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**TITLE:** Numerical Understanding in Mind, Brain, and Education Relations (N.U.M.B.E.R.)

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**YEAR:** 2015

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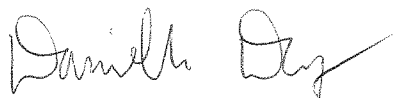
## Numerical Understanding in Mind, Brain, and Education Relations (N.U.M.B.E.R.)

### Abstract

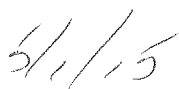
Past studies have demonstrated that non-human animals, infants and adult humans can process numerical information across multiple sensory modalities, and that number decisions are more accurate when number presented in multiple senses (Jordan and Baker, 2011). However, the neural mechanisms that support this ability are relatively unexplored. In a series of behavioral experiments, we investigated the cognitive mechanisms that 1) allow estimation and comparison of number between and within sense modalities 2) support integration of congruent number information from multiple senses. These studies, in turn, lay the ground work to investigate how networks in frontal and parietal brain areas processes numbers when presented in auditory and visual modalities. This research could provide insight into the brain's ability to integrate information about number from multiple senses, and, in turn, lead to improvements in the educational system and enhance teaching techniques.

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## **Introduction**

### The Approximate Number System: A Foundation for Mathematics

The ability to estimate quantities is a critical evolutionary ability, which has been found across many species of animals (Brannon & Merritt, 2011). Imagine a lioness roaming alone in the savanna. She does not smell or see any of her sisters near her when she suddenly hears three sets of sounds from unfamiliar lionesses in the depths of the savanna. She quickly realizes that she is outnumbered and runs in the opposite direction to avoid the sounds. Now imagine a lioness exploring the savanna with two of her sisters. She can smell, see and even hear them by her side when unexpectedly they hear two sets of sounds from unfamiliar lionesses coming from within the savanna. Instead of avoiding the sounds, the lioness calculates that her group outnumbers the strangers and decides to investigate (McComb et al., 1994). How can the lioness process all of this information obtained from multiple senses and transform it into a coherent thought? What brain systems allow for the accuracy of these approximations?

Lionesses demonstrate the ability to discern between quantities using a multisensory integration system (McComb et al., 1994). Similarly, monkeys successfully matched numbers across auditory and visual modalities with equal accuracy, supporting the existence of a similar modality-independent, abstract numerical code (Jordan et al., 2008). This ability to approximate number without counting is mediated by a cognitive system called the approximate number system, or ANS (Piazza, 2010). Behavioral studies suggest that the ANS allows individuals to detect deviances in magnitude between quantities, regardless of the sensory modality in which they are presented. Individuals can distinguish between different amounts of a substance, even in species who cannot count, or in infants prior to learning how to count using verbal number words.

The ANS follows Weber's Law, which relates the different intensities of sensory stimuli (Piazza et al., 2004; Dehaene, 2003; Nieder and Miller, 2004). The discrimination between two quantities depends on their ratio and relative position to each other on a hypothetical mental continuum. For instance, it is easier to distinguish between the numbers six and twelve, compared to the numbers six and eight, due to the farther distance between them. The numerical distance effect has been demonstrated with numerosities presented as arrays of dots (Piazza et al., 2004) and as brief touches to the hand (Krause et al., 2013) suggesting that the same processes are involved for number, independent of the sense used. These studies have consistently found that the larger the semantic distance between the two numerosities, the faster and more accurately participants made their judgments.

The ANS develops early in infancy, as even newborn human infants show ratio-dependent number judgments (Xu and Spelke, 2000), but its precision increases with age. Newborn infants can distinguish a 3:1 ratio even across different senses, as demonstrated by an increase in looking time when the number of shapes on the screen matches the number of voices infants hear, relative to when they do not match (4 vs. 12) (Izard et al., 2009). However, newborns fail to show this effect if the ratio is 2:1 (e.g., 4 vs. 8). By six months of age, infants can discriminate visual arrays showing a 2:1 ratio of dots as well as puppet jumps, but not a 3:2 ratio (Wood and Spelke, 2005; Xu and Spelke, 2000). By 9 months, infants can discriminate 8 dots from 12 dots, 4 puppet jumps from 6 puppet jumps, and 8 tones from 12 tones (Lipton and Spelke, 2003). This development continues through the early school years and even into adulthood (Halberda et al., 2008; Piazza, 2010). ANS precision reaches its maximum around age 30, after which it slowly decreases (Halberda et al., 2012).

