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Correlation Between Automatic Processing of Symbolic and Non-symbolic Magnitudes in Children

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Abstract

Does the automatic activation of number influence children's decision-making on physical size judgments? Previous work dealing with how children process symbolic and non-symbolic numbers typically involves making direct judgments about numerical values. In this study, instead of asking for judgments about numerical magnitude, we assessed the automatic activation of number by asking children to make physical size judgments. This will allow us to further learn how children use their understanding of numbers to help them make decisions that do not directly involve numbers. In addition to this, by looking at how the processing of symbolic and non-symbolic numbers relate, we will get a closer look at when children acquire an understanding of both symbolic and non-symbolic numbers. In the symbolic task, children were asked to indicate which number was physically larger; and in the non-symbolic task, children were asked to indicate which dot array took up a larger area. Through these tasks we hope to address two questions. First, if the automatic activation of numbers will facilitate or interfere with the required size judgments; and second, the extent to which responses on the symbolic and non-symbolic tasks relate. Fifty-two children between the ages of 6 and 9 completed the study on a laptop computer. Response time and accuracy were recorded for each participant on each task. Results indicate that in the non-symbolic task, the automatic activation of number facilitates and interferes with size judgments, but in the symbolic task, automatic activation of number only interferes with size judgments. To assess the relationship between the two tasks, we correlated interference and facilitation effects; however, no significant correlations were found. The findings from this study will help further our understanding of how children learn numbers, and the mechanisms involved in number processing.

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Correlation Between Automatic Processing of Symbolic and Non-symbolic Magnitudes in Children

In almost any aspect of life, one common characteristic is the need for an understanding of numbers. Numbers help us make decisions, communicate with others, and solve problems. For example, a simple activity like grocery shopping involves our number processing abilities. As we approach the checkout area, we scan to see which line looks the shortest. In this instance we are using what is referred to as our non-symbolic number processing. It is non-symbolic because we do not use any symbols. When we actually get to the cashier however, we are using what is referred to as our symbolic number processing. It is symbolic because in this instance we are using digits to understand the amount we need to pay.

Amongst the literature looking at symbolic and non-symbolic number development, a common topic is the study of the mechanisms behind number processing. When we talk about the processing of numbers, we are interested in whether symbolic and non-symbolic numbers share a mechanism through which numbers are represented. When dealing with non-symbolic number information, the most common theory is that humans possess an Approximate Number System (ANS; Dehaene, 1997; Gallistel & Gelman, 1992). The ANS is seen to be our basic, automatic, and innate system for representing numbers. If we go back to our grocery store example, we use our ANS to pick which line to stand in. The ANS is our system for approximation and estimation of quantities, and we use this approximation to get a sense of which line has a smaller number of people waiting in it, and therefore will be the fastest to wait in.

Symbol Grounding

Symbolic number information is different. There does not appear to be an innate understanding of symbolic numbers. Instead, we need to learn what a symbolic number means and represents. Current research looking into how we learn symbolic numbers, proposes that number symbols acquire their meaning by being mapped onto the preexisting non-symbolic representation of that number (Dehaene, 2007; Piazza, 2010; Stoianov, 2014). For example, if a child is presented with the symbolic number three, a child acquires the meaning for that three by mapping it to the non-symbolic representation of three in our ANS. This idea is referred to as symbol grounding. Although we do not know for sure if the ANS provides the basis for acquiring symbolic numbers, if this were the case, it would point to a shared mechanism for processing symbolic and non-symbolic information. Symbol grounding suggests that without our non-symbolic representation of number, we would not be able to acquire symbolic representations of number (Harnad, 1990, 2003).

Although current theories propose that we acquire symbolic meaning by mapping to the preexisting non-symbolic representation, a recent review paper by Leibovich and Ansari (2016) indicates the literature is mixed on this finding. A correlational study conducted by Halberda, Mazzocco, and Feigenson (2008) found a positive association between 14-year-old children's approximation abilities and past scores on math achievement tests. Other studies however, have not found such relationships. In a study conducted by Holloway and Ansari (2009), a non-significant correlation was found between symbolic and non-symbolic distance effects, suggesting symbolic and non-symbolic numbers are processed separately. As these papers highlight, the current state of literature regarding the relationship between symbolic and non-symbolic number processing is filled with contradictory results (De Smedt, Noel, Gilmore, & Ansari, 2013). In the present study we hope to learn more about the relationship between symbolic and non-symbolic number processing in children. Specifically, we hope to add to the literature regarding the mechanisms behind processing numbers by focusing on children just entering school. In order to understand how children develop a relationship between symbolic and non-symbolic numbers, it is important to first have a good understanding of both sides of the argument when it comes to the mechanisms behind number processing. Only then can we focus on the relationship between symbolic and non-symbolic number processing in children. We now turn to focus on a number of important studies that provide evidence both for and against a shared mechanism for processing symbolic and non-symbolic numbers.

In a study using functional brain imaging, Fias, Lammertyn, Reynvoet, Dupont, and Orban (2003) set out to test if there is a shared mechanism for representing different types of magnitudes. These experimenters hypothesized that there is a common representation of magnitude, and used brain-imaging techniques to identify regions in the brain that activate as a result of symbolic and non-symbolic information processing. Using an adult sample, experimenters employed a comparison task with three different conditions. The comparison task asked participants to indicate which of two stimuli was larger. The first condition was a digit comparison, and tested symbolic magnitude processing. Participants were presented with two numbers, and had to indicate which number was numerically larger. Non-symbolic magnitude processing comprised the other two conditions, and these tasks involved saying which of two lines was larger, and which of two angles was larger. Through a conjunction analysis of the three comparison tasks, Fias et al. (2003) found a region in the intraparietal sulcus (IPS) in the left hemisphere that activated in each task. After controlling for all extraneous variables between tasks, such as mental effort or attentional load, the authors concluded that that the only possible activation of these regions was due to the processing of symbolic and non-symbolic magnitudes in the comparison tasks (Fias et al., 2003). Providing evidence for a shared mechanism that processes both symbolic and non-symbolic information.

Another study that supports the idea of a shared mechanism was conducted by Kolkman, Kroesbergen, and Leseman (2013). Using a longitudinal design, the experimenters tested children's non-symbolic and symbolic skills at ages 4, 5, and 6. There were two tasks involved, each containing a symbolic and non-symbolic component. In the first task, children had to indicate where on a horizontal number line a given number should be found. In the symbolic version they were given an Arabic digit to place on the number line, while in the non-symbolic version they were given a dot array (a non-symbolic representation of number) to place on the number line. The second task involved indicating which of two values was larger. In the symbolic version they had to choose which of two Arabic digits was larger, while in the non-symbolic version they had to choose which of two dot arrays contained more dots. Through the use of a factor analysis, Kolkman et al. (2013) found evidence that prior to age 6, children process symbolic and non-symbolic information through separate mechanisms. However, once children reach the age of 6, evidence appears to suggest that symbolic and non-symbolic information are processed similarly through the use of a common mechanism. This study provides support that children originally process symbolic and non-symbolic information through separate mechanisms, but that around the age of 6, children begin to process symbolic and non-symbolic information through a shared mechanism.

