target number 5 by having to circumnavigate a panel, in the center of the apparatus, displaying five identical elements. After training, each chick underwent two tests in random order: a small number test with 2 versus 2, and a large number test with 8 versus 8. Chicks showed a spontaneous association of small numbers (i.e., 2) with the left space and large numbers (i.e., 8) with the right space. This association was observed again in the second experiment where the target number was 20 and chicks underwent a small number test with 8 versus 8, and a large number test with 32 versus 32.

Chimpanzees also became the participants of similar experiments on number-space mapping (Adachi, 2015). Here, the subjects were trained to perform a number sequence task in which they touched a sequence of small to large numbers presented in random locations on a monitor. Test trials were also included and consisted of only two numbers (i.e., 1 and 9) horizontally arranged. In half of them, the number 1 was on the left and the number 9 on the right, while in the other half 9 was on the left and 1 on the right. Chimpanzees responded quicker when 1 was on the left and 9 on the right, thus in the SNARC-like condition.

Both of the priorly described studies suggest that non-human species map numbers onto space in a way that resembles humans.

Research was also carried out on preverbal infants. Using an adaptation of the Posner task (Posner, 1980), Bulf and colleagues (2015) tested 8- to 9-month-old infants' ability to orient their visual attention towards the left and right sides of a monitor after a non-symbolic numerosity appeared. It was observed that infants were faster at detecting targets appearing on the right when preceded by a large number, and targets appearing on the left when preceded by a small number. This study represented the first piece of evidence that a predisposition to represent numbers on a left-to-right oriented line is present in humans from very early in life, not only before the ability of reading and writing, but also before the acquisition of symbols.

In 2019, a new study was carried out on 55-hour-old newborns (Di Giorgio et al., 2019). In this experiment, a monitor on which different numerical stimuli appeared in identical pairs was used. After the subjects had been habituated with some numerical value, the test started and pairs of stimuli presenting both small numbers or large numbers of objects appeared. Newborns showed a spontaneous association of small numbers with the left-space and large numbers with the right-space (Experiment 1). Moreover, it was noticed that newborns that habituated with the number 4, associated the number 12 with the right, while those habituated with the number 36, associated the number 12 with the left (Experiment 2), revealing that SNA in newborns does not depend on the absolute value of the number but it is instead relative (Di Giorgio et al., 2019).

Taken together, all the literature focusing on non-human animals and preverbal infants mentioned by far suggests that non-verbal individuals (non-human animals, non-reading and non-writing infants, and newborns) associate numbers and space on a right-to-left MNL which corresponds to the one adopted by adult humans.

Thus, the role that cultural factors (e.g., reading-writing habits) play in shaping the spatial-numerical association clearly assumes a secondary position, and biological origins become primarily investigated.

2.2.2 Biological Influences

The above discussed research studies demonstrating the existence of a SNA in non-human species and non-verbal humans constitutes evidence for the presence of a biological root. Additional support is issued by some neuroanatomical studies exploring the neurobiological origins of the number-space association. Neuroanatomical evidence shows that common structures in the parietal region of the brain have a role in both spatial and numerical tasks (Dehaene et al., 2003). It was also shown that spatial length and numerosity are encoded by groups of parietal neurons which share the same functions (Tudusciuc et al., 2007).

So far, we have focused first on evidence supporting culture as the main shaping factor of the association between space and numbers, then moved to an innovative body of research interested in the biological origins instead. In the next section of this work, I will report a new study which follows this second line of research (i.e., the Card Game).

3. THE CARD GAME EXPERIMENT

The Card Game experiment refers to the computer-based game that we researchers administered to the children in their nursing schools.

In this section I will focus on the objective of the study, describe the participants' characteristics, and then the methods used. I will also discuss the game setting, the stimuli and the procedure put in process and I will conclude reporting the results.