Critically, previous studies have demonstrated that even infants can map numerical representations across the visual and auditory modalities (Jordan and Brannon, 2006). Newborn infants demonstrate the ability to map between sensory modalities by longer looking times when the number of visual shapes matches the number of voices heard, relative to when they do not match (Izard et al., 2009). Similarly, seven-month-old infants preferentially attended to visual displays of adult humans that numerically matched the number of adult humans they heard speaking. This indicates that intersensory redundancy may improve young children's abilities to match representations of number across multiple sensory modalities (Jordan and Baker, 2011).

### The Role of Multisensory Integration

Brains combine information from multiple senses to enable more effective perception and action in a multisensory environment (Maculuso and Driver, 2005). Audiovisual speech perception is an everyday occurrence where information is integrated from different senses, and since human lives rely on such a high amount of synchronicity, a discrepancy is obvious when sensations fail to line up. When the images of the speakers' mouths movements in a video are slightly delayed in timing, trailing the auditory speech of the video, the incongruity between the visual cues seen and the sounds heard are instantly recognized by the brain, even with a delay of milliseconds (Grant et al., 2004).

The parietal lobe is one of several brain regions that are responsible for multisensory integration (Driver and Nosselt, 2008). In particular, the intraparietal sulcus (IPS) has shown similar activations when participants are presented with auditory, visual or tactile motion, independent of which sensory modality is stimulated (Bremmer et al., 2002). The extensive bidirectional anatomical connectivity between the IPS and visual and auditory brain areas renders it an ideal candidate for integrating inputs from multiple senses. Responses are larger in

the parietal cortex than in early areas (like the auditory or visual cortex) when stimuli are presented in both modalities simultaneously. Not only does the parietal cortex receive input from multiple modalities, but it is also an important site for integration across them (Lewis and Van Essen, 2000a; 2000b).

### Examining the Neural Mechanisms behind the Multisensory Integration of Numbers

Multimodality is fundamental to the ANS in regards to number representation for quantities greater than four. Neurons in the IPS of the monkey are tuned to specific quantities, independent of whether they are presented as four beeps or four flashes (Nieder, 2012). This generalized magnitude system supports the ability of the brain to process general magnitude information, independent from the sensory modality that is stimulated. The behavioral studies cited previously provide only indirect evidence for the presence of a multimodal integration system in the brain, but do not provide direct evidence for its existence, nor do they provide information about the neural structures responsible for such integration.

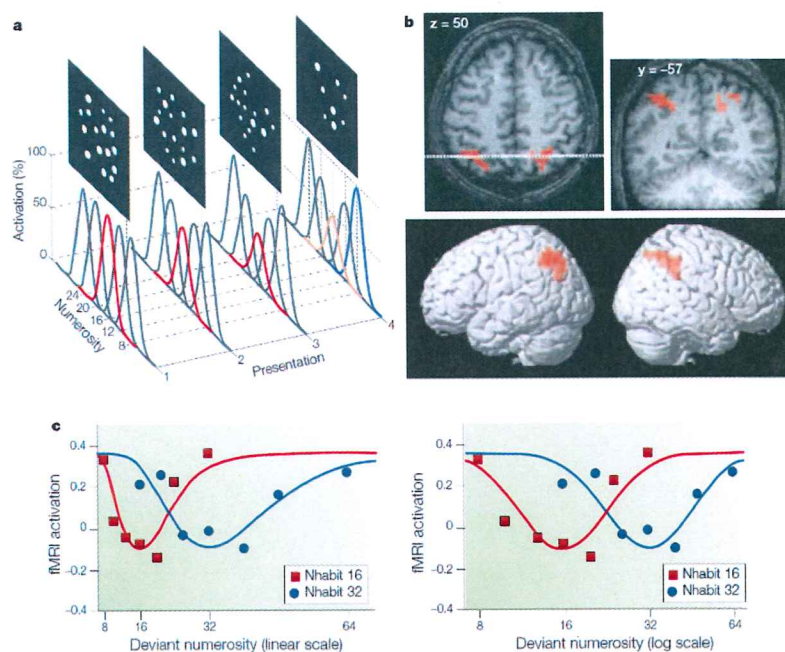
A preliminary investigation of the neural basis of multisensory number processing found that symbolic numerical stimuli presented as either spoken or seen words both activated the IPS (Eger et al., 2003). However, since these findings were with number symbols, and in adults, the development of the neural basis of the ANS for multisensory number processing is still unclear. Single-unit studies of individual neurons in the parietal cortex of the cat and the monkey have identified neurons that are tuned to respond to specific quantities, such that they respond to (e.g., four), independent of whether the four stimuli were presented as auditory beeps or as visual flashes (Thompson et al., 1970; Nieder, 2012). Based on these findings, the parietal ANS is likely to be the neural basis of the human ability to integrate number from multiple sensory modalities. However, these studies have not directly demonstrated that the parietal ANS is

multisensory. Additionally, these studies have not investigated the development of the ANS in human children, nor do they allow us to understand how educational experiences, like learning to use number symbols, may affect these multisensory number responses.