Although there is evidence supporting a shared mechanism, it is important to also discuss some evidence against a shared mechanism. A study conducted by Sasanguine, Defever, Maertens, and Reynvoet (2014) provides evidence against a shared mechanism. With a sample of kindergarten children, the experimenters conducted a non-symbolic comparison task, followed by a second non-symbolic comparison task as well as a symbolic comparison task six months later. Through a correlation analysis, the experimenters found that a child's ability on the first non-symbolic comparison task did not predict ability on the symbolic comparison task six months later. As well, no relation was found between the non-symbolic and symbolic comparison tasks that were completed at the same time. It there were a shared mechanism, we would expect to see some correlation between a child's performance on the two tasks. However, the finding that the scores do not correlate, points to separate mechanisms for processing symbolic and non-symbolic information.

The correlational study conducted by Sasanguine, Defever, Maertens, and Reynvoet (2014) provides a good base foundation for the finding that symbolic and non-symbolic information is processed through separate mechanisms, however it is important to look at a study that experimentally tested this relationship. A study conducted by Lyons, Ansari, and Beilock (2012) provides experimental evidence against a shared mechanism. In this study, a comparison task was employed in a sample of adults in which there were three conditions; a symbolic, non-symbolic, and mixed condition. In the symbolic condition, participants had to indicate which of two numbers was larger. In the non-symbolic condition, participants had to indicate which of two dot arrays contained more dots. Lastly, in the mixed condition, participants were presented with one number, and one dot array, and had to indicate which quantity was numerically larger. If it were the case that numbers share a mechanism, we would expect no difference in response times between the three conditions. However, this is not what the experimenters found. Response times were longest in the mixed condition, indicating it took them longer to figure out which quantity was larger. This points to the idea that symbolic and non-symbolic numbers are processed by separate mechanisms.

Automaticity of Numbers

One common characteristic from all the studies presented here, is that experimenters ask participants directly about numbers. Whether it is a symbolic or non-symbolic task, participants are told to indicate which value is numerically larger. In the present study, we moved beyond asking directly about number, and asked about size or area. We were interested in the automatic processing of symbolic and non-symbolic number, and asked participants about size or area to see how automatic processing differs between symbolic and non-symbolic numbers.

To do this, we used a numerical congruity task, which was employed in a study conducted by Henik and Tezlgov (1982). In a numerical congruity task, participants are presented with two digits in different physical size. The numerical size and the physical size are manipulated to create three conditions. In the congruent conditions, the size or area judgment will match the numerical judgment (i.e. 2 6). In the incongruent conditions, the size or area judgment will not match the numerical judgment (i.e. 6 2). Lastly, in the neutral condition, the two stimuli presented will contain the same numerical value, but the size or area judgment will be larger for one of the stimuli (i.e.2 2). In the symbolic version of this task, we asked children to make a size judgment by indicating which number was physically larger. In the non-symbolic version of the task, groups of dots appear instead of digits, and children were asked to indicate which dot array had a larger area. The non-numerical features of the dots (e.g., physical size, total surface area, density, etc.) are positively correlated with the quantity of the dots in congruent trials, and negatively correlated with the quantities in incongruent trials (Hurewitz, Gelman, & Schnitzer, 2006). In neutral trials, the two groups contain the same number of dots and differ only in their non-numerical magnitudes. Figure 1 provides an example of the congruity task used in this study.

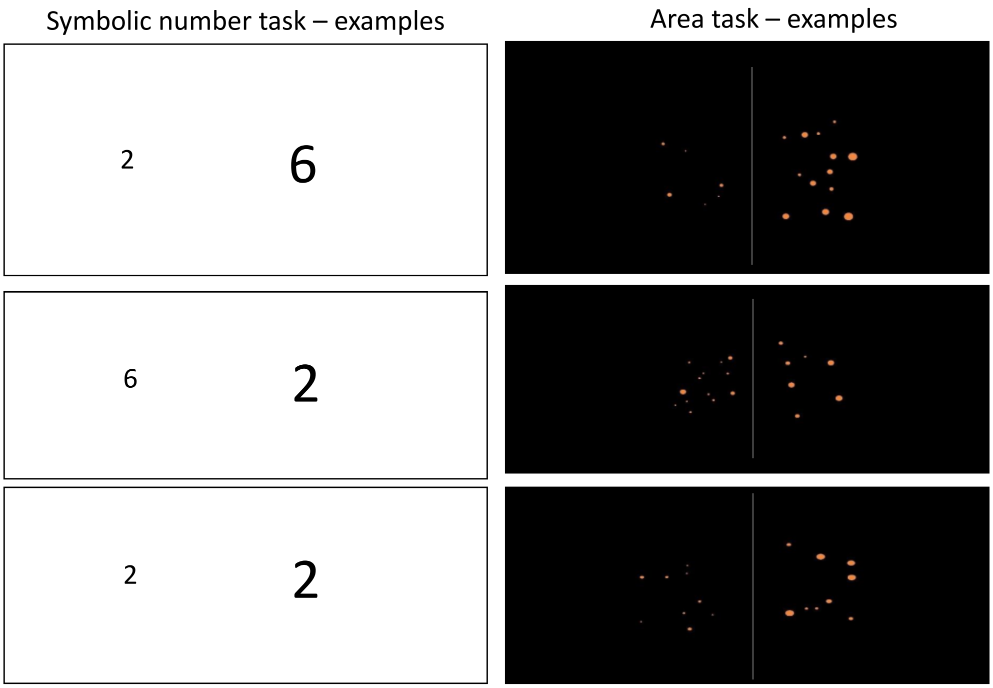

Figure 1. The stimuli used in both the symbolic and non-symbolic congruity tasks.

Studying automatic processing allows us to learn the extent to which a child understands numbers. Specifically, automatically processing numbers indicates that children have acquired the understanding between a symbolic number and its meaning (Gebuis, Cohen-Kadosh, de Haan, & Henik, 2008). To study automatic processing in this experiment, two sources of information were employed in the numerical congruity task: physical and numerical. When these sources of information are congruent, the decision making process should be faster, and we should see a decrease in response time compared to neutral trials (Gebuis, Cohen-Kadosh, de Haan, & Henik, 2008; Henik & Tzeldov, 1982). This decrease in response time is referred to as a facilitation effect. Facilitation is when we use our understanding of number to our advantage when making a size judgment. However, in the case of incongruent trials, when the physical and numerical judgments are opposite, it should take longer for children to respond compared to neutral trials. This increase in response time is referred to as an interference effect. Interference is when our understanding of number inhibits our ability to make a size judgment. Figure 2 provides a graphical explanation of the congruity task findings, as well as a representation of the facilitation and interference effects. Through the presence or absence of interference and facilitation effects, we will be able to determine if a child has an understanding of number without directly asking them about numbers. For example, in the symbolic task, a child would be asked which of two numbers is physically larger. If that child is faster at making this judgment when the physically larger number is also numerically larger, this suggests that the numerical magnitude of the symbol was automatically activated. If a child is able to automatically access the meaning of a number it will result in a faster response time when the judgments are congruent, and a longer response time when the trials are incongruent. Such a

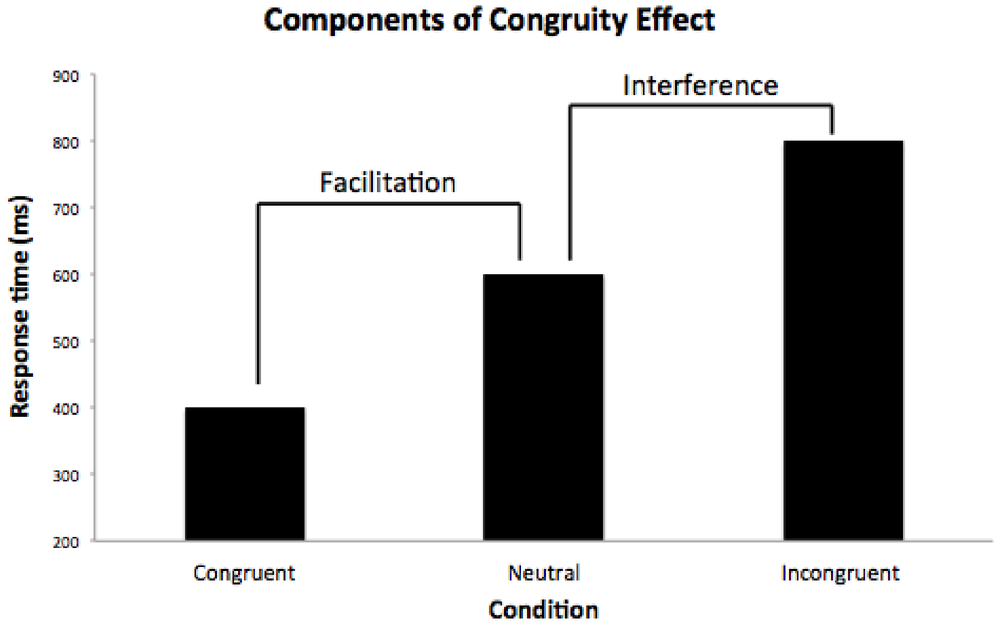

Figure 2. Expected findings from the congruity task, as well as a representation of both a facilitation and interference effect. Congruity effect as a whole is calculated as the difference between response time on incongruent and congruent trials.

finding would support that the given individual has acquired the meaning of the presented symbolic numbers.

Current Study

The current study was conducted with children between the ages of 6 and 9. We were interested in this age range for several reasons. First, the results of a study conducted by Rubinsten, Henik, Berger, and Shahar-Shalev (2002) show a facilitation effect only once children reached third grade (i.e. 8-9 years old). A finding we expect to replicate in this study. These authors propose this result has to do with memory retrieval for experiences with Arabic digits. As we get older we have more instances in which we compare Arabic digits, and we begin to store memories for these moments of comparisons. Rubinsten et al. (2002) argue that as children get older and encounter more Arabic digit comparisons, they are able to process these digits faster and in an automatic fashion. It is because of this that we see a facilitation effect only once children reach the third grade. Children in Grades 1 and 2 have not had enough experience with Arabic digit comparisons to be able to process them automatically. The second reason we were interested in this age range is to further explore the relationship between symbolic and non-symbolic number processing in young children. Specifically, we were hoping to learn more about whether or not symbolic and non-symbolic numbers are linked early in a child's development. This will help address the symbol-grounding problem of whether children learn the meaning for symbols by associating them to their non-symbolic representation.

In this study, we investigated two research questions. The first question was whether the automatic activation of number facilitates or interferes with both symbolic and non-symbolic size judgments. Second, we asked whether the automatic representation of symbolic and non-symbolic magnitudes correlate with one another. There were two goals we hoped to accomplish from answering these questions. The first was to investigate how automatic activation of numbers influences our decision-making when we are not directly asked about numbers. The second was to add to the literature concerned with whether symbolic and non-symbolic magnitudes are processed through the same mechanism.

Similar to previous studies looking at symbolic and non-symbolic number processing, participants were presented with two stimuli. What is different about this study, is that in the symbolic task, participants were asked to indicate which number was physically larger; while in the non-symbolic task, participants were asked to indicate which dot array took up a larger area. No questions were asked about the numerical magnitude of the digits or dot arrays. There were three conditions in each task; congruent, neutral, and incongruent. We measured both accuracy of responses and response time.

Based on the current state of the literature, we hypothesized that the automatic representation of number will facilitate participants processing during congruent trials, and interfere with participants processing during incongruent trials. Facilitation and interference effects have been found in adult samples, and we believe the same will be found in children (Gebuis, Cohen-Kadosh, de Haan, & Henik, 2008; Henik & Tzeldov, 1982). Due to the conclusion drawn in a recent review paper by Leibovich and Ansari (2016), in which current evidence does not support the notion that number symbols are grounded in the ANS, we believe that there are different mechanisms for processing symbolic and non-symbolic numbers. With this in mind, we hypothesized that the absence of a correlation would imply separate processing mechanisms, while the presence of a correlation would imply a shared processing mechanism.

These findings will add to our knowledge of how we process symbolic and non-symbolic numbers, and more importantly, whether they are processed through a shared mechanism.

Although it is widely claimed that symbols acquire their meaning by being grounded in the non-symbolic representation of that number, there is still evidence that speaks against this. This evidence indicates that symbolic numbers may not acquire meaning by being mapped to non-symbolic information; pointing to separate mechanisms for processing symbolic and non-symbolic numbers. By employing automatic representation in our task, we will be able to see whether or not participants have acquired the meaning for symbol numbers, and further understand how, and when, we acquire symbolic number meaning. The findings from this study will add to our knowledge of how we process symbolic and non-symbolic information, and help resolve the discrepancy of whether or not symbolic and non-symbolic numbers share the same processing mechanism.

Method

Participants

The sample for this study was comprised of 52 children between the ages of 6 and 9 (M_{AGE} = 7.28, SD_{AGE} = 1.02; 27 Female, 25 Male; 41 right-handed, 11 left-handed) enrolled at River Heights Public School in Dorchester, Ontario, Canada. Seven participants were excluded from the non-symbolic task, and eight were excluded from the symbolic task, due to lack of understanding the task or lack of focus. Data was collected over a three-week period. All participants were typically developing children between the ages of 6 and 9, with no participants being in a class below the first grade. In order to participate the child must have had no attention deficits, learning disabilities, or neurological disorders, as reported by his or her guardian or parent. Upon completion of the study participants were presented with a $10 gift card to their local bookstore as a thank you for their participation. The research protocol was approved by the University's Research Ethics Board.

Materials

The first material was the assent form any child aged 7 and older was required to sign, indicating they understood the study and agreed to participate. Second, a practice booklet that comprised the tasks the children would see during the experiment was created. This allowed the children to familiarize themselves with the various tasks, and practice for the real experiment. Third, a laptop was required so that OpenSesame, a computer software that specializes in creating psychology and neuroscience experiments, could be opened for participants to complete the experiment (Mathôt, Schreij, & Theeuwes, 2012). OpenSesame presented all instructions and stimuli, in addition to collecting all responses made throughout the experiment. Fourth, a numerical keypad was used so participants could make their responses. The numerical keypad is a reduced keyboard, saving space and limiting distractions for the children. Compared to a typical desktop keyboard, it is equivalent to the right hand section of the keyboard, which is made up primarily of numbers. The keypad will connect to the laptop through a USB attachment. Fifth, a numerical keypad cover was created specially for this experiment. The keypad cover is placed directly over the numerical keypad, and allows for only two responses to be made during the experiment. This limited distractions for the children, and made responding easier. Lastly, $10 gift cards to the participants' local bookstore were purchased to be given to each child as a thank you for their participation in the study.

