DO DEVELOPMENTAL DYSCALCULIC CHILDREN HAVE SPATIAL BIASES IN PROCESSING NUMBERS? EVIDENCES FROM SNARC EFFECT

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Abstract

Developmental dyscalculia (DD) is a specific learning disability affecting the normal acquisition of arithmetic skills, it is hypothesized that they may be lacking ability to represent and manipulate numerical magnitude nonverbally on an internal number line. Hence the present study was attempted with the aim of observing spatial biases if any in children with developmental dyscalculia using spatial numerical association of response codes (SNARC) paradigm. Participants consisted of 12 children with developmental dyscalculia and thirty typically developing children in the age range of 9-10 years. Each participant received four white pages containing written instructions on the first page; and the other 2 pages contained 16 strings of digits and the other with 16 lines. All participants were instructed to bisect each stimulus in the middle. The distance between a bisection mark and both ends of a line was determined to the nearest millimeter, yielding a left and right interval for each stimulus. The difference score (left interval minus right interval) yielded a negative value when performance was biased to the left and a positive value when performance was biased to the right. The results revealed no evidence of SNARC effect in both the groups of children i.e., normal controls exhibited a right handed bias for both small and large numbers and left handed bias for lines whereas children with developmental dyscalculia exhibited a left sided bias for both lines and numbers. In the present study, we investigated spatial biases if any while processing numbers in children with developmental dyscalculia. The results revealed no evidence of SNARC effect in both the groups of children. The present observations, if substantiated by further research, may be useful for the diagnosis of number comprehension skills in children with developmental dyscalculia.

Key Words: SNARC effect, Developmental dyscalculia, internal number line

Numbers consist of one unique feature, which represents a particular aspect of quantitative information (Noel, 2001). Psychologists have tried to answer the question of how quantitative information is internally represented in the brain (Dehaene, 1989; Moyer & Landauer, 1967; Reynvoet & Brysbaert, 1999). Galton (1880a, 1880b) surveyed a mental representation of numbers and reported that subjects saw each number as a stable spatial mental structure. Seron, Pesenti, Noel, Deloche, & Cornet (1992) reported that 10 of his 15 subjects possessed a left-to-right-oriented mental representation. These studies indicate that the quantitative representation of numbers has a spatial structure, and that it may orient from left to right. In line with this, behavioral data also indicate that the quantitative representation might orient from left to right (Brysbaert, 1995; Fias, 2001; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Ratinckx & Brysbaert, 2002).

Earlier behavioral data were collected by asking subjects to conduct a parity (i.e., odd even) judgment task (Dehaene, Bossini, & Giraux, 1993). These data provided evidence of an association between number magnitude and the spatial location of response. Of late, a bisection task has been used for the same. Here digits are positioned in a left-to-right order according to the magnitude they represent. Digits representing small magnitudes (henceforth, called small digits) would be located further on the left along this number line and would benefit from a spatial compatibility advantage when speeded responses were required with the left hand. Digits representing larger magnitudes (i.e., large digits) would be positioned further on the right along the number line and would benefit from a spatial compatibility advantage when speeded responses were required with the right hand. The assignment of response (left

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or right) to a certain digit varies across blocks. Responses are found to be more towards the left hand when the number represented a small magnitude (e.g., 1 or 2) and more towards the right hand when the number represented a large magnitude (e.g., 8 or 9). This result was obtained despite the fact that magnitude information was not required to perform the task. The reaction time advantage of a spatially compatible mapping between stimulus numerals and manual responses is termed as spatial numerical association of response codes (SNARC) effect (SNARC; Dehaene, Bossini, & Giraux, 1993; Shaki & Petrusic, 2005; Vallesi, Binns, & Shallice, 2008). This effect emerges with numerical skill acquisition but does not extend to the categorization of letters of the alphabet. Normally developing children tend to show a subtle leftward bias on versions of line bisection task giving rise to negative values for asymmetry indices (Dobler, et al., 2001).

The SNARC effect might reflect automatic activation of the semantic representation of numbers, namely a spatially coded magnitude representation. This SNARC is notable because magnitude information is not strictly needed for deciding parity. Consequently, the presence of the SNARC effect has been taken to support the idea that the meaning of numerals (i.e., numerical magnitude) is activated in an automatic fashion when numerals are presented for view for any purpose. It is this explanation of the SNARC effect that we investigated in children with developmental dyscalculia.