### Using fMRI-Adaptation to Explore the ANS in Humans

Previous functional magnetic resonance imaging (fMRI) experiments have examined the ANS in participants adapted to either 8 or 16 dots, who were then tested on either a number change or shape (Piazza et al., 2004). By presenting the same number of dots (e.g., 8) repeatedly, Piazza et al. adapted populations of neurons that were tuned to that number. When participants were then presented with sets of items that differed from the adapting number (“deviants”), the bilateral IPS responded more strongly to the deviants, and this increase was larger for numbers that differed more from the standard. This difference was selective to

number change, as different regions in the posterior parietal and inferior temporal cortex responded to shape change. Functionally, the shape of this response indicates that humans, like



**Figure 1.** fMRI-adaptation methods. a. Repeated presentation of dots (e.g., 16) leads to habituation of neurons tuned to that particular numerosity (indicated in red). Neurons tuned to similar numerosities also adapt, but less strongly, while neurons tuned to far numerosities do not respond, and therefore do not adapt (curves centered at 8 and 24). Presentation of deviant numbers of dots (e.g., 8) lead to larger fMRI responses, which indirectly indexes neural tuning in humans. b. Brain regions that showed an fMRI adaptation response specifically to number in Piazza et al., 2004. c. and d. Pattern of fMRI responses plotted on a linear and log scale. Adapted from Piazza et al., 2004.

number change, as different regions in the posterior parietal and inferior temporal cortex responded to shape change. Functionally, the shape of this response indicates that humans, like

other animal species, encode approximate number on a compressed internal scale. Subsequent studies have demonstrated similar sensitivity to non-symbolic quantity in four-year-old children (Cantlon et al., 2006) and even in four-month-old infants (Izard et al., 2008).

We will investigate whether ANS responses to numerosity (quantity) stimuli change depending on the sensory modality presented. To examine the role of the IPS in cross-modal numerical representations, we will use these same established methods, in which we expect that the repeated presentation of a stimulus will lead to decreased neural responses. Presentation of semantically dissimilar stimuli will lead to a “rebound” effect, in which fMRI responses increase to baseline levels or beyond with increasing semantic distance leading to greater responses (see **Figure 1**).

### **Systems for Multisensory Number**

The purpose of this study was to provide evidence for the existence of a system in our brain that can represent multisensory number. This study was divided into three experiments. The first two experiments focused on behavioral mechanisms. In Experiment 1, participants estimated the number of auditory or visual stimuli presented; in Experiment 2, they discriminated which of two intervals contained the larger number of items. Within the blocks of trials in both Experiments 1 and 2, the order of the trials was randomized to minimize the effects of habituation to a certain numerosity or sensory modality (e.g., in Experiment 2, participants could have first been presented with 7 “beeps” paired with 8 “flashes,” then 8 “flashes” paired with 10 “flashes,” etc.). Experiment 3, a future neuroimaging experiment, will test whether IPS and PFC regions contain populations of neurons tuned to specific quantities, independent of sensory modality. This experiment will involve participants who are suitable for fMRI (no incidents of claustrophobia, no metal in their bodies, etc.).

The stimuli were presented as either 7, 8, or 10 auditory (abbreviated as ‘A’) “beeps” or visual (abbreviated as ‘V’) “flashes.” The beeps and flashes were created in Matlab R2013a (Mathworks, Natick, MA). The beeps were pure sine wave tones of 800 Hz converted to .wav files using the Audacity program, and the flashes were .avi movies. The experiments were programmed and presented in the E-prime software (Psychology Software Tools, Sharpsburg, PA).

The stimuli numerosities were carefully chosen as 7, 8, and 10 by logarithmic calculations. The goal was to find a set of numbers that were close enough so that the discrimination task was not too easy. As the ANS is known to follow Weber’s Law, and hence to represent number logarithmically, we chose pairs of numbers that would be roughly equidistant on a log scale. For example,  $\log(10/8)$  and  $\log(8/7)$  are closer in distance than  $\log(11/8)$  or  $\log(9/8)$  with  $\log(8/7)$ .

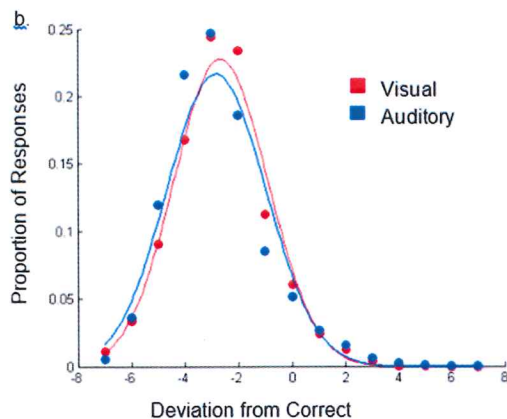
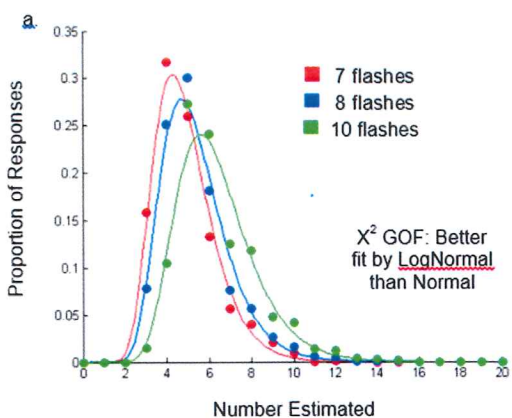
### Experiment 1: System Estimation

#### **Methods**

In this behavioral task, 50 participants were presented with one interval containing numerosity stimuli (7, 8, or 10) and attempted to estimate the number of beeps/flashes they heard/saw. Participants were presented with 8 blocks of 36 trials (18 each of V and A) for a total of 288 trials, which took approximately 20 minutes. We recorded the number of times participants reported seeing or hearing a particular number of flashes or beeps (e.g., “7”) when presented with different numerosities (e.g., 7 flashes or 8 beeps), and time taken to respond in milliseconds.

## Results

We aimed to use this data to ensure that participants could not count the number of stimuli, and instead, rely on their approximate number system (ANS). **Figure 2a** shows the data of perceived numerosities for each number of flashes presented (e.g., how often did the



**Figure 2.** a) Results for Visual Estimation. Estimated number increases with presented number. b) Data for visual and auditory modalities.

participant report “7” when actually presented with seven flashes?). Consistent with the findings of Izard and Dehaene (2007), the mean responses for each numerosity were lower in number than the number of stimuli presented, indicating underestimation as seen in **Figure 2b** (e.g., the presentation of 7 beeps/flashes resulted in a mean response of 4). Additionally, the mean responses increased with increasing number presented (e.g., the mean response when presented with 8 stimuli was higher than the mean response when presented with 7 stimuli). Lastly, the variability in responses increased as a function of the number of stimuli presented; therefore, the response accuracy was higher for trials when the value was 7 – regardless of the sensory output – than when the value was 8 or 10, also shown in **Figure 2a**. The coefficient of variation – a value derived by dividing the standard deviation by the mean response – was constant across numerosities presented and similar across modalities (Whalen et al., 1999).

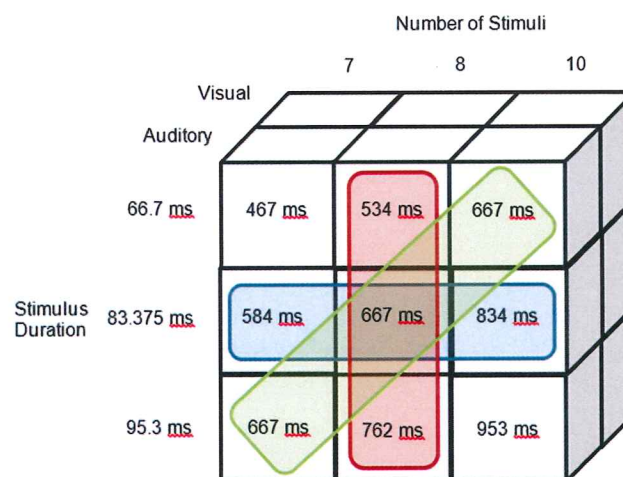
participant report “7” when actually presented with seven flashes?). Consistent with the findings of Izard and Dehaene (2007), the mean responses for each numerosity were lower in number than the number of stimuli presented, indicating underestimation as seen in **Figure 2b** (e.g., the presentation of 7 beeps/flashes resulted in a mean response of 4). Additionally, the mean responses increased with increasing number presented (e.g., the mean response when presented with 8 stimuli was higher than the mean response when presented with 7 stimuli). Lastly, the variability in responses increased as a function of the number of stimuli presented; therefore, the response accuracy was higher for trials when the value was 7 – regardless of the sensory output – than when the

Overall, because the functions were better fit by a log, the responses from the 50 participants showed the trends associated with the ANS: underestimation, an increased mean response with increasing number presented, and an increased variability in responses with increasing number presented.

### Experiment 2: System Comparison

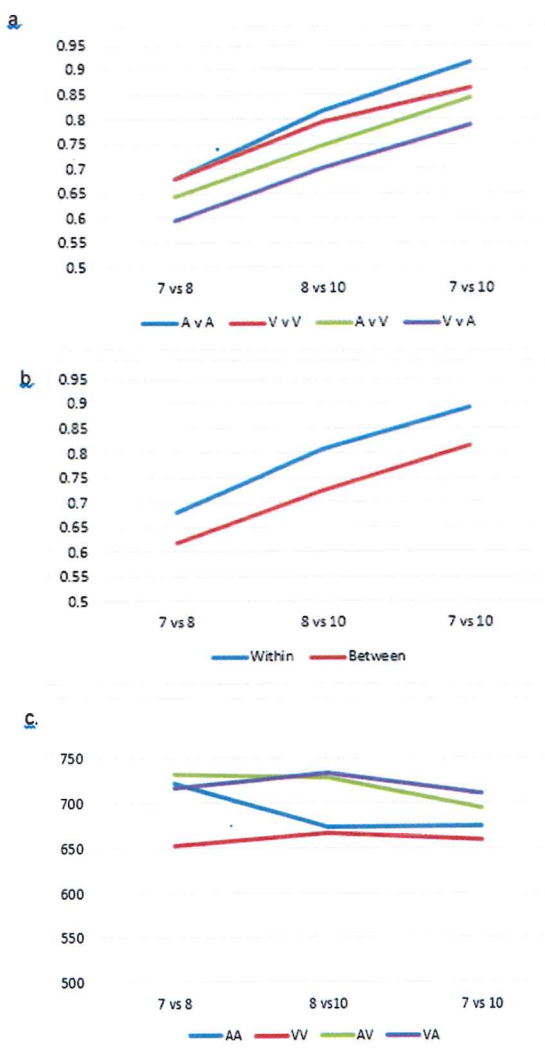
#### **Methods**

In this behavioral task, 16 participants were presented with two intervals containing numerosity stimuli, and were asked to discriminate which stimulus interval (the first or second) had the larger numerosity. The stimuli were presented as 7, 8, or 10 auditory beeps or visual flashes. Stimulus duration and total duration were controlled using the methods shown in **Figure 3**, and pilot studies determined beep/flash durations that were fast enough to discourage counting, but not so fast that they led to sensory fusion. Participants were presented with 216 trials, which took approximately 25 minutes. Total correct responses were measured for each modality pair as a function of number magnitude (7, 8, or 10) and numerical distance (close: 7 vs. 8 and 8 vs. 10 and far: 7 vs. 10).



**Figure 3.** Experimental design of auditory and visual cross-modal adaptation trials. The labels indicate individual stimulus duration (y-axis) and number of adapting stimuli (x-axis). Values in the cells indicate total stimulus duration. Controls for individual stimulus duration are indicated in blue, number in red, and total stimulus duration in green.

## Results



**Figure 4.** Accuracy as a function of distance. As distance increases, accuracy increases (a) and reaction times decreases (c) consistent with the distance effect. The shape of the distance effect is the same for both within and between modality comparisons (b and c), but there is a main effect of modality congruence. Reaction times show a similar distance effect.

As we predicted, participants showed increasing accuracy with increasing distance between number magnitudes, shown in **Figure 4a**. The basis for this prediction lies in the numerical distance effect (as mentioned in the introduction), where discrimination between two quantities is more accurate when their relative position to each other on the number line is farther. **Figure 4b** shows that participants performed with more accuracy in the within-modality (AA and VV) than in the across-modality (AV and VA), and **Figure 4c** shows that the participants were faster when responding to within-modality stimuli. Therefore, they were not only more accurate in their responses, but also faster in their reaction times. These results indicate that there was not a speed-accuracy trade-off, which describes the idea that the participant is more accurate by taking more time to respond.

### Experiment 3: System Cross-Modal fMRI Adaptation

## Methods

In a separate session, suitable participants will be asked to perform an additional behavioral task while we record brain activity using fMRI. We will use an fMRI-adaptation paradigm like those described above (Piazza et al., 2004). Participants will be presented with a small white central fixation cross on a black background that will remain visible throughout the experiment. Participants will be instructed to fixate solely on the cross and avoid letting their gaze wander to the stimuli, which will be monitored using an MRI-compatible eye tracker. The eye-tracking data will allow us to reject trials in which the participant makes an eye movement, or during periods of drowsiness, as measured by eye closing. To further ensure alertness, participants will be instructed to press the response button when the fixation cross briefly (500 ms) dims from white to dark gray.

In separate runs, participants will be adapted to either seven or ten beeps or flashes. After adaptation, participants will be presented with an array of numerically distinct stimuli at different durations as shown in **Figure 3**. Following Nieder (2012), the design of this study will create controls for individual beep or flash duration (the blue loop in **Figure 3**), the number of stimuli (the red loop in **Figure 3**) and total stimulus duration (the green loop in **Figure 3**). Keeping beep or flash duration constant controls for any differences in how short and long stimuli are processed, but necessitates that eight beeps take 1.25 times as long as seven beeps. Conversely, contrasting seven beeps lasting 95.3 ms each (667 ms total) with eight beeps lasting 66.7 ms each (667 ms total) isolates the effect of number independent of overall duration. Combining data from these two control conditions allows us to isolate the effect of number change, independent of differences in both individual beep/flash duration and total duration. Order will be counterbalanced across participants; half the participants will be adapted to the auditory stimulus first, while the other half will be adapted to the visual stimulus first.

Functional and anatomical brain images will be collected using the General Electric 3-Telsa scanner (GE Medical Systems, Waukesha, WI) at the Waisman Laboratory for Brain Imaging. Functional images will be collected using a standard T2\*-weighted gradient-echo, echo planar imaging (EPI) pulse sequence [30 sagittal slices, 4mm thickness, 1mm interslice gap; 64×64 matrix; 240mm (FOV); repetition time (TR)/echo time (TE)/Flip, 2000ms/30ms/90°, 81 whole-brain volumes per run]. A high-resolution T1-weighted anatomical image will also be acquired (T1 weighted inversion recovery fast-gradient echo; 256×256 in-plane resolution; 240mm FOV; 124×1.2mm axial slices).

All data will be pre-processed and analyzed using BrainVoyager QX 2.8 (BrainInnovation, Maastricht, The Netherlands). Data will be slice time corrected, motion corrected and temporally filtered prior to coregistration. Subjects whose movement is greater than 3 mm or 3 degrees in four or more of the eight runs will be rejected, and will be replaced by other subjects in the same order. All data will then be rotated into AC-PC alignment and Talairach transformed using a rigid-body affine transformation. Functional data will be smoothed with an 8 mm smoothing kernel to decrease noise and to account for individual differences in brain anatomy. Data will be analyzed using general linear model (GLM) and random effects analysis of covariance (RFX ANCOVA) procedures. Region of interest (ROI) analyses will be performed using 10 mm spheres centered on fusiform and parietal coordinates derived from previous meta-analyses of regions involved in numerical cognition in adults (Dehaene et al., 2003) and children (Houdé et al., 2010). Coordinates will be transformed from the MNI/spm reference frame used in these meta-analyses to Talairach coordinates for use with BrainVoyager using the `icbm_spm2tal` transformation (Lancaster et al., 2007).

## **Expected Results**

We expect that our findings will help to identify neural mechanisms involved in extracting numerosity information when stimuli are presented in multiple sensory modalities. In accordance with Piazza et al. (2004), we expect the activation in the IPS and PFC to be higher when presented with a stimulus differing in numerical value from the adaptation value (7 or 10) even when the sensory modality is switched from auditory to visual (and vice versa). Additionally, we expect that responses in modality specific auditory and visual areas will be larger to modality switch, independent of number. This response will demonstrate that the IPS is a multisensory region that integrates numerosities across various modalities. The expected results from this novel study can be anticipated due to the findings of Jordan and Baker (2011), which suggest that intersensory redundancy may improve children's abilities to match numerosities.

### **Integrating Congruent Multisensory Number**

The purpose of this study was to discover if congruent bimodal number enhances learning and brain activation. This study was divided into three experiments; however, we will only discuss one behavioral experiment. In Experiment 5 (similar to Experiment 2 in the System study), participants discriminated which of two intervals contained the larger number of items. The stimuli numerosities were 7, 8, and 10; however, the stimulus durations were longer than in the System study. Within the blocks of trials, the order of the trials was randomized to minimize the effects of habituation to a certain numerosity or sensory modality.

#### **Experiment 5: Congruent Comparison**

### **Methods**

In this behavioral task, 16 participants were presented with two intervals of unimodal or bimodal numerosities (7, 8, or 10) in the form of beeps, flashes, or both and discriminated which

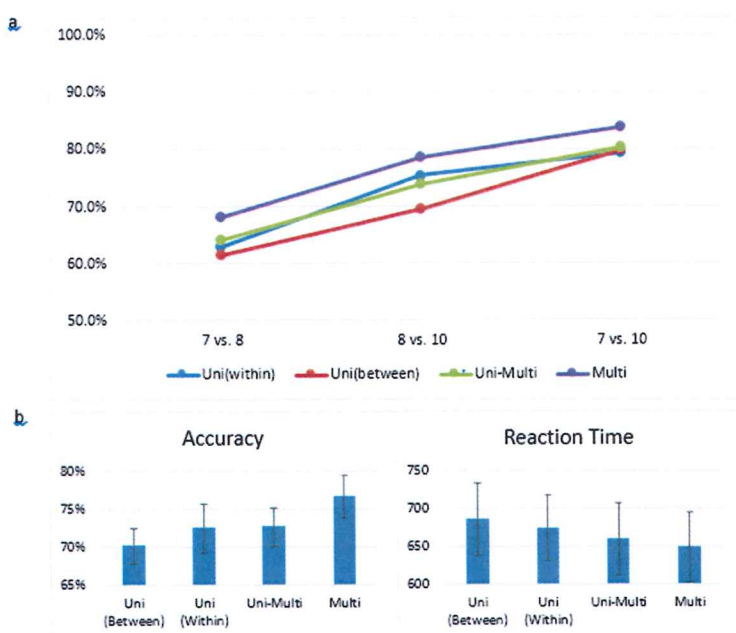
interval contained the larger quantity. Participants were presented with 9 blocks of 54 trials for a total of 486 trials, which took approximately one hour. Responses were recorded and the numerical distance/ratio was analyzed.

## Results

Participants' responses increased in accuracy when presented with bimodal stimuli (AV) as opposed to unimodal stimuli (A or V) as depicted in **Figure 5a**. Consistent with the numerical

distance effect and Weber's Law, the participants performed with faster reaction times and higher accuracy when the distance between number quantities was greater, shown in **Figure 5b**. Once again, this shows that there was not a speed-accuracy trade-off. These results contribute to the idea that presenting multisensory stimuli leads to an enhancement in performance in both accuracy and reaction time. We expect that the process of coactivation will lead to enhancement of number and the super-additivity effect we

hope to see in the fMRI experiment (Experiment 6).



**Figure 5.** a) Accuracy as a function of distance. As distance increases, accuracy increases for all conditions. The shape of the distance effect is the same for both within and between modality comparisons, but there is a main effect of modality. b) Accuracy and reaction times collapsed across distance. Both measures demonstrate improved performance in the multisensory condition.

## **Integrating Incongruent Multisensory Number**

The purpose of this study was to investigate how conflicting information about number from individual sensory modalities is integrated, whether one sensory modality is dominant, and how this dominance is modulated by attention. This study was divided into three experiments as well; however, we will only discuss one behavioral experiment. In Experiment 7, participants were presented with either congruent or incongruent stimuli in the form of beeps or flashes and asked to estimate the number of stimuli presented. The stimuli numerosities were 7, 8, and 10; however, the stimulus durations were longer than in the System study. Within the blocks of trials in Experiments 7, the order of the trials was randomized to minimize the effects of habituation to a certain numerosity or sensory modality.

### **Experiment 7: Incongruent Estimation**

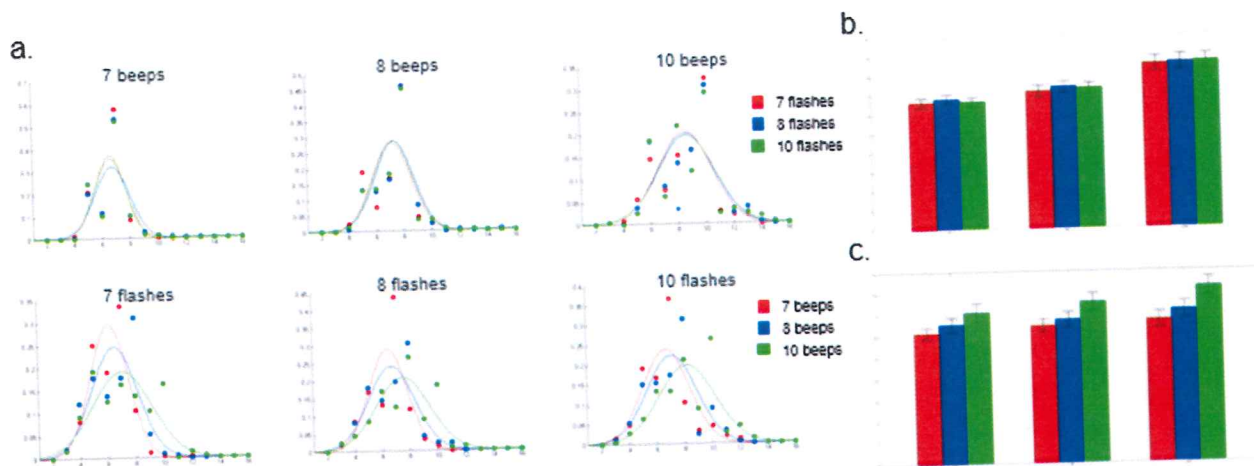
#### **Methods**

In this behavioral task, 16 participants were presented with two intervals containing 7, 8, or 10 beeps and flashes (congruent and incongruent), and were asked to estimate the number of beeps/flashes heard/seen. Stimuli were congruent (e.g., 7 beeps with 7 flashes) or incongruent (e.g., 10 with 8) in numerosity. To draw attention to the visual or auditory stimuli, each participant was instructed to estimate either the number of visual flashes seen or the number of auditory beeps heard, counterbalanced across participants. We calculated the percentage of correct responses and measured the distribution of responses (mean, mode, and dispersion) for each participant, as well as the reaction time.

#### **Results**

Consistent with previous studies showing multisensory enhancement (Driver & Noesselt, 2008), the participants' responses were more accurate and faster in the congruent condition than

in the incongruent condition. As shown in **Figure 6**, the data suggests that the auditory modality was dominant in our tasks. Regardless of which sensory modality the participant was instructed to focus on (“how many beeps did you hear?” or “how many flashes did you see?”), the responses were highly affected by the number of beeps heard.



**Figure 6.** a) Estimates of auditory beeps with incongruent flashes (top) or visual flashes with incongruent beeps (bottom). Bar graphs show estimated auditory (b) and visual (c) number.

## Discussion

The results from the System study (Experiments 1 and 2) suggest that people can use the ANS to estimate the number of visual and auditory events, and that this system obeys many of the rules of multisensory integration observed for other simple stimuli. Furthermore, the similarity of estimation behavior across modalities supports the claim that the ANS houses an abstract representation of number. Successful comparison in within and between modality conditions supports the claim that the ANS representation may be abstract, but performance decrease in between relative to the within modality suggests that number comparison is not fully abstract. Based on the results from the Congruent study (Experiments 5), multisensory enhancement suggests a convergence of information, but as we measured both accuracy and reaction time, standard race models are not appropriate. The results from the Incongruent study

(Experiment 7) shows signs of auditory dominance in a conflict, consistent with modality appropriateness, if we think of sequential number as a temporal task.

Functional neuroimaging with adults will also allow us to test whether the intraparietal sulcus contains an abstract representation of number across sensory modalities. fMRI-adaptation should show adaptation to number across sensory modalities in the IPS, with early sensory areas showing modality specific effects. Intersensory facilitation should increase IPS responses, while intersensory conflict should decrease IPS responses.

After testing adults to provide neurological evidence of a multisensory integration system, we plan to conduct further experiments with young children. The purpose of this future study will be to observe developmental changes, as the acquisition of number symbols may change representation of auditory and visual stimuli across multiple sensory modalities. Furthermore, we intend to use a neurological approach to investigate and contribute to Dr. Jordan's theory that multisensory integration can improve numerosity discrimination.

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