Procedure

Participant selection. In order to encourage children to participate, a specific selection procedure was employed. The selection procedure started when Dr. Daniel Ansari, the principal investigator for this study, contacted the Thames Valley District School Board (TVDSB) to present the study, and ask for their help to identify possible schools that may be interested in participating. Second, the TVDSB then provided Dr. Ansari with a list of schools that may be interested in participating. Third, the experimenters contacted these schools and provided them with additional information regarding the study. Fourth, the schools that agreed to participate contacted the experimenters, and the experimenters then dropped of Letters of Information (LOI) to each of the schools. Fifth, the LOIs were given to students to take home for their parents or guardians to read. Sixth, if the parents or guardians consented to their child's participation, they signed the LOIs, and the child returned the form to his or her teacher. Lastly, the forms were collected, and once all forms were returned, the experimenters were notified that data collection could begin.

Instructions and Paper Practice. Participants were taken out of class one or two at a time to complete the study. Each experimenter assisted only one participant at a time. Prior to beginning the task on the computer, experimenters walked through the instructions with the participants, and asked for written assent from participant's aged 7 and up, and verbal assent for any participants below the age of 7. Upon assent, participants were then given the chance to go through the practice booklet to practice each of the tasks, and familiarize themselves with that the study entailed. After going through the booklet, participants moved to the computer where they began the study.

Non-symbolic task. In this task, children were presented with two dot arrays, and asked to indicate which dot array had a larger overall area (see Figure 1). In each trial, a blank screen was presented for 500 ms, followed by a green fixation dot in the middle of the screen also for 500 ms. The fixation dot was followed by another blank screen for 500 ms, followed by the presentation of the dot arrays for 700 ms. After the stimulus was presented, a blank screen appeared for 1300 ms to allow extra time for the children to make their response. As soon as the stimulus was presented, children could make their response; so the 700 ms for the stimulus presentation, and the 1300 ms for the response blank, allowed for a window of 2000 ms for children to respond using the numerical keypad. The end of one trial was signified by a red stop sign with a hand in the middle, meaning responses for that trial could no longer be recorded. This process was repeated for a total of 60 trials, split into two blocks of 30 trials. This allowed for a break halfway through the task to ensure the children did not get too tired or lose focus.

The nonsymbolic task was the first task all participants completed upon beginning the study. The task was open and ready to go in OpenSesame, and the laptop was set to the first part of the task, the instruction screen. The experimenter allowed time for the child to read the screen, and answered any questions the child may have had before starting the task. The task began with a three-trial practice phase. This allowed the children to understand what to expect from the study, as well as provided them with feedback so they could tell if they were responding correctly or incorrectly. If the experimenter felt the participant needed more practice, or if the participant wanted more practice, the practice trials were repeated until the participant was comfortable with the task. After the practice phase, the real trials took place. A screen popped up indicating that practice was over, and that the real trials were about to begin. After the first 30 trials were completed, a screen popped up to allow for a short break before the participants went on to complete the remaining 30 trials. Upon completion of the task, the last screen thanked the child for his or her participation.

Symbolic Task. The symbolic task employed the exact same procedure as the non-symbolic task. The only differences being that the stimuli in this task were Arabic digits opposed to dots, and that participants were asked to indicate which of two Arabic digits was physically larger.

After completing the non-symbolic task, participants were given a short break before they began the symbolic task. The symbolic task was always completed after the non-symbolic task because we did not want to prime participants with the concept of number, since number was the irrelevant dimension in these tasks.

Completion of Study. From beginning to end, the experiment took roughly 30 minutes to complete. Upon completion of the study, participants were thanked for their participation, and presented with a $10 gift card to their local bookstore as a token of appreciation.

Results

Three different analyses were run in this study, all of which were conducted through Just Another Statistics Program (JASP, https://jasp-stats.org). All three analyses involved reaction times in milliseconds (ms) for only correct trials on both the symbolic and non-symbolic tasks. Figure 3 demonstrates that accuracy was very high in this study, and is not a concern moving forward with our analyses. As seen in Figure 4 reaction times were fastest in the non-symbolic task, with congruent trials being fastest (*M* = 620 ms, *SE* = 13.63), followed by neutral trials (*M* = 646 ms, *SE* = 15.14), and lastly, incongruent trials (*M* = 673 ms, *SE* = 14.56). In the symbolic task, the reaction time on congruent trials (*M* = 685 *SE* = 11.72) was just barely faster than the neutral trials (*M* = 686, *SE* = 11.20), while the reaction times on the incongruent trials (*M* = 712, *SE* = 11.12) was the longest. The first analysis was a 3 (Congruency: congruent, neutral, and incongruent) X 2 (Task: symbolic and non-symbolic) repeated measures ANOVA to ensure the congruity task had its intended effect. This analysis revealed a main effect for congruency, $F(2, 86) = 56.8$, $p < .001$, $\eta^2 = .569$, indicating that at least one of the mean reaction times differed significantly from the others. The analysis also revealed a main effect for task, $F(1, 43) = 7.66$, $p = .008$, $\eta^2 = .151$, indicating that the reaction times differed significantly between the symbolic

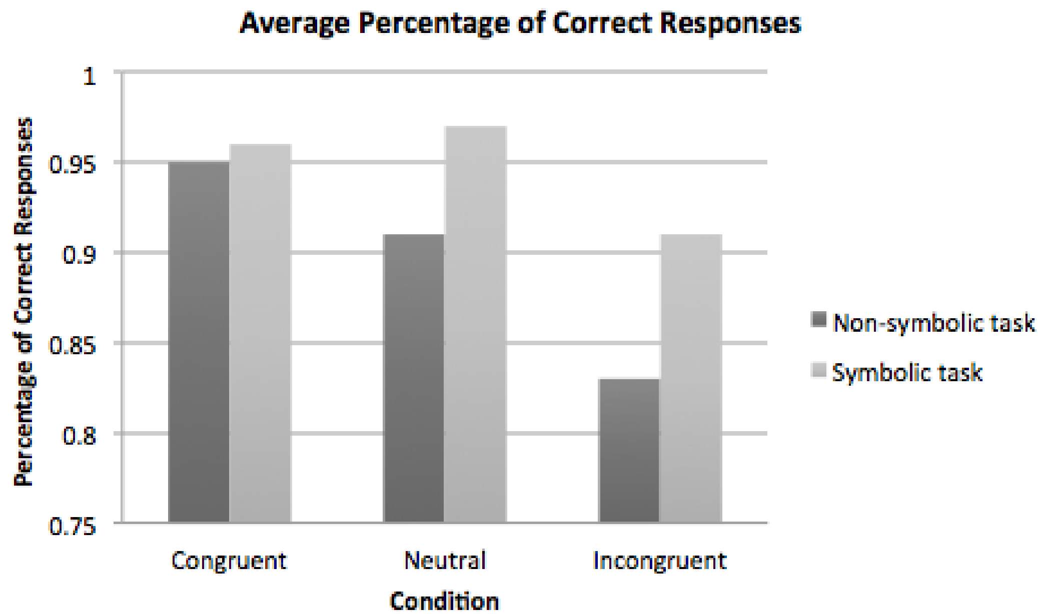

Figure 3. Accuracy of each condition in each task. Represented by the average percentage of correct responses.