3.1 Aim of the study

The concept of the mental number line was found in humans and evidence showed how its presence was mainly due to cultural reasons (Shaki and Fischer, 2008; Shaki et al., 2009; Zebian, 2005). However, this long-held belief was challenged by evidence of the existence of a spatial numerical association in non-human animal species (Rugani et al., 2015; Adachi, 2015), early infants (Bulf et al., 2015) and newborns (Di Giorgio et al., 2019). In this way, culture assumed a secondary role, and a new biological aspect began to be researched.

The Card Game experiment that we have conducted is a study that takes part to the area of research investigating the development of the SNA in children.

A significant feature of the experiment is the age of the subjects, which ranges from 3 to 6 years of age. This allows us to assess the participants' behavior in a clearer and more direct way than how it is possible to do with infants and newborns. More importantly, this study aims at exploring the SNA in children in their preschool years, which have thus not been impacted by the cultural influence of school yet. In this way, the biological influences behind can be further investigated.

3.2 Participants

We tested 59 preschool children in total (22 males and 37 females) aged from 3 to 6 years old. However, only data from 31 subjects was analyzed (13 males and 18 females; N 6-year-old = 6, N 5-year-old = 13, N 4-year-old = 12). In fact, the test was modified twice after having observed that the number of trials originally adopted was not sufficient, and only the results of the final version were considered.

All participants spoke fluent Italian and were able to hear, talk and initiate movement. All children showed typical behavior except for one (form of selective mutism) but this had no impact on performance, and handedness was controlled for.

All the participants were recruited through a form given to the nursery schools that was voluntary filled out by the parents or legal guardians of the subjects. Before the start of the experiment, a written informed consent provided by the researchers had to be signed too, and the experiment had to receive ethic approval by the Ethic Committee of the Department of General Psychology of the University of Padua (Protocol 2970). At the end of the experiment, we gave each participant a "Scientist" certificate as a reward for participating in the research study.

3.3 Methods

Data was tracked and gathered through a bendable and touchscreen computer that was used as a tablet (Surface Book). Four different computer-based games were first administered to children during the "Researchers' Night" event in Padova on 30th September 2022. Then, both paper-and-pencil tests and the computer-based ones were conducted in four distinct nursing schools in the province of Padua (PD).

Before starting testing, a complete list of the children participating in the research project was provided to us (the researchers) by the school teachers. This one included all the participants' information (complete name, month and year of birth, potential issues).

Participants were tested in two separate rooms, one delineated for the paper-and-pencil tests, and the other one for the computer-based games. Each child was tested on either the computer-based games first and the paper-based ones second, or viceversa. Each participant was tested on two sessions taking place in two different days, as to avoid tiredness and attention overload, and the order of the tests was always inverted. Each daily session lasted approximately forty-five minutes per child, for a total of ± one hour and a half distributed in two days.

We administered the paper-based games as to gain a better understanding of the child's cognitive abilities. These tests include:

1 – Test Neuropsicologico Lessicale per l'Età Evolutiva (TNL) - *Lexical Neurologic Test for Children* (Cossu G., 2013);

2 – Test delle Campanelle - *The Bells Test* (Gauthier et al., 1989);

3 – Protocollo Memoria Uditiva - *Auditory Memory Protocol* (D'Amore B., 1993);

4 – Batteria per la valutazione dell'Intelligenza Numerica (BIN) - *Numerical Intelligence evaluation Battery* (Molin A., Poli S., Lucangeli D., 2007).

The computer-based games are the four novel tests developed by PhD Zhang Yujia with the program Psychopy 2021.2.3 and they consist in:

1 – *Arithmetic task*;

2 – *Number Line Bisection task*;

3 – *Train Game*;

4 – *Card Game.*

I personally contributed to the administration of all the above mentioned games, both the paper-based and the computer-based ones. However, in my dissertation I am focusing in particular on the Card Game, which will be described in detail in the next two sessions.

After the development of the computer-based games, we, as experimenters, devised the script for each game. In such manner, it was possible to have a set of formatted and objective instructions that could be used by different experimenters to explain the same game in the same way to different children and on different days.

The original Card Game script was the following (translated in English from Italian):

(Familiarization)

Very well.

Now, we will play the magic cards game. Some cards will appear on the screen and you will have to swipe one towards you. Some of these cards are magic, and when you swipe them, there will be a surprise. Let's see if you can find them!

CLICK MOUSE TO START THE FAMILIARIZATION

(Test-practicing)

Great! Now two cards will always appear together on the screen. One of them is magic. Your job is to find it and swipe it towards you. Are you ready?

CLICK MOUSE TO START THE TEST

However, it was then observed that some changes were needed as to suggest more strongly the existence of a rule behind. In fact, most participants did not quite understand the concept of succeeding in finding the magic card, and were answering randomly. We thus introduced the idea of a treasure hunt, encouraging the participants to find the rule that would allow them to find the treasure hiding behind the card. Therefore, the script was adjusted to this concept.

3.4 Game Setting

In the Card Game, the participant was seat down on a chair in front of a desk on which the computer was situated in a central position. On the opposite side of the desk, the experimenter was seating and guiding the participant through the task. Another researcher, called the "observer" was seating behind the participant, taking notes of observations on the participant's characteristics (e.g., name, age, handedness, etc.), behavior and performance (e.g., level of attention, understanding of the task, etc.).

The experimenter activated the game by inserting the identification number of the subject, and then proceeded to explain the task following the script of the game.

In the original script adopted, participants were asked to find the magic card that would reveal a surprise. The script was then adapted to further encourage participants to find a rule behind their decisions, thus we introduced the idea of a treasure hunt, asking them to find the right card behind which the treasure was hidden.

3.5 Stimuli and Procedure

The program used for creating the stimuli of the game is Psychopy 2021.2.3.

The stimuli consist of squares of 6x6 cm representing different cards, containing either two, five or eight dots (radius = 0.36 cm). When two cards were presented, the distance between them was of 3 cm.

Feedback is also present: Negative feedback consists in the chosen set being highlighted and accompanied by a flipping sound; Positive feedback consists in the chosen set being highlighted and then fireworks appearing on the screen accompanied by sound (2,000 ms).

An interval is present between trials (500 ms) and there is no time limit for answers.

SESSION 1 – Familiarization: The first part of the game consists in the familiarization, and cards with five dots are presented singularly with random feedback (4 out of 6 trials are positive). Participants are asked to swipe the card each time it appears on the screen. They are told that a treasure can be hidden behind the card, and fireworks appear when it is found.

SESSION 2 – Test Intuition: In the second part of the game the participant's intuition is tested. Two pairs of cards both having either two or eight dots are presented without feedback, and the participant is asked to choose one card. The order of the two trials (2_2 and 8_8) is randomized, half of the participants following the order A, with the 2_2 trial being presented first, and the other half following the B order, with the 8_8 one appearing first.
Then, a single card with five dots appears on the screen followed by positive feedback. The aim is to keep the participant's level of attention and interest high.

SESSION 3 – Training: The third part of the game consists of the Training, and pairs of cards with the same numbers of dots are presented, both having either two or eight dots (either 222 888 222 888 plus 10 trials in random order, or 888 222 888 222 plus 10 trials in random order). Two conditions are available:

1) SNARC condition (2_8 = reinforcement on the left for 2-2 and on the right for 8-8): Half of the subjects receive positive feedback when they choose a two-dots card on the left and an eight-dots card on the right (SNARC condition).
2) NON-SNARC condition (8_2 = reinforcement on the left for 8-8 and on the right for 2-2): The other half of the participants receive positive feedback when they choose a two-dots card on the right and an eight-dots card on the left (NON-

SNARC condition). In the first version of the game, there were only ten random trials in this session. After realizing that children needed more time to learn well, six trials with a fixed order were added ahead the ten ones. Other six training trials were added since they still seemed insufficient.

At the end of the test, the participant would have completed thirty trials in total.

The participants' answers and response times were automatically recorded and registered by the device used, and then reported to an excel table.

