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Trang Nguyen

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Name: Trang Thuy Thi Nguyen

Panther ID: tnguyen229

Panther number: 001-86-8865

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Completed under the direction of
David A. Washburn, Ph.D.
Professor of Psychology & Neuroscience

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Introduction

Visual stimulation activates receptors on the retina, which in turn transmit the information neutrally to the primary visual cortices. (Adam & Gunturkun, 2009; Verleger, Dittmer, & Smigasieqicz, 2013). There is only one fovea in each eye, but there are two primary visual cortices, or areas of the brain that function to process visual information—one in each hemisphere. A large number of studies in psychology and cognitive neuroscience suggest that these hemispheres have differences in specialization of processing. In other words, the left hemisphere tends to process certain types of stimuli better than the right hemisphere, and vice versa (Verleger et al., 2013).

Human physiology of the visual system dictates that each eye sends information to both hemispheres, with information appearing in either visual field sent directly to the primary visual cortex of the contralateral (opposite side) hemisphere. The left visual hemifield (i.e., parafoveal stimuli that fall to the left of fixation) is associated with the right cerebral hemisphere, whereas information in the right visual hemifield gets transmitted initially to the left hemisphere. As will be discussed below, this organization of the visual system makes possible one popular noninvasive method for scientists to study the specializations of each hemisphere. The two hemispheres then communicate and interact with each other to form a unified perception of the stimulus, and ultimately a coordinated response (Adam & Gunturkun, 2009).

There is much research showing that one hemisphere processes certain stimuli better than the other (for one of many excellent reviews, see Springer & Deutsch, 1985). The object’s properties such as shape, color, and texture may be processed preferentially in the two hemispheres (Lloyd-Jones et al., 2012). Moreover, the hemispheres tend to be specialized for complex capacities such as language (predominantly localized to the left hemisphere) and visuospatial attention (typically localized to areas of the right cerebral hemisphere; see Gotts et al., 2013; Heilman & Van Den Abell, 1980; Posner & Raichle, 1994). However, this is not always the case. Many tasks are not lateralized to specific hemispheres (Adam and Gunturkun, 2009). Additionally, there are individual differences: For example, language processing is left-lateralized for the vast majority but not for all people.

The right hemisphere mainly processes visual stimuli at filler and lower stream (Verleger et al., 2013). This hemisphere specializes in processing spatial selective attention and target detection (Gotts et al,.2013; Shulman et al., 2010). It also processes limbic system and poly-semantic context (Rotenberg and Weinberg, 1999), and tends to be dominant for tasks involving nonverbal form color, music, imagination, and creative expression (Brynie, 2009; and au.af.mic-lesson 5). The right hemisphere shows global or holistic bias, or a processing bias for the "big picture" (Gotts et al., 2013; and au.af.mic-lesson 5). This character gives the right hemisphere the preferential ability to process information in facial identity (Verosky & Turk-Browne, 2012). Additionally, the right hemisