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Final Dissertation

AN EXPERIMENTAL INVESTIGATION OF THE SPATIAL-NUMERICAL ASSOCIATION IN PRESCHOOL CHILDREN

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INTRODUCTION

1. Spatial Numerical Association

Sir Francis Galton, during the 19th century, observed that when individuals are asked to illustrate their mental visualization of numbers they tend to arrange them linearly, positioning smaller numbers on the left and larger numbers on the right. This organization is called the mental number line (MNL). Galton's observations have laid crucial foundations for subsequent explorations in the domain of spatial numerical association (Galton, 1889).

1.1 SNARC effect

In 1993, Dehaene, Bossini, and Giroux conducted a study that provided additional evidence supporting the existence of the Mental Number Line. This study involved French adult students in a parity judgment task that required them to press either the right or left response key based on whether a number was even or odd. The researchers observed that the participants responded faster when the smaller numbers were linked to left-hand responses and larger numbers were linked to right-hand responses, regardless of their parity judgment. This phenomenon has been termed the spatial numerical association of response codes (SNARC effect) (Dehaene et al., 1993).

Dehaene and colleagues further explored this phenomenon and observed that when participants made parity judgments on numbers ranging from 0 to 5, numbers such as 4 and 5 exhibited quicker right-hand responses. Conversely, when participants were judging numbers between 4 and 9, the same numbers 4 and 5 revealed faster response times when associated with left-hand responses. This indicates that the SNARC effect is dependent on the relative magnitude of the target number, rather than its absolute numerical magnitude (Dehaene et al., 1993).

An important line of research has developed from Dehane's experiment to further investigate the origin of the association between space and numbers.

1.1.2 Cultural Influences

The direction of reading and writing has been thought to play a major influence on the development of spatial numerical association. The findings of Dehaene and colleagues (1993) suggested a potential influence of writing directionality on the orientation of the mental number line. Iranian students who had relocated to France were subjected to testing. The results indicated that those who had recently moved from Iran and were more accustomed to a right-to-left writing system associated larger numbers with the left. Conversely, individuals who had lived in France for a more extended period displayed the conventional association of smaller numbers with the left and larger numbers with the right (Dehaene et al., 1993).

Zebian also discovered a reverse SNARC effect in Arabic mono-literates, who utilize a right-to-left writing system, as well as a diminished SNARC effect in Arabic biliterates (Zebian, 2015).

Another noteworthy study is that of Shaki, who explored the impact of writing directionality of numbers and words on spatial numerical association among Canadians (who write numbers and words from left to right), Palestinians (who write numbers and words from right to left), and Israelis (who write numbers from left to right and words from right to left). The results revealed a standard SNARC effect in Canedians, a reversed SNARC effect in Palestininans, and no significant SNARC effect in Israelis due to the conflict between spatial associations for words and spatial associations for numbers (Shaki et al. 2009).

Collectively, these studies provide important evidence of the influence of culture in determining the orientation in which numbers are mapped into space.

1.1.2 Experiments in newborns and children

Additional research has been conducted to investigate the potential influence of factors beyond culture in the development of spatial numerical association.

In 2010, Opfer made a significant discovery indicating that 4-year-olds showed quicker response times when objects were arranged from left to right, in contrast to arrangements from right to left. The experiment investigated individuals' covert attention in a spatial-search task involving two boxes, each containing 7 pictures verbally labeled either from left to right or from right to left. The hidden object was positioned beneath the same numeral in both boxes. After the experimenter revealed the location of the first hidden object, children were asked to find the hidden object in the second box. This finding suggests that spatial numerical association emerges before the acquisition of formal reading skills (Opfer et al., 2010).

Furthermore, there is compelling evidence that preverbal infants exhibit an overt attentional preference for sequentially increasing numerosities from left to right. A study involving 7-month-olds exposed infants to numerical sequences that either increased or decreased from left to right. During the subsequent test phase the infants exhibited prolonged gazes towards the increasing sequence as opposed to the decreasing one. Whereas no significant difference was observed when the sequences of numbers were arranged from right to left (De Hevia et al. 2014).

Research has also been conducted with numbers as task-irrelevant stimuli. Bulf, de Hevia, and Macchi Cassia conducted a study on 8 and 9-month-old infants using a Posner-like visuospatial attention task (Posner, 1980). In this task, small or large magnitude cues (e.g., 2 dots or 9 dots) were presented before the appearance of a visual target on either the left or the right side of the screen. The results revealed that even non-symbolic numbers' magnitude is responsible for the overt attentional shift. Infants demonstrated quicker target detection for stimuli appearing on the left when preceded by smaller numerosities and for stimuli appearing on the right when preceded by smaller numerosities (Bulf et al., 2015).

To better rule out cultural factors, research has also been conducted on newborns and a few days old children. De Hevia and colleagues conducted research on 0 to 3 days-old children demonstrating that even neonates associate small quantities with the left and large quantities with the right (De Hevia et al., 2017).

Even 55-hour-old newborns have been the subject of experiments. Di Giorgio and colleagues habituated newborns to a numerical value and observed that participants spontaneously associate greater magnitude numbers to the right and smaller magnitude to the left. As in adults, this phenomenon is dependent on numbers' relative magnitude. Neonates associated the same number (12) with either the left or the right side depending on the magnitude of the number they were habituated with (Di Giorgio et al., 2019).

These findings have not disproven the influence of culture on spatial numerical association, but rather found an innate human predisposition to order numbers along a mental number line from left to right since birth.

1.2 Number line bisection

Research studies have also employed number line bisection tasks in the investigation of spatial numerical association.

In 2001 Fisher used identical or different digits as flankers positioned at each end of the line. Participants were found to bisect the line depending on the magnitude of the pairs. When smaller digits were presented (eg."1-2" "2-1") the bisection was biased toward the left, when bigger digits were used (eg. 8/9 9/8) subjects were inclined to bisect the line toward the right. No bias was observed in the bisection of lines flanked by identical numbers (Fisher, 2001).

An unfilled space flanked by numbers was instead used by De Hevia, Girelli, and Vallar in 2006. In this study, it was observed participants' tendency to bisect toward the larger digit. These results have been interpreted by the researchers as a cognitive illusion, in which the perceptual representation of the line is influenced by the numerical symbols (De Hevia et al., 2006).

Similar bias was observed in 5 and 7 years-old in a line bisection task with non-symbolic numerosities. Children bisected the line toward the larger numerosity (De Hevia, Spelke, 2009).

NUMBER LINE BISECTION TASK

2. Methods

The present study was part of a larger body of research investigating spatial numerical association in preschool children. Different evaluation tools were incorporated in the experiment including paper-and-pencil assessments such as Lexical Neurologic Test for Children (Cossu G., 2013), The Bells Test (Gauthier et al., 1989), Numerical Intelligence evaluation Battery (Molin et al., 2007), along with the Auditory Memory Protocol (D'Amore B., 1993). Additionally, computer-based games such as Arithmetic, Number Line Bisection, Train Game, and Card Game were used.

In this thesis, I will be focusing on the number line bisection task. For this game, our specific aim was to explore whether an attentional shift can be observed in a line bisection task in alignment with the representation of numbers from left to right along a mental number line. More precisely, we investigated whether smaller numbers induce a leftward shift of participants' attention while larger numbers induce a rightward shift.

We employed non-symbolic numerosities, represented by groups of colored dots as flankers on both sides of the line to be bisected. This experimental design was inspired by the previously mentioned research conducted by De Hevia and colleagues in 2009. In De Hevia and colleagues' study, dot groups consisted of either 2 or 9 dots, with the leftward group always differing in magnitude from the right group.

Their study demonstrated a tendency of participants to favor bisecting the line toward the larger numerosity (De Hevia 2009).

Unilike the past study, we employed groups consisting of 2 or 8 dots with equal magnitude on each side of the line to be bisected, creating conditions of “2-2” or “8-8”.

3. Participants

The experiment involved 60 preschool children (29 females, 31 males). Their age ranged between 3 to 5 years. The sample was constructed by voluntary subjects from the schools in Padova, Cittadella (PD), or Chioggia (VE). All subjects spoke fluent Italian and showed typical behavior, except for one subject, affected by a form of selective mutism, whose behavior did not affect performance. Before testing, parents or legal guardians had to sign the written informed consent provided by the researchers. A “scientist” certificate was given to children as a form of reward after the completion of testing.

4. Procedures

All participants were tested on both paper-and-pencil assessments and computer-based games. Half completed the paper-and-pencil tests first, followed by the computer-based games, while the other half followed the reverse order.

The sequence of games was presented in the following predetermined order:

1. Card game
2. Number line bisection task
3. Train game
4. Arithmetic task

The testing procedure was conducted over two 45 minute sessions, which took place on separate days. Two separate rooms were used: one devoted to paper-and-pencil tests and the other dedicated to computer-based games. In each room, a table and three chairs were used. The participant and experimenter sat facing each other at the table, while an observer was positioned approximately 1.5 meters behind the participant. On the table, either the paper tests or the computer were placed.

To administer the tests, the experimenter followed a predetermined script. In contrast, the observer was responsible for walking subjects from the classes to the designed rooms and making detailed notes about participants' engagement in the task as well as recording participants' names, ages, and handedness.

To facilitate the administration of computer-based games, a bendable touchscreen computer (Microsoft Surface Book 3) was used. The computer programs were developed by Zhang Yujia using Python 3.6.6 and implemented using Psychopy 3 2021.1.4.

I played a role in administering all the mentioned tests, both as an experimenter and as an observer. However, the subsequent paragraphs will provide a detailed description of the number line bisection task.

4.1. Number line bisection procedures

This game was made up of 6 main sessions: 1 introduction, 4 practicings, and 1 testing.

INTRODUCTION: To introduce the game, an experimenter presented a cover story. The dots used in the testing phase were presented as ladybugs. The experimenter went on to explain that the ladybugs wanted to play with each other and for them to be able to play, they had to meet exactly in the middle of the road which separated them.

An animation of two happy and two sad ladybugs was used to reinforce the story.

PRACTICE 1: Participants were asked to touch the ladybug that appears on the screen. Positive feedback was provided when subjects were able to touch the center of the target. This phase was used to train touch precision.

A 12 by 12 mm figure of a ladybug was employed as target and a visual and auditory stimulus was used as feedback. A 6mm range of accuracy was predetermined and used throughout the experiment. Subjects were required to correctly touch the ladybug 3 times to move to the next phase.

PRACTICE 2: Starting from this phase a black 20x20 mm square first appeared on the screen in the same position (0,-80 mm) and individuals were asked to touch it. This step was used to ensure that every participant was looking toward t the same position before the testing started.

In practice 2, children were presented with a white 80mm long line. Subjects were invited to touch the center of it to make the ladybugs play together. The line was placed in a randomly assigned position in each trial.

This phase was composed of 4 trials, with a 10-second time limit for each trial. If no response or an incorrect response was given, no feedback appeared on the screen. A ladybug along with applauses' sound was instead used when participants were able to touch within 6mm from the center of the line. The same positive feedback was used throughout the whole test.

PRACTICE 3: Non-symbolic numerosities in the form of red dots (3mm radius) were introduced in this phase.

At the extremities of the white line, on the left and the right, dots were positioned in two square frames (50x50mm) arranged in groups of either 2 or 8 dots. As mentioned earlier, the same number of dots was presented on either side of the line to be bisected, resulting in conditions "2-2" and "8-8".

The different arrangement of the dots inside the frame was determined with the use of software to avoid the influence of variables that could influence the perception of the numerosities. **Fig 1** and **Fig 2** illustrate the layouts of dots employed in the experiment.