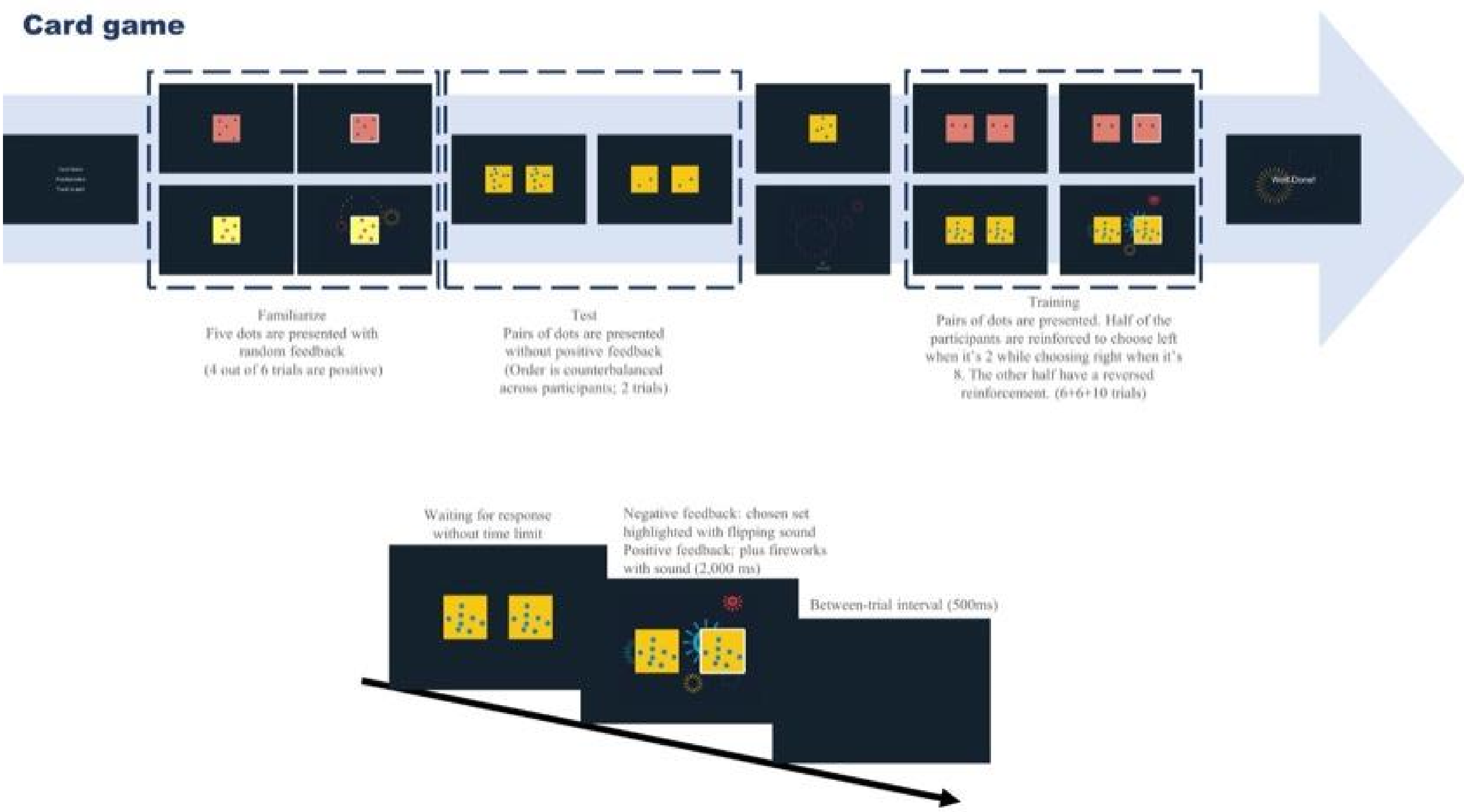

Fig.1: **Card Game Procedure**. Schematic representation of the procedure of the game. In the experiment participants underwent three different sessions: 1)Familiarization; 2)Test; 3)Training. In Training, a SNARC and a non-SNARC

Although the Card Game was the shortest among the other tests, it still required children to be focused and responsive for a significant amount of time for their young age. Throughout the task, the experimenter had to strongly encourage the participants, making sure that answers were not given randomly as a result of tiredness or frustration if their answer was wrong. Beside the formatted scripts adopted during the tests, researchers often recurred to more spontaneous sentences in order to support the child (e.g., “Non ti preoccupare, riproviamoci!” – “Don’t worry, let’s try again!).

The color pairs used for the background and for the dots are reported in the following tables 1, 2, and 3:

Color of dots	**Color of background**
[0.6549, -0.2549, 0.4353]	[0.9922, 0.9922, -0.2314]
[-0.2706, -0.5451, 0.2157]	[0.8040, 0.0559, -0.1510]
[-0.4980, 0.3804, 0.3020]	[0.7647, 0.4902, -0.1686]

Tab. 1: **rgb colors Familiarization**. In the table above, the color pairs used in the first Familiarization session are reported in rgb format.

Color of dots	**Color of background**
[-0.9059, -0.0353, 0.7255]	[1.000, 0.5216, -0.9216]

Tab. 2: **rgb colors Test**. In the table above, the color pairs used in the second Test intuition session are reported in rgb format.

Color of dots	**Color of background**
[0.6549, -0.2549, 0.4353]	0.9922, 0.9922, -0.2314]
[-0.2706, -0.5451, 0.2157]	[0.8040, 0.0559, -0.1510]
[-0.4980, 0.3804, 0.3020]	[0.7647, 0.4902, -0.1686]
[-0.9059, -0.0353, 0.7255]	[1.000, 0.5216, -0.9216]

Tab. 3: **rgb colors Training**. In the table above, the color pairs used in the third Training session are reported in rgb format.

3.6 Results

Out of the 59 children tested, only the results of the 31 subjects who participated in the last version of the test were considered. In this section, I will report the results obtained from the Card Game test and discuss some data analysis. Specifically, three aspects were investigated: intuition, training accuracy, and the side choice in training.

3.6.1 Test Intuition

- Intuition

As already stated, Section 2 of the Card Game (Test intuition) is aimed at testing the participants' intuition. The thesis behind is that if a spontaneous association exists between space and numbers such that small numbers are associated to the left and large numbers are associated to the right, then the preschool children tested would spontaneously associate the small number 2 with the left side and the larger number 8 with the right side, without needing training. Thus, when presented with the pairs of cards displaying either 2 and 2 or 8 and 8, they would tend to select the card on the left when it displayed 2 dots and the card on the right when it had 8 dots, even if feedback did not occur.

In the following table and plot (Tab. 5 and Fig. 2):

- first2 refers to order A of the trials (2_2 first, 8_8 second)
- first8 refers to order B of the trials (8_8 first, 2_2 second)
- test_2 refers to the 2_2 trial
- test_8 refers to the 8_8 trial

	left	right
first2_test_2	6	11
first2_test_8	8	9
first8_test_2	7	7
first8_test_8	4	10

Tab. 4: **Test intuition data table**. The table shows the number of times participants chose left or right in the two different orders (firs2 and first8) for the two different trials (2_2 and 8_8).

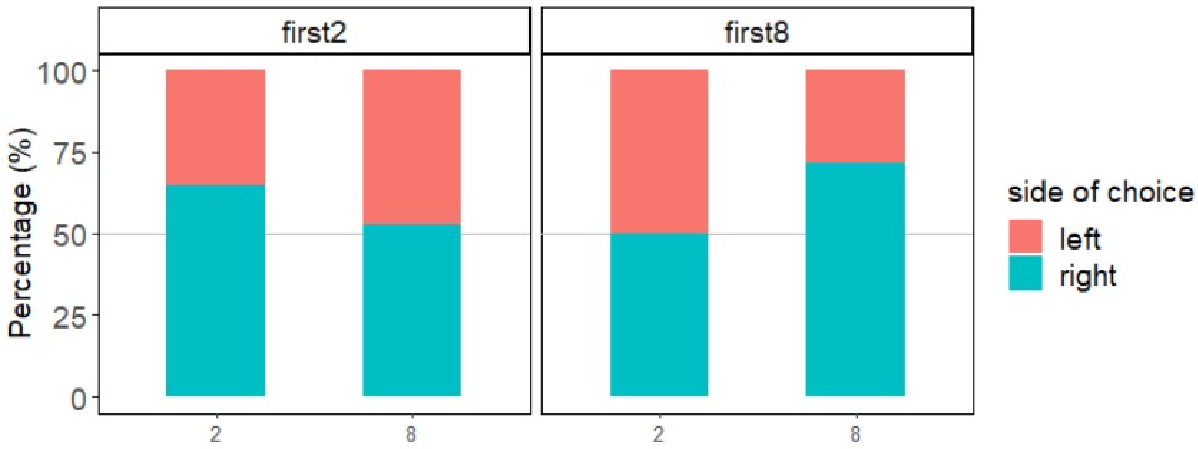

Fig. 2: **Test intuition data plot**. The percentages of times participants choose left or right in the two different orders (first2 and first8) for the two different trials (2_2 and 8_8).

The Chi square was calculated three times:

First, it was computed for the participants assigned to the first2 order (X-squared = 0.12143, df = 1, p-value = 0.7275);

Second, to assess the participants assigned to the first8 order (X-squared = 0.59893, df = 1, p-value = 0.439);

Third, the total Chi-square between the previous two ones was calculated (X-squared = 1.8475, df = 3, p-value = 0.6047).

However, no significant result emerged from these calculations.

3.6.2 Training

Concerning Session 3 of the Card Game (Training), two aspects were taken into consideration: training accuracy and the side chosen in training.

- Accuracy in training

Subjects were divided into three groups based on age (4-years-old, 5-years-old, and 6-years-old). Performance was compared for the first six trials, the second six trials and the final ten random trials, to check the subjects' accuracy in training.

In Table 5 and Figure 3, we find:

- Train_fix1 = the 1st six trials
- Train_fix2 = the 2nd six trials
- Train_random = 10 trials in random order

The two conditions are:

2_8 = reinforcement on the left for 2 and right for 8 (SNARC);

8_2 = reinforcement on the left for 8 and right for 2 (NON-SNARC).

ageY	**num_to_train**	**n**
4Y	2_8	6
4Y	8_2	6
5Y	2_8	7
5Y	8_2	6
6Y	2_8	3
6Y	8_2	3

Tab. 5: **Accuracy in training data table**. The table shows the number of participants choosing left or right according to their age (4, 5, or 6 -years-old) and the training condition (2_8 or 8_2).

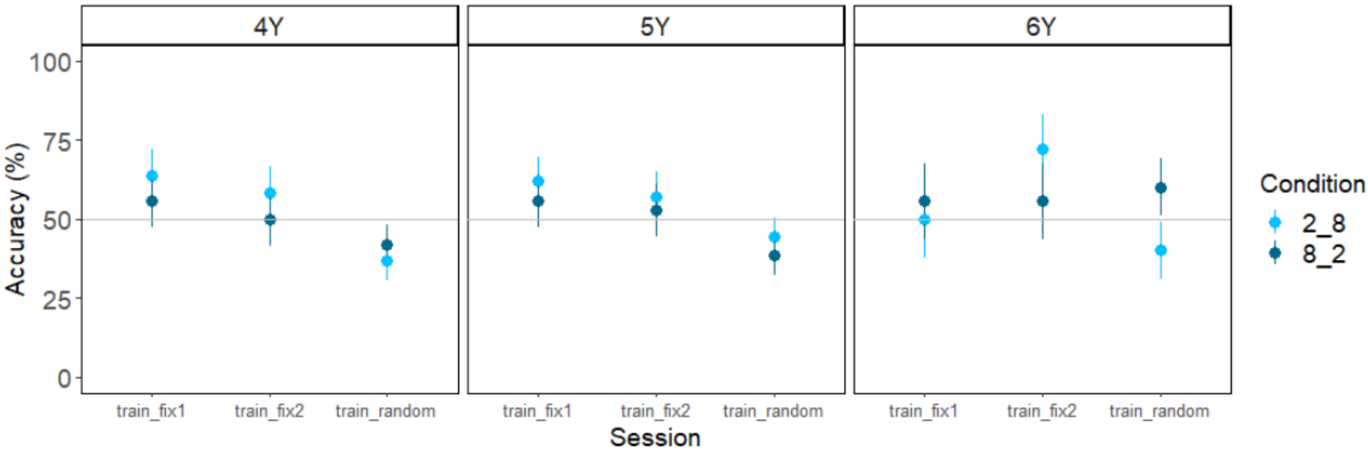

Fig. 3: **Accuracy in training data plot**. The performance of 4, 5 and 6 -years-old participants during the first six trials, the second six trials and the ten random trials is reported here.

The relation of the correct answers given by the participants, depending on the condition they trained on (2_8 or 8_2), their age (4, 5, or 6 -years old), and the session (1st six trials, 2nd six trials, 10 randomized trials) was calculated (Binomial GLMM). One significant result was obtained: the Effect of session. It refers to the fact that performance worsened in the last 10 trials, when trials were randomized (ps < 0.05).

```
> pairs(posthoc, simple = "session",adjust="bonferroni",paired=TRUE)
 contrast                   estimate    SE  df z.ratio p.value
 train_fix1 - train_fix2     -0.0315 0.226 Inf  -0.139  1.0000
 train_fix1 - train_random    0.5565 0.201 Inf   2.770  0.0168
 train_fix2 - train_random    0.5881 0.204 Inf   2.885  0.0117
```

Fig. 4: **Post hoc for the effect of session**. This table shows that children outperform in the fix sessions (fix1 and fix2) compared to the random session.

- Side choice in training

The interest was now on which side, either left or right, the participants would choose during training. Here the main thesis of the research study is tested, that is whether a spatial numerical association exists such that the preschool children tested would be more inclined to choose the stimulus on the left when it showed a small number (2), and the stimulus on the right when it displayed a large number (8).

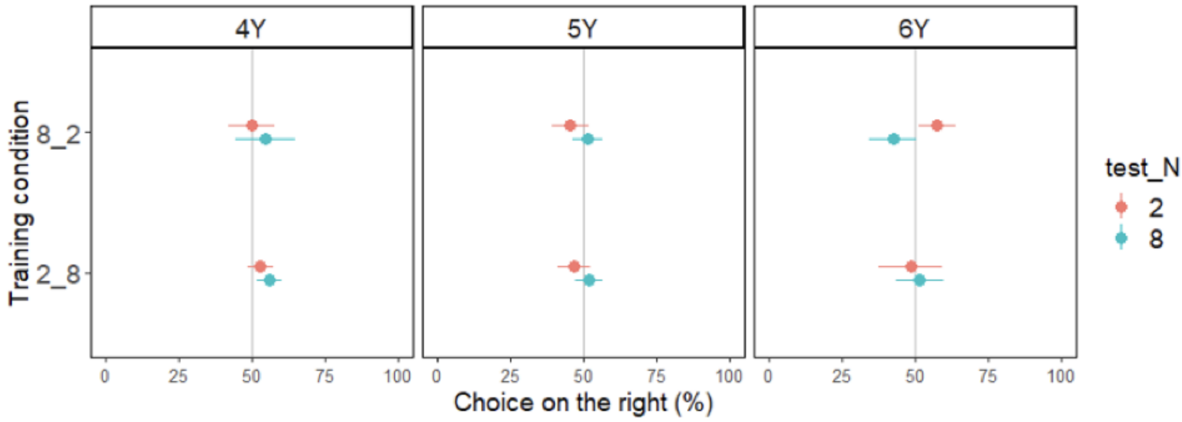

Fig. 5: **Training data plot**. The plot shows the side choice of the numbers 2 and 8 of 4, 5, and 6 -years-old participants in the 8_2 and 2_8 conditions.

The percentage of choices on each side (left and right) were analyzed by age (4, 5, or 6 -years-old), condition (2_8 or 8_2) and number displayed (2 or 8) (ANOVA).

