The Non-Symbolic (NS) numerosity and symbolic number processing abilities of children were tested

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ABSTRACT

The approximate system of numeration (ANS) theory and therefore the ANS mapping account are the foremost prominent theories on non-symbolic numerosity processing and symbolic number processing respectively, over the last 20 years. Recently, there's a growing debate about these theories, mainly supported research in adults. However, whether the ANS theory and ANS mapping account explain the processing of non-symbolic numerosity and symbolic number in childhood has received little attention. Within the current ERP study, we first examined whether non-symbolic numerosity processing in 9-to-12-year-old children (N = 34) is intuitive, as proposed by the ANS theory. Second, we examined whether symbolic number processing is rooted in non-symbolic numerosity processing, as proposed the ANS mapping account. ERPs were measured during four same-different match-to-sample tasks with non-symbolic numerosities, symbolic numbers, and combinations of both. We found no evidence for intuitive processing of non-symbolic numerosity. Instead, children processed the visual features of non-symbolic stimuli more automatically than the numerosity itself. Moreover, children don't seem to automatically activate non-symbolic numerosity when processing symbolic numbers.

INTRODUCTION

Numerical processing is a vital early marker of mathematical performance. Numerical processing may be subdivided into no--symbolic numerosity processing (e.g., comparison between two sets of dots) and symbolic number processing (e.g., comparison between two Arabic numerals or number words). A prominent theory on non-symbolic numerosity processing is that the ANS (approximate number system) theory. This theory states that approximate numerosity, i.e., the quantity of objects in a very set, is intuitively extracted when one is confronted with a collection of objects, like a dot pattern. this implies that the visual properties of a collection of objects are removed or normalized, such the numerosity of the set can easily be established, which this process goes without much effort. The ANS mapping account concerns symbolic number processing, and theorizes that symbolic number processing in adults is rooted in non-symbolic numerosity processing. Approximate non-symbolic numerosity is believed to be activated automatically when processing symbolic numbers. There's currently a hot debate about whether the ANS theory and ANS mapping account hold or whether alternative theories are more likely to elucidate non-symbolic numerosity processing and symbolic number processing. The aim of this study was to look at whether the ANS theory and ANS mapping account do underlie non-symbolic numerosity processing and symbolic number processing in children. An event-related potential (ERP)-paradigm was employed to achieve insight into the processing of non-symbolic numerosity and symbolic number. ERP-research on the validity of the ANS theory and ANS mapping account in children is restricted. ERP-research in adults shows both evidence confirming the ANS theory and ANS mapping account, furthermore as more moderen evidence against the ANS theory and ANS mapping account. Children's numerical processing mechanisms may either be the identical or different from those in adults. Research has shown that even infants seem to own a rudimentary understanding of non-symbolic numerosity. However, it's not yet completely clear whether this can be purely supported numerosity, or whether it's supported the visual features of a collection of objects.

Moreover, the event of symbolic number processing only starts at a later age The present study had two aims. The primary aim was to research whether non-symbolic numerosity processing in children between 9 and 12 years old is intuitive, in line with the ANS theory, or whether numerosities are processed supported the processing of visual features instead, as is proposed by alternative theories like the sensory-integration theory and sense of magnitude theory. Second, we examined whether children's processing of symbolic number will be explained by the ANS mapping account, or whether this processing is independent of numerosity, supported symbol-symbol associations.

Non-Symbolic Numerosity Processing

The ANS theory states that non-symbolic numerosity processing relies on an innate approximate number representation system. Non-symbolic stimuli are thought to be processed by an intuitive estimation of numerosity, independently of physical features of the stimuli, like the dimensions of the objects. Proof of concept for this theory is especially supported behavioural ratio effects within comparison tasks: Comparing two non-symbolic numerosities is tougher when these numerosities are closer in magnitude. This ratio effect is assumed to result from a mental number line wherein numerosities that are spatially located together are automatically co-activated, suggesting that non-symbolic numerosities are processed intuitively. Results from ERP research mirror the behavioural results by showing early ratio-dependent ERP amplitudes around 200 ms after stimulus presentation, suggesting that numerosity processing is fast. Although the ANS theory suggests that stimuli are processed independent of physical properties, physical features are inherently associated with numerosity in world. for example, if one child has two pieces of candy and another child has four pieces of candy, then the second child's candy will occupy more of the beholding. in keeping with the ANS theory, these visual features would be removed in an exceedingly very early stage of numerical processing, after which numerosities are estimated or compared. However, rather than estimating numerosity after removal of visual features, one might better use visual properties of the objects to work out which child has the foremost candy. To prevent the employment of visual properties to estimate or compare

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numerosities, most research on non-symbolic numerosity processing therefore aims to regulate for visual properties of the stimuli. Even when using this sort of control, some studies still find early effects of numerosity, independent of visual features, which can be interpreted as evidence for the ANS theory. However, there are studies that show that with proper control over visual features, effects of numerosity are absent or only starting around 650 ms. These results don't align with the ANS theory, since intuitive processing is unlikely to require such an extended time, because it should take little effort. Hence, these results are better explained by alternative theories, like the sensory-integration theory which posits that the combination of visual features is at the idea of an approximation of numerosity. In children, it's become evident that the processing of non-symbolic stimuli relies more and more on actual non-symbolic numerosity with age and education, whereas physical properties of the stimuli quieten down relevant. this might reflect the increasing precision of the ANS. Alternatively, it's going to reflect a growth in inhibition, withdrawing the kid from intuitively responding to visual features and basing their decisions on the amount of elements instead. The argument of accelerating precision of the ANS would end in early effects of numerosity within the ERP with smaller and comparatively short-lasting effects for visual properties. However, growth in inhibition would lead to late effects of numerosity within the ERP together with early and possibly longer-lasting effects of visual properties. Our first aim was thus to look at whether non-symbolic numerosity processing is indeed intuitive, as proposed by the ANS theory, leading to early effects of numerosity. Alternatively, children could process visual features more automatically than numerosity, which might be more in line with the sensory-integration theory, leading to early effects of visual features together with later or no effects of numerosity.