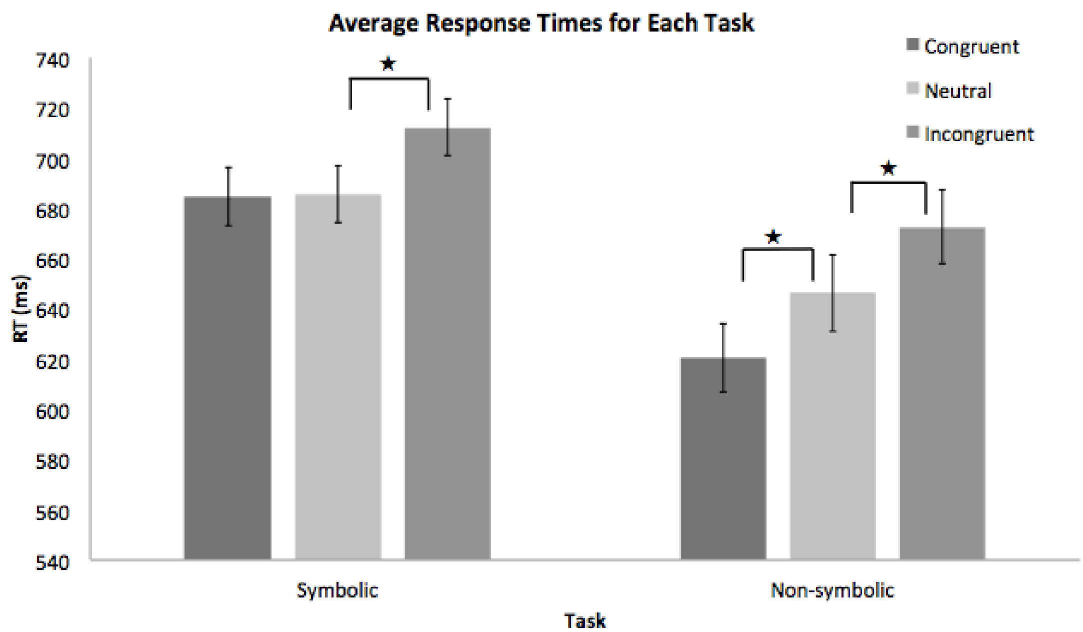

Figure 4. Average reaction times for each congruity level in both the symbolic and non-symbolic tasks. ★□= $p < .05$.

and non-symbolic tasks. Lastly, an interaction effect between task and congruency was found, $F(2, 86) = 5.96$, $p = .004$, $\eta^2 = .122$, indicating that reaction times varied significantly depending on the task and level of congruency.

To follow up this interaction, we conducted our second analysis, which involved paired sample t-tests to look for interference and facilitation effects in both tasks. A facilitation effect is calculated by subtracting the reaction time on congruent trials from the reaction time on neutral trials (Neutral – Congruent). An interference effect is calculated by subtracting reaction times on neutral trials from the reaction time on incongruent trials (Incongruent – Neutral). In the non-symbolic task, a facilitation effect was found, as the reaction times for the congruent trials were significantly faster than the reaction times on the neutral trials, $t(44) = -4.93$, $p < .001$, $d = -0.74$. In addition to a facilitation effect, an interference effect was also found in the non-symbolic task, as the reaction times for the incongruent trials were significantly longer than the reaction times for the neutral trials, $t(44) = -4.14$, $p < .001$, $d = -0.62$. In the symbolic task however, only an interference effect was found. Namely, response times were significantly longer for incongruent trials compared with neutral trials, $t(43) = -5.13$, $p < .001$, $d = -0.77$. However, when comparing the reaction times between the congruent and neutral trials, no significant difference was found, $t(43) = -0.14$, $p = .887$, $d = -0.02$, as participants took roughly the same amount of time to respond to both.

Lastly, to assess the relationship between symbolic and non-symbolic magnitude processing, a correlation analysis was conducted. Three correlations were conducted. The first involved correlating facilitation scores between the symbolic and non-symbolic task. As seen in Figure 5, a non-significant correlation was found, $r(42) = -.15$, $p = .328$. The second correlation was between interference scores from the symbolic and non-symbolic tasks. Similar to the facilitation correlation, and as seen in Figure 6, a non-significant correlation was also found $r(42) = -.07$, $p = .661$. The last correlation was conducted for only the reaction times of the incongruent trials. Reaction times from the incongruent trials on the symbolic task were correlated with reaction times from the incongruent trials on the non-symbolic task. Similar to the previous two correlation analyses, and as seen in Figure 7, a non-significant correlation was found, $r(42) = .00$, $p = .994$.

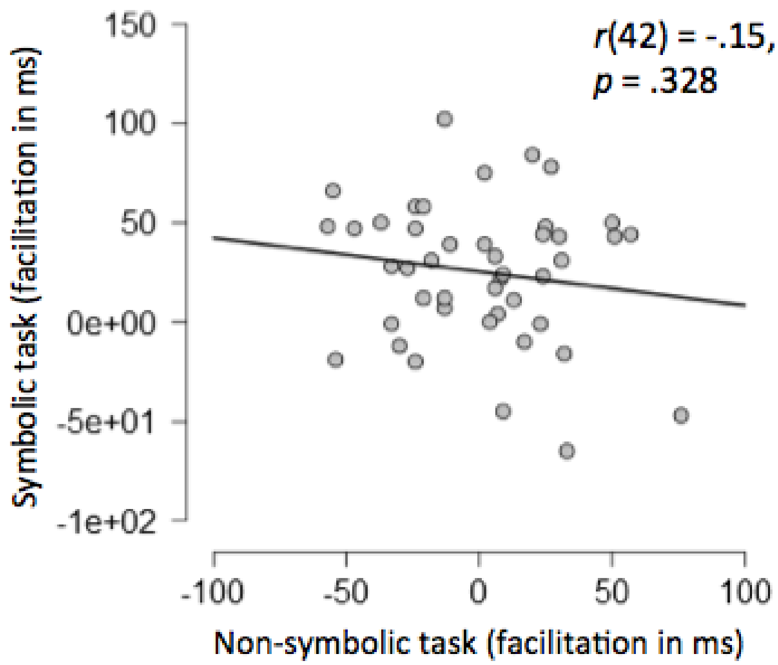

Figure 5. Correlation between facilitation scores from the symbolic and non-symbolic tasks.