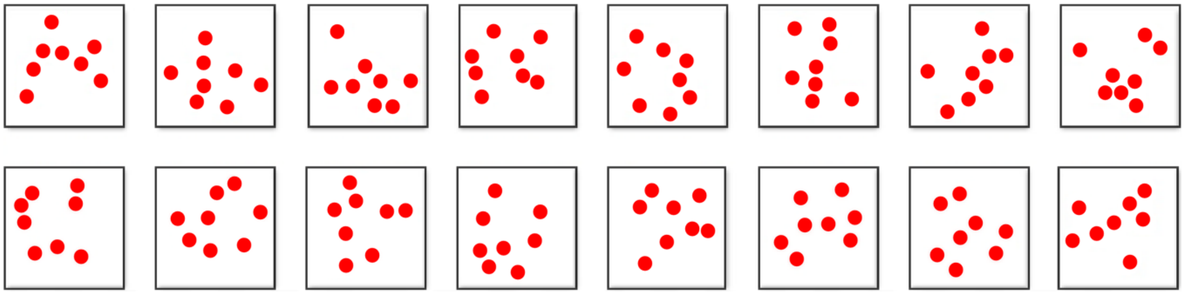

Fig. 1 - Dots layout in “2-2” condition.

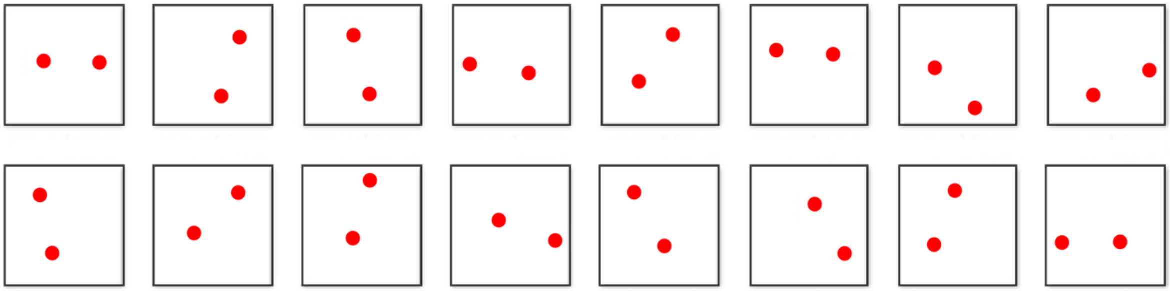

Fig. 2 - Dots layout in “8-8” condition.

PRACTICE 4: The same paradigm as in practice 3 was utilized and a recall phase was added. This phase was implemented to assess the influence on the performance of directing subjects’ attention to the numerosities.

After the line bisection task participants were asked to remember the groups of dots that were used as flankers.

Individuals had to choose between a frame with 2 dots and one with 8 dots. The order of presentation of the numerosities from left to right was controlled.

The experimenter explicitly invited the children to observe and remember the dots.

The preschoolers underwent four trials, each composed of a line bisection task and a recall task.

TESTING: The testing phase followed the identical procedure as practiced in Step 4: a horizontal line, flanked by two frames containing either 2 dots each or 8 dots each, appeared on the screen. Initially, participants were instructed to focus their attention on the dots and were told that the game will subsequently test if they remember them. The subjects were then invited to touch the center of the line.

Once completed the line bisection two frames each made up of either 2 or 8 dots appeared on the screen. The children were asked to select the frame that which represented the dots seen in the bisection task. Upon completion of all trials the experimenter congratulated the participant and positive feedback appeared on the screen. The test consisted of 16 trials of both line bisection and recall tests. A 10-second time limit was selected for each task.

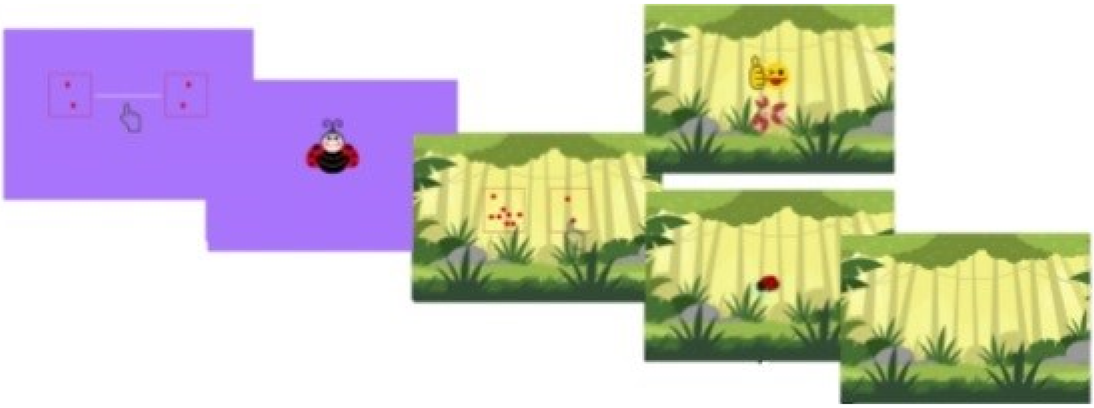

Fig. 3 - **Testing phase procedure.** Schematic representation of the procedure of the testing phase of the game

RESULTS

6. Statistical analysis of the results

As already stated, the primary aim of the experiment was to investigate whether the magnitude of flankers produce a directional bias in participants performance in a line bisection task. The findings did not suggest a significant directional bias in the task.

To comprehensively analyze the data, the results from each condition were first examined separately. Specifically, we considered the data for condition “2-2” and condition “8-8”. In the “2-2” condition, where participants were presented with flankers containing 2 dots each, the average position where they located the central point of the line was at a mean distance of -2.44 mm from the line's center. Similarly, in the “8-8” condition, characterized by flankers with 8 dots each, subjects identified the center of the line at a mean distance of -2.35 mm from the center.

However, while the mean values offered insight into the central tendency of the results a high standard deviation, of 10.41 in the “2-2” condition and 10.22 in the “8-8” condition was observed indicating a high dispersion of responses.

Six outliers were identified in the dataset. These individuals exhibited mean responses deviating by more than 2 standard deviations from the mean. Subsequent reanalysis of the data, with the exclusion of outliers, revealed that participants’ mean distance from the center in the “2-2” condition was -0-03 mm (SD 3.52), and for the “8-8” condition was 0.04 mm (SD 3.38).

Furthermore the results distributions displayed a high degree of symmetry, with skew values close to 0 (-0.32 with flanker “2”, 0.08 with flanker “8”). Additionally statistical significance of the data was assessed using a two-tailed t-test. However, the results (t-value = 0.15, degrees of freedom = 53, p-value = 0.88, effect size= 0.02) of this test did not indicate statistically significant differences between the two means.

DISCUSSION AND CONCLUSIONS

7. Discussion

The number line bisection task was a key component of a larger study exploring how preschool children perceive numbers in space. The methodological framework we adopted for this task (explained in section 4.2) was designed to investigate whether children tend to shift their attention leftward for smaller numbers and rightward for larger numbers.

In prior studies a similar line bisection task was used, but with flanker stimuli on the left differing in magnitude from the ones on the right (De Hevia 2009). These studies have revealed a perceptual bias of the participants to split the line toward the larger numerosities. To avoid this bias and focus on our research question, we used flankers with corresponding values as described in previous. However, the results of this experiment remained inconclusive.

7.1. Limitations and suggestions for further research

One potential limitation of this study could have been related to the chosen paradigm itself. The task predisposed by the experimenter might not have been appropriate for effectively measuring participants' attentional shifts.

Despite the introduction of a recall task, insufficient attention might have been directed by the participants to the numerical magnitudes, potentially leading to an absence of observable bias. These concerns were further amplified by participants’ susceptibility to distractions and fatigue. In future studies, an alternative approach could be considered to better engage participants' attention

Moreover, the experimental settings might have created substantial limitations to the study outcomes. Testing preschoolers within the school structure during regular school hours presented challenges. Some children exhibited signs of tiredness from the start of the test and occasional noises coming from nearby classrooms often constituted a source of distraction. To address these issues, future researchers could explore alternative timings and environments. Additionally, opting for briefer sessions could help reduce participants' fatigue.

8. Conclusions

As indicated by the results, no significant effect was detected. This outcome could potentially be attributed to the experimental setup or the chosen paradigm. Nonetheless, this study constitutes an important piece of evidence for future research. Particularly, conducting research involving preschool children has the potential to enrich our understanding of the development of spatial-numerical association. Additionally, future studies might explore the correlation between participants' cognitive abilities and their spatial-numerical associations.

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

Author contribution: Rosa Rugani, Silvia Benavides, Yujia Zhang.

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