Symbolic Number Processing

The ANS mapping account theorizes that symbolic number processing is rooted within the processing of the corresponding non-symbolic numerosity. As such, when encountering variety, the corresponding numerosity is assumed to be automatically activated in adults. Evidence for this account is principally supported similar ratio effects for symbolic numbers and non-symbolic numerosities, which was assumed to flow from to similar overlapping representations of numerosities and numbers. The timing of those non-symbolic ratio effects and symbolic distance effects is additionally similar, as has been shown by ERP research. Arguments for the ANS mapping account thus seem convincing. However, recent research has challenged the ANS mapping account, by raising several theoretical concerns about important assumptions and caveats in those theories. for instance, ratio and distance effects have also been found in non-numerical comparison tasks like ordering letters of the alphabet, which don't have overlapping representations. This means that the results are likely task-related rather than numerosity-related. Supported these results one cannot conclude that numerosity and number share the identical numerical representation. Recently, symbolic numbers are suggested to be processed independently of numerosity. Moreover, we showed that adults don't automatically activate numerosities when processing symbolic numbers. Measuring EEG (ERPs) during four different match-to-sample tasks, we demonstrated that processing a non-symbolic target is different when the target is preceded by a non-symbolic prime compared to being preceded by a symbolic prime. If one would assume that a symbolic prime automatically activates the corresponding non-symbolic numerosity, one would expect that the processing of the non-symbolic target wouldn't differ supported whether it's preceded by a symbolic or non-symbolic prime. As such, these results suggest that even when a task requires mapping, symbolic stimuli don't seem to be automatically mapped onto their corresponding non-symbolic numerosities in adults. From a developmental perspective, it seems that symbolic number processing is intertwined with non-symbolic numerosity processing in (young) children. When children learn numbers, they learn them by mapping these onto numerosities. For instance, many children start learning numbers by counting their (and others) body parts. However, symbolic skills appear to require a more prominent place than non-symbolic skills within the development of mapping skills in four-to six-year-old children. Whereas non-symbolic skills are associated with symbolic skills and mapping skills within the first year of kindergarten, the relation between non-symbolic and symbolic skills becomes insignificant within the second year. Moreover, research shows that symbolic processing predicts non-symbolic skills as soon as children have initial number understanding, rather than the opposite way around. this implies that if these skills are still related in older children, non-symbolic processing might not be the first format as proposed by the ANS mapping account. Instead, (larger) symbolic numbers is also acquired by the successor function, and should be embedded during a semantic network of numbers rather than grounded within the ANS. this might explain why the relation between non-symbolic and symbolic number weakens with age. In purely symbolic tasks, children from kindergarten to 3rd grade, still as children in sixth grade are found to use digits' physical properties to see their magnitude, instead of their numerical value during a same-different task. No distance effect was found for numerical value. in a very mixed notation task–in which digits needed to be compared to non-symbolic numerosities–a distance effect was found, showing no development with age until the top of elementary school. In contrast, other research on symbolic digit comparison and comparison of non-symbolic numerosities found that the sizes of the symbolic and non-symbolic distance effects both decreased between six and eight years old. The researchers concluded that children's magnitude representations become more precise as they get older. Whether the gap effect becomes more fine-tuned with age or not, it seems evident that an impact is present in children, even when controlling for visual properties of the non-symbolic stimuli. Therefore, it can be that in children symbolic number processing is rooted in non-symbolic numerosity processing, in line with the ANS mapping account and findings in younger children. This could especially be the case when numbers must be associated with numerosities, which can involve either activation of the non-symbolic numerosity supported the processing of the symbolic number, or the activation of notation-independent code that's also activated by non-symbolic numerosities. However, supported adult literature, it should even be that older children don't activate the corresponding numerosity in a very purely symbolic task. In mapping tasks, they'll map numerosities onto numbers, thus within the other way as predicted supported the ANS mapping account.

CONCLUSION

To conclude, our results show very late numerosity-related ratio effects, together with early effects associated with the visual features of non-symbolic stimuli. As such, these results seem to contradict the ANS theory, and suggest that processing of non-symbolic numerosity is unlikely to be automatic. Moreover, we found that non-symbolic numerosity isn't automatically activated when processing symbolic numbers, which contrasts the ANS mapping account (Dehaene, 1997). Although children can relate numbers and numerosities, given their behavioral ratio effect within the mapping tasks, this process doesn't seem to be automatic. In adults, it's been suggested that symbolic number might be the first format of processing, and non-symbolic numerosity processing may occur by estimating the quantity of dots, so compare the numbers during a symbolic format (Van Hoogmoed and Kroesbergen, 2018). However, this hypothesis doesn't seem to carry either, since we found that the processing of symbolic targets is additionally captivated with task format in children. this might however result to the very fact that children, contrary to adults, don't anticipate on the upcoming target. The difference between the symbolic targets within the mapping task and therefore the purely symbolic task may well be explained by the notion that children still have to process the prime once the target it presented. Future research including both a blocked design and a mixed design (i.e., manipulating expectancy of a particular format) would be suitable to look at this idea.

Moreover, future research including younger children could shed light on differences within the dependence or independence of symbolic number processing on non-symbolic numerosity processing over development. This might substantiate this evidence against the ANS theory and ANS mapping account.