As it is shown by the results reported in the table found in the next page, also here no result was found to be significant.

```
> count_side.fit <- aov(percent ~ ageY*num_to_train*test_N*choice_side + Error
(participant/(test_N*choice_side)), data = count_side0)
> summary(count_side.fit)

Error: participant
     Df    Sum Sq   Mean Sq
ageY  1 1.262e-29 1.262e-29

Error: participant:test_N
       Df    Sum Sq   Mean Sq
test_N  1 2.848e-28 2.848e-28

Error: participant:choice_side
            Df Sum Sq Mean Sq
choice_side  1  147.4   147.4

Error: participant:test_N:choice_side
                   Df Sum Sq Mean Sq
test_N:choice_side  1  287.8   287.8

Error: Within
                                     Df Sum Sq Mean Sq F value Pr(>F)
ageY                                  2      0    0.00   0.000  1.000
num_to_train                          1      0    0.00   0.000  1.000
test_N                                1      0    0.00   0.000  1.000
choice_side                           1    157  156.56   0.634  0.428
ageY:num_to_train                     2      0    0.00   0.000  1.000
ageY:test_N                           2      0    0.00   0.000  1.000
num_to_train:test_N                   1      0    0.00   0.000  1.000
ageY:choice_side                      2    331  165.35   0.670  0.514
num_to_train:choice_side              1     42   42.33   0.172  0.680
test_N:choice_side                    1    136  136.10   0.552  0.459
ageY:num_to_train:test_N              2      0    0.00   0.000  1.000
ageY:num_to_train:choice_side         2     19    9.72   0.039  0.961
ageY:test_N:choice_side               2    379  189.25   0.767  0.467
num_to_train:test_N:choice_side       1     49   49.42   0.200  0.655
ageY:num_to_train:test_N:choice_side  2    466  232.88   0.944  0.393
Residuals                            96  23688  246.75
```

Fig. 6: **ANOVA results of training**. Here, the side choice is tested by age, number to train (condition), and testing number.

4. DISCUSSION

In this last part of my work, I will conclude mentioning the limits that the study faces and discussing some suggestions for future research. At last, I will make some final observations on the results obtained.

4.1 Limitations

A limitation of the study is the sample size (N=31), not big enough to detect meaningful effects and to represent the general population of preschool children. Other limits concern the device used during the test and the setting in which the test took place. In fact, the "tablet" showed sometimes glitches or was occasionally not responsive to touchscreen. These situations caused the participants to either change their answers or to become frustrated and more easily tired. Additionally, the study took place in nursing schools during normal school days. For this reason, noise was at times present, and this could distract the subjects.

4.2 Suggestions for Future Research

In the future, research focusing on the development of the SNA should carry on investigating the association in preschool children. Researchers should increase the size of the sample tested in order to be able to represent a bigger population and to better interpret the meaning of the outcomes. In addition, the device implemented for the test should always guarantee an appropriate functioning (optimal touchscreen and limited number of glitches should be present), and the setting should be controlled as much as possible (no outside noise while conducting the study).

4.3 Conclusion

The results reported in the previous section showed that nothing significant emerged from the calculations performed in data analysis investigating intuition and the side choice in training. An interesting finding was the Effect of session in accuracy in training, where children reported a decrease in their performance in the ten randomized trials of the training sesssion. This aspect could be useful to consider when devising future tests.

Our thesis of the existence of a numerical association between space and numbers by which small numbers are spontaneously associated with the left-space and large numbers with the right-space, is thus not supported by the results we obtained with the Card Game test.

Nevertheless, the Card Game study still represents an important point in the area of research investigating the development of the spatial-numerical association. In fact, not a large body of research has implemented preschool children as subjects, and we hope that this study will encourage experimenters to bring their focus on this group.

This work was carried out as part of a larger research project led by the professors Rosa Rugani and Silvia Benavides.
Caterina Gattinara's contribution is restricted to a part of the project adapted to meet the requirement criteria for the bachelor/master mandatory internship.
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