Since developmental dyscalculia (DD) is a specific learning disability affecting the normal acquisition of arithmetic skills, it is a disorder of the notion termed 'number sense', characterized by deficits in very basic numerical skills such as number comparison(Dehaene, 1997, 2001; Landerl, Bevan, Butterworth, 2004; Rubinsten & Henik, 2005; Butterworth, 2005). There is available literature on developmental aspects of the SNARC effects in DD affected children aswell as typically developing normal children. Gender based differences have been reported as positive correlations between SNARC effect and mathematical ability in male children but not in the female children in the second grade levels. Although females possessed a mental number line representation, they were not as prepared as males to use this newly acquired tool to solve mathematical problems. This is attributed to female preference for language dependent strategies as with male preference for visuospatial and functional motor strategies. But controversy remains if the SNARC effect remains true for people who write from right to left as in Arabic and Hebrew. However, SNARC effect was found to be missing in 7-12 year old children with visuospatial deficits (Geary & Hoard, 2001; Bachot, Gevers, Roeyers, 2005; Von Aster & Shalev, 2007). As the number comprehension deficits are usually seen in DD populations we felt the need for investigating the SNARC effect in children with developmental dyscalculia without requiring them to perform arithmetic computations or generate results. Hence the present study is an attempt in this direction.

Method

Participants: Participants were divided into two groups. Group 1 consisted of twelve children with developmental dyscalculia in the age range of 10-11 years. All these children were studying in 4th and 5th grade. The diagnosis of mathematical disability was confirmed through arithmetic diagnostic test of primary school children (Ramaa, 1994). All these children have reading and writing deficits as assessed through informal testing procedures and diagnostic reading test in kannada developed by Purushothama (1992). Group 2 consisted of thirty typically developing age matched children studying in the 4th and 5th grade. All participants had normal or corrected vision and had no known speech, language, hearing and neurological disorders. They were naive about the hypothesis to be tested.

Materials: Each participant received four white pages, each 21.1 cm wide by 29.6 cm long. The first page contained written instructions, emphasizing accuracy and speed of responding. In addition, it contained blanks in which the participants entered their initials, age, and sex. The other two pages contained 16 strings of digits and fourth page consisted of 16 lines. The digit strings were generated as follows (Appendix 1): Two sets of digits represented small (1,2) and large magnitudes (8,9). From each of these four digits, two strings were generated, containing an odd (17 digits) or even (18 digits) number of elements yielding 52mm and 55mm respectively. This was done to see whether participants could bisect digit strings accurately. The strings were printed in 18 point Times New Roman font, yielding 3.05 mm per digit.

Each of the eight digit strings was positioned in a random fashion on a single page (left half, right half and center of the page). Position on the page was manipulated to see whether this spatial variable affected the spatial accuracy of responses, for example in a compensatory fashion. Endpoints of the stimuli were not aligned to prevent participants from referring to their previous bisection judgments. These numbers (1,2,8,9) were selected on the basis of previous study by Fishcer, 2001.

The 16 control stimuli were horizontal black lines with 0.9 mm width that matched the digit strings with respect to their length and positions on the page, yielding eight lines each of 84 mm and 87 mm in length. Order of stimulus type (lines and digit strings) was counter balanced across participants, and all sheets were presented in midsagittal plane.

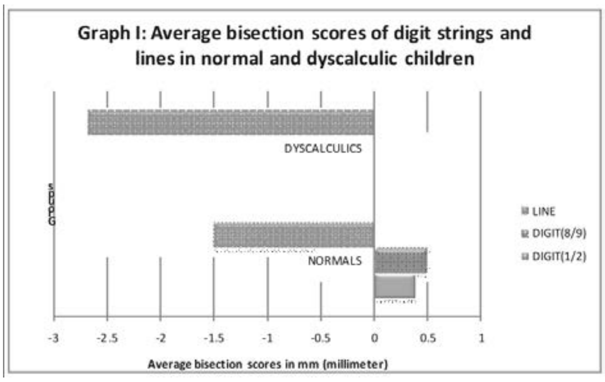
Procedure: All participants used a sharp pencil and positioned the stack of last three pages (stimuli) in their midsagittal plane. Participants were asked to give visual estimates and to avoid counting digits. All the participants waited until the experimenter gave a signal and their task was to bisect each stimulus in the middle. For digit strings, they were instructed to position a vertical mark such that half the digits were on the left and the other half on the right of it. After bisecting all stimuli on the second page, participants immediately turned to the third page and bisected all stimuli there.

Analysis: The distance between a bisection mark and both ends of a line was determined to the nearest millimeter, yielding a left and right interval for each stimulus. The difference score (left interval minus right interval) yielded a negative value when performance was biased to the left and a positive value when performance was biased to the right. Similarly, the number of digits to the left and right of each bisection mark was determined for each digit string. The difference score (number of digits on the left minus number of digits on the right) yielded a negative value when performance was biased to the left and a positive value when performance was biased to the right. The digits which were bisected at the midline were not considered for the analysis.

Results

In the present study, we investigated spatial biases if any in children with developmental dyscalculia using SNARC effect. Descriptive statistics was employed to find out the mean and standard deviation.

The results are shown in the graph 1



Graph I: Average bisection scores of digit strings and lines in normal and dyscalculic children

From the graph1, it is clear that normal controls have a differential processing for number and lines indicated by right sided bias for numbers and left sided bias for lines whereas in children with learning disabilities, left sided bias was seen for both numbers and lines.

Independent t-test and paired t-test was employed to find out the statistical inferences. The average bisection scores for lines in the clinical and the control group were -2.67 and -1.50 respectively and there was no statistically significant difference between the two groups at $p>0.05$ representing a reliable left bias in both the group of children. The average bisection scores for small and large numbers in the control group were +.1208 and +.2028 respectively and there was no significant difference between the bisection scores for small and large numbers indicating a reliable right bias for both small and large numbers and no evidence of SNARC effect. Comparisons across lines and numbers in the control group revealed significant differences indicating numerical symbols require specialized visuospatial processing than non meaningful stimuli like lines.

The average bisection scores for small and large numbers in children with developmental dyscalculia were -.0870 and - .1087 respectively and there was no significant difference between the bisection scores for small and large numbers at $p>0.05$ indicating a reliable left bias and no evidence of SNARC effect even in the clinical group. Comparisons across lines and numbers revealed no significant differences indicating children with developmental dyscalculia process both numbers just as processing of non meaningful stimuli such as lines.

However comparisons across the two groups for small and large numbers revealed a significant difference i.e., right side bias for typically developing children and left side bias for developmental dyscalculia group suggests that children in the typically developing group are on their way towards developing SNARC effect.

Discussion

In the present study, we investigated spatial biases if any while processing numbers in children with developmental dyscalculia. The results revealed no evidence of SNARC effect in the typically developing children i.e., bias was observed towards right hand side for small and large numbers. This suggests that SNARC effect has not developed completely even at the age of 9-10 years. The result of the present study contradicts the previous findings that SNARC effect emerges over the course of elementary school years (Berch, Foley, Hill, & Ryan, 1999; van Galen & Reitsma, 2008; Bachot, Gevers, Fias, & Roeyers, 2005). Though the SNARC effect is not evident in the control group, the difference between line bisection and digit string bisection is highly significant indicating that normal children have a differential processing for both numerical symbols and lines at the age of nine and ten. This supports the view that numerical symbols receive specialized visual processing which differs from the processing of non meaningful numbers such as line (Fischer, 2001). This finding also indicates that human beings are not endowed with the complete association between number magnitude and internal representational space, but this association may be constructed completely at a relatively later stage of development presumably after fifth grade. As there were uneven number of males and females, gender based differences were not carried out which adds limitations to the present study.

On the other hand, left sided bias was observed in developmental dyscalculia for both small and large numbers as well as lines. The difference between line bisection and digit string bisection is not significant indicating that developmental dyscalculia process numbers just as the processing of non meaningful stimuli such as lines. This indicates the difficulty with mapping the numbers on an internal number representation indicating the visual-spatial deficits in children with developmental dyscalculia. This could be that number line for children with developmental dyscalculia are misoriented i.e., more towards left than normal children where the bias is more towards right. A possible reason for the misoriented number line is that the children with developmental dyscalculia are far too heterogeneous to obtain reliable measures. However, this does not seem plausible because the subjects were carefully selected in order to obtain homogeneity in the group. Probably, the involvement of spatial working memory processes in the neural underpinnings of developmental dyscalculia might be a contributing factor (Rotzer et al., 2009). These poor spatial working memory processes may inhibit the formation of spatial number representations (mental number line) as well as the storage and retrieval of arithmetical facts.

Though SNARC effect is not evident in both the group of children, normal controls exhibited a right handed bias and children with developmental dyscalculia exhibited a left sided bias. This suggests that children in the control group are partially on their way towards developing SNARC effect. However, this is not observed in children with developmental dyscalculia suggesting that there could be a visual spatial deficit in children with developmental dyscalculia. This presumption is supported by the findings that SNARC effect was missing in 7 to 12-year-old children with visual-spatial deficits (Bachot, Gevers, Roeyers, 2005).

Conclusions

In the present study, we investigated spatial biases if any while processing numbers in children with developmental dyscalculia. The results revealed no evidence of SNARC effect in both the groups i.e., normal controls exhibited a right handed bias for both small and large numbers and left handed bias for lines whereas children with developmental dyscalculia exhibited a left sided bias for both lines and numbers. This suggests that children in the control group process numbers and lines differently. However children with developmental dyscalculia did not exhibit a differential processing of numbers and lines indicating the visual spatial deficit in these children. The present observations, if substantiated by further research with more number of samples in both the gender in normal and DD children, may be useful for the diagnosis of number comprehension skills in children with developmental dyscalculia. Also, SNARC effect in people who write from right to left as in Arabic and Hebrew would be interesting and adds further information to the existing knowledge.

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APPENDIX 1 : MATERIAL 1

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