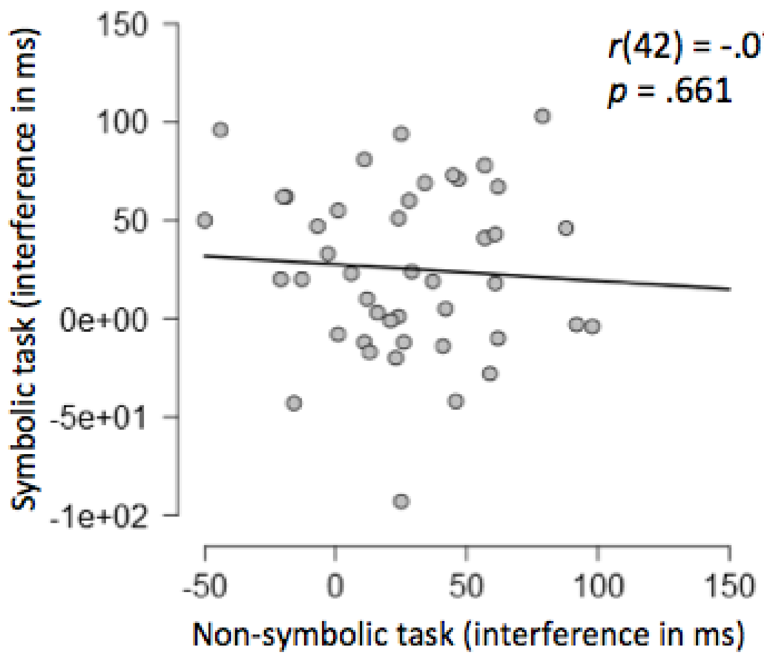

Figure 6. Correlation between interference scores from the symbolic and non-symbolic tasks.

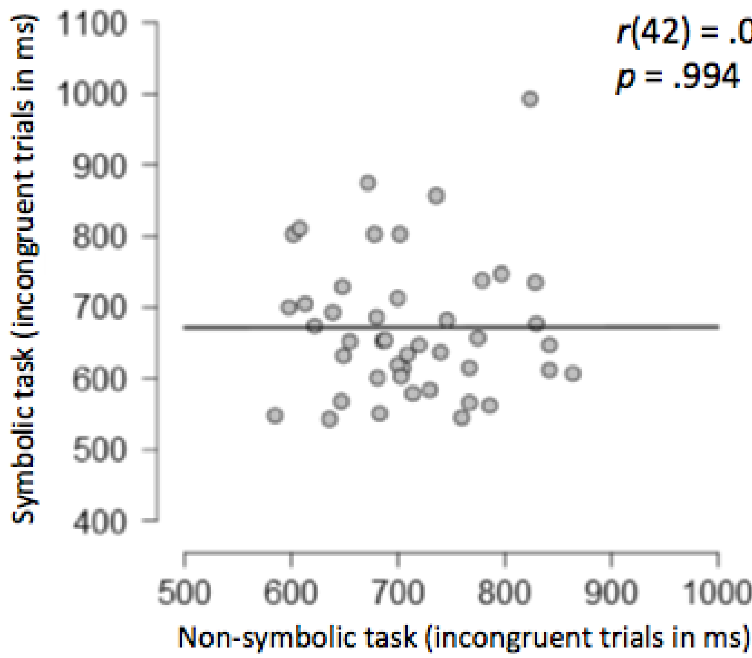

Figure 7. Correlation between reaction times for incongruent trials in the symbolic and non-symbolic tasks.

Discussion

This study set out to answer two questions: 1. Whether the automatic activation of number facilitates or interferes with symbolic and non-symbolic size judgments, and 2. Whether the automatic representations of symbolic and non-symbolic magnitudes correlate. By answering these two questions we will further our understanding of how children process and learn numbers, as well as the mechanisms involved in understanding symbolic and non-symbolic magnitudes.

The first analysis we conducted was a repeated measures ANOVA. We found a significant interaction between task and congruity, as well as main effects for both task and congruity. The interaction between task and congruity tells us that response times vary depending on the task, and the level of congruity of that task. The main effects tell us that there was a significant difference in response time between the symbolic and non-symbolic tasks, and that within the tasks themselves, at least one of the levels of congruity differed significantly from the other two. By investigating figure 3, we can conclude that the non-symbolic task had a significantly faster response time than the symbolic task. However, because we cannot be certain which levels of congruity differ significantly from each other through our ANOVA, follow up analysis must be conducted to determine which levels of congruity differed significantly.

Facilitation and Interference

To follow up our ANOVA, and to answer our first research question of whether the automatic activation of number facilitates or interferes with symbolic and non-symbolic size judgments, we conducted paired sample t-tests between the mean reaction times on congruent, neutral, and incongruent trials. As seen in Figure 3, we found both a facilitation and interference effect in the non-symbolic task. In other words, participants were significantly faster at responding on the congruent trials, and significantly slower at responding in the incongruent trials, compared to their reaction times on the neutral trials. This tells us that even when children are not asked to make a direct magnitude judgment, the magnitude of the non-symbolic stimuli still influences their decision making while making a size judgment. On the other hand, in the symbolic task we see only an interference effect. These data show that participants took significantly longer to respond to the incongruent trials compared to the neutral trials, however there was no significant difference in response times between the congruent and neutral trials. This tells us that when making symbolic size judgments, the automatic activation of number appears to only interfere with our decision-making. At this young age, the representation of numerical magnitude when number symbols are processed does not appear to facilitate or speed up processing.

These findings are consistent with previous work conducted by Rubinsten, Henik, Berger, and Shahar-Shalev (2002) as well as Girelli, Lcangeli, and Butterworth (2000). These experimenters conducted a symbolic physical size comparison task just like the one in this study, and found that an interference effect emerges prior to a facilitation effect. In addition, they discovered that a complete congruity effect, consisting of both a facilitation and interference effect, is not seen until children reach the third grade. Considering the sample for this study is comprised mainly of children in the first grade, our findings are in line with the results from these prior studies. As expected with a sample comprised of children mainly below the third grade level, an incomplete congruity effect was found, as only an interference effect was discovered in the symbolic task.

While there have been many studies of congruity using symbolic stimuli, this study is part of a growing literature employing a non-symbolic congruity task. A previous study conducted by Gebuis, Cohen-Kadosh, de Haan, and Henik (2008) conducted a non-symbolic congruity task with 5 year old children, and found both a facilitation and interference effect. Although Gebuis et al. (2008) used a younger sample, their findings are consistent with the findings from this study; that a facilitation and interference effect were observed on the non-symbolic task in children between the ages of 6 and 9. The consistency between these results can be explained through our understanding of how children develop their math abilities and number sense. As discussed earlier, humans have an innate ANS that is said to be involved in the processing and understanding of non-symbolic magnitudes (Dehaene, 1997; Gallistel & Gelman, 1992). If the ANS is something we are born with, then we would expect to see a full congruity effect in the non-symbolic condition. Observing both a facilitation and interference effect tells us that when children make an area judgment, the irrelevant dimension of number is activated, and both facilitates and interferes with their area processing. Since the ANS argues that we have an innate sense for non-symbolic information, and do not need to learn how to represent non-symbolic information, it follows that children as young as Grade 1 would demonstrate a full understanding of non-symbolic magnitudes. As well, the fact that Gebuis et al. (2008) found both a facilitation and interference effect on a non-symbolic congruity task in children as young as 5 years old, adds support to the notion that we possess an innate ANS.

If the ANS underpins our understanding of non-symbolic information, how then do we understand symbolic information? Earlier we touched on symbol grounding, which argues that we learn what symbols represent by mapping their meaning to that numbers preexisting non-symbolic representation (Dehaene, 2007; Piazza, 2010; Stoianov, 2014). In other words, symbolic information is not innate like non-symbolic information. In this case, we must learn what a symbolic number means by forming an association between the symbol and its non-symbolic representation. The symbolic task shows an incomplete congruity effect, as only an interference effect was found. It is possible that these results are due to the fact that children just entering grade school, who are at the early stages of their formal education, have not yet fully formed the proper association between a symbolic number and its non-symbolic representation. Essentially, these children do not yet have a clear understanding of what symbolic numbers represent. With this in mind, it makes sense that the automatic activation of number in children does not seem to provide any advantage when making a symbolic size judgment.

Correlation Between Symbolic and Non-Symbolic Magnitudes

The second research question this study investigated was whether the automatic representations of symbolic and non-symbolic magnitudes correlate. The goal of answering this question was to add to the literature regarding the mechanisms involved in processing numbers. The current state of literature is mixed regarding if symbolic and non-symbolic magnitudes are processed by the same or different mechanisms (De Smedt, Noel, Gilmore, & Ansari, 2013). A study by Fias, Lammertyn, Reynvoet, Dupont, and Orban (2003) would argue for a shared processing mechanism, as they found the same brain region activated when symbolic and non-symbolic information were processed. However, a study by Lyons, Ansari, and Beilock (2012) would argue for separate mechanisms, as participants took significantly longer to determine which value was numerically larger between a symbolic and non-symbolic magnitude.

To answer this research question, we conducted a correlation analysis. The logic behind running a correlation was the idea that a positive correlation would indicate one processing mechanism, while no correlation would point to separate mechanisms. In addition to correlating facilitation and interference scores, we decided to include the incongruent trials because of the finding that an interference effect emerges before a facilitation effect (Rubinsten, Henik, Berger, & Shahar-Shalev, 2002; Girelli, Lcangeli, & Butterworth, 2000). Since an interference effect involves incongruent trials, we felt that this indicates that in both tasks children have enough of an understanding of number to interfere their judgments on the incongruent trials. If this were the case, we would expect to see some relationship between the processing of incongruent trials on both tasks. However, this was not the case, and consistent with our hypothesis that there are separate mechanisms for processing symbolic and non-symbolic magnitudes, all three correlations we conducted were non-significant.

This result was similar to the result from a study conducted by Sasanguine, Defever, Maertens, and Reynvoet (2014) in which they found no correlation between kindergarten children's scores on symbolic and non-symbolic comparison tasks. Since both Sasanguine et al.'s (2014) study, and the current study, use a sample known to show only an interference effect, the similarity between the results from these two studies can be explained through our understanding of the relationship between the ANS and how children acquire a number sense. As we learned, children have an innate sense for processing non-symbolic magnitudes, but need to learn what a symbolic number represents. However, not everyone is convinced that we learn what a number means by associating a symbol to its non-symbolic representation in the ANS. Carey (2004) proposes we learn what numbers mean through bootstrapping processes. Bootstrapping processes involve the use of external symbols such as words and icons. In the case of numbers, Carey (2004) suggests we associate a specific value to its number word. Although this process of learning is different than the idea behind symbol grounding, it still involves forming an association between a number and something that represents that numerical quantity. Therefore, it is plausible that as children we have two separate mechanisms for processing numbers; one that is innate and processes non-symbolic magnitudes, and another that involves associating a symbol to a specific representation, which in this study we argue is its non-symbolic representation. It is likely this difference in processing numbers that resulted in non-significant correlations.

Limitations and Future Directions

The first limitation of this study is that our measure of response time may not be reliable. This is due to the setting of the study. The majority of public schools do not have any empty rooms, so data collection for this study was done in a room that was also two teachers' office. This meant there were times when the children were completing the study when the teachers were working at their desks. In addition to this, it also meant that on days when two researchers were at the school collecting data, there was no other room that could be used by the second researcher. There were a few participants who had to complete the study while one of their peers was sitting only a few feet away. Both of these scenarios could have caused the children to become distracted and lose focus on the task at hand, and could have skewed our response time data. A second limitation involves the small sample size. A small sample size can reduce the power of an analysis and make it more difficult to find significant results. This is especially a concern when conducting a correlation analysis, and is why correlations typically have very large sample sizes. A final limitation is that the symbolic and non-symbolic tasks were accompanied by a third task that was not used in this study. For some participants, this meant that they completed a task in between the non-symbolic and symbolic tasks. In children this young, it is possible that having to do a task in between caused a lack of focus, or even made the children tired. This could have resulted in slower reaction times on the symbolic task.

Moving forward, the first way to extend this study would be to replicate it with a larger sample size, as well as be able to better control the environment of the study. This would allow for stronger conclusions to be drawn from the analysis, and would minimize any potential distractions that may influence the children's response times on the tasks. Second, because of the importance of math in our everyday lives, it would be interesting to see how a child's ability on each task predicts math abilities now and in the future. Math achievement is directly related to children's perceptions of their social and intellectual capabilities, as well as future academic and professional success (Fogleman, 1984; Levine, Lindsay, & Reed, 1992). Math can be a very difficult subject for some children, and because of the vast impact math skills have on our life, it is important we learn as much as we can about children's math development. Maybe there could be a relationship between poor ability on the symbolic task and poor math abilities down the road; or poor ability on the non-symbolic task and difficulty acquiring a number sense in general. Either way, being able to predict learning difficulties through these tasks may allow for earlier detection of children who may struggle with math, and an increased ability to help these children overcome their number difficulties.

Conclusions

To summarize, there are three main points to make. First, even when children are not asked directly about number, the automatic activation of number appears to influence their judgments. This was seen mainly in the non-symbolic task, but it was evident in the symbolic task too. Second, the current study provides evidence pointing to separate mechanisms for processing symbolic and non-symbolic numbers. This was evident through our analysis revealing no significant correlations between the symbolic and non-symbolic tasks. Although we cannot draw very strong conclusions from a correlation analysis, our results seem to be inline with previous work that points to separate processing mechanisms. Third, our results appear to add support to the notion that there is an asymmetry in the development of symbolic and non-symbolic numbers. We see the automatic activation of number interfere with both symbolic and non-symbolic size judgments in young children, but in the case of facilitation, the automatic activation of number facilitates non-symbolic size judgments prior to facilitating symbolic size judgments.

Numbers are an integral part of our everyday lives. We all use numbers in very different ways. The overarching theme of this research paper was to add to our understanding of how children acquire and process numbers, with the hope of identifying new ways to maximize children's learning in order to prepare them for whatever they choose to pursue in their future. A waiter needs to understand numbers to provide change to his customers, while a CEO needs to understand numbers in order to run his or her business. Although these two individuals use numbers in a very different way, one thing they have in common, is that at one point in their life they were both sitting in their first grade classroom learning numbers.

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Appendix A

Western

Letter of Information and Consent

The development of size estimation and math abilities

Principal Investigator

Prof. Daniel Ansari, PhD, Psychology
Western University, X80548

1. Invitation to Participate

I am a Professor and researcher in the Department of Psychology at the University of Western Ontario. I am conducting this research with several students from my research laboratory.

Your child is being invited to participate in this research study looking at the development of numerical and mathematical skills because your child is between the ages of 6 and 13 years.

Who can participate in this study? Typically-developed children between the ages of 6 and 13 years, with no reported attention deficits, learning disabilities or neurological disorders can take part in this study.

2. Why is this study being done?

The purpose of this study is to look at how children develop a basic understanding of number and how that is related to math abilities.

3. How long will your child be in this study?

It is expected that your child will be in the study for one session of about 45 minutes.

4. What are the study procedures?

If your child participates in this study, he/she will leave class and sit with two researchers in a quiet room. Testing will last about 45 minutes. During this time, we will explain the study to your child in order to obtain his/her assent. Children over the age of 7 will be asked to give a written assent. If your child is interested in participating, s/he will be asked to complete three computerized activities and a paper and pencil task.

In one game, your child will see two groups of orange dots on the screen and will be asked to decide which group has more orange area. In another game, your child will see two digits in different sizes and will be asked to choose the larger one. In another game, your child will see a row of fish on the screen and will be asked to decide whether the fish in the middle swims to the left or to the right. Your child will get breaks every few minutes and when they request one. In the paper and pencil task your child will be asked to solve as many simple arithmetic problems as they can (like 5+3) in 3 minutes.

Each computer game will take up to 10 minutes. Your child will be able to stop his/her participation at any time, without any consequences.

5. What are the risks and harms of participating in this study?

There are no known or anticipated risks associated with participating in this study. While your child does these tests, s/he will be able to take breaks so that they don't become tired. If your child becomes tired or bored, s/he can tell the experimenter and they will take a break or stop testing if your child wishes to stop.

6. What are the benefits of participating in this study?

Your child may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include helping children to learn numbers.

7. Can participants choose to leave the study?

Participation in this study is voluntary. Your child may refuse to participate, to answer any question or withdraw from the study at any time with no effect on their future or academic status. You and your child have the right to be given all important information about this study and what your child will be asked to do. Your child should only agree to take part if he/she feels that they know enough about the study. If your child wants to withdraw from the study, he/she can let the experimenter know.

8. How will participants' information be kept confidential?

Your child's research records will be securely stored in a locked cabinet and only members of the research team will have access to your information. If the data are stored on a computer, they will be stored in such a way that your child's identifying information will not be connected to the results. If the results are published, your child's name will not be used and no information that discloses your child's identity will be released to the publisher without your specific consent.

Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to your study-related records to monitor the conduct of the research.

While we do our best to protect your child's information there is no guarantee that we will be able to do so. If information is disclosed during the project which may be required to report by law, we have a duty to report.

The researcher will keep any personal information about your child in a secure and confidential location for a minimum of 5 years. A list linking your child's study number with his/her name will be kept by the researcher in a secure place, separate from your child's study file

9. Are participants compensated to be in this study?

Your child will be given a $10 gift card to a book store as an expression of our appreciation, even if he/she will not complete all the tasks.

10. What are the rights of participants?

Your child's participation in this study is voluntary. Your child may decide not to be in this study. Even if you and your child consent to participate, your child has the right to not answer individual questions or to withdraw from the study at any time. If your child chooses not to participate or to leave the study at any time it will have no effect on his/her academic standing.

We will give you new information that is learned during the study that might affect your decision to let your child stay in the study.

You and your child do not waive any legal right by signing this consent form

11. Whom do participants contact for questions?

If you or your child have questions about this research study, please contact

Professor Daniel Ansari
Department of Psychology
The University of Western Ontario
Westminster Hall, Room 325, London, ON N6A 3K7, Canada
Tel. +1-519-661-2111 Ext. 80548 e-mail: daniel.ansari@uwo.ca

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Human Research Ethics (519) 661-3036, email: ethics@uwo.ca

This letter is yours to keep for future reference.

Behavioural studies of numerical and mathematical skill development
Written consent

PI contact:
Professor Daniel Ansari
Department of Psychology
The University of Western Ontario
Westminster Hall, Room 325, London, ON N6A 3K7, Canada
Tel. +1-519-661-2111 Ext. 80548 e-mail: daniel.ansari@uwo.ca

I have read the Letter of Information, have had the nature of the study explained to me and I agree to allow my child to participate. All questions have been answered to my satisfaction.

Please return a copy of the consent form (this page) to the teacher.

CONTACT FOR FUTURE STUDIES
Please check the appropriate box below and initial:
___ I agree to be contacted for future research studies via email:____________
___ I do NOT agree to be contacted for future research studies

Print Name of Participant	Signature	*Date (DD-MMM-YYYY)*

Child's Name: ____

Parent / Legal Guardian / Substitute Decision Maker (Print): _______________
Parent / Legal Guardian / Substitute Decision Maker (Sign): _______________
Parent / Legal Guardian / Substitute Decision Maker (Date): _______________

My signature means that I have explained the study to the participant named above. I have answered all questions.

Print Name of Person Obtaining Consent	Signature	*Date (DD-MMM-YYYY)*

If you do not consent, please check the box below and return the form unsigned

☐ I do not consent to my child's participation.

Appendix B

Assent Letter

The development of size estimation and math abilities
Letter of Information and Consent

Assent Letter – Student

Principal Investigator

Prof. Daniel Ansari, PhD, Psychology
Western University, X80548

Why are you here?

Prof. Ansari want to tell you about a study he is doing on children your age that will look at how children learn numbers. He wants to see if you would like to be in this study. Other researchers will also work with Prof. Ansari on this study.

Why are they doing this study?

Prof. Ansari and his researchers want to see how children learn numbers.

What will happen to you?

If you want to be in the study, you will complete a math task and play games that involve numbers.

In the **first** game, you will see two groups of orange dots on the screen and will be asked to decide which group has more orange area. In the **second** game, you will see two digits in different size. You will be asked to choose the bigger one.
In the **third** game, you will see a row of fish on the screen. You will be asked to decide whether the fish in the middle swims to the left or to the right. You will get breaks every few minutes, and when you will ask one. **In the math task** you will be asked to solve as many simple arithmetic problems (like 5+3) in 3 minutes.

Playing all these activities will take about 45 minutes, and we will take lots of breaks during the games and in between the games. When you feel like you want a break you should just tell us.

Will there be any tests?

Yes, there will be one test (the math task) but your scores will not be shared with anyone at your school or with anyone in your family.

Will the study help you?

This study will not help you directly, but in the future, it might help children to learn numbers.

Do you have to be in the study?

You do not have to be in the study. No one will be mad at you if you do not want to do this. If you do not want to be in the study, tell the researcher or your parents. Even if you say yes, you can change your mind later. It is up to you.

What if you have any questions?

You can ask the researchers questions any time, now or later. If you have questions about the study, you can ask Prof. Ansari at any time and he'll answer your questions. His telephone number is 661-2111 x 80548. You can also ask you teacher or your parents.

Consent

I want to participate in Prof. Ansari's study.

Print Name of Child ______________________ Age: ______________

Date____________________ signature: ______________

Name of Person Obtaining Assent

____

Signature of Person Obtaining Consent _____________

Date _______________

This letter is yours to keep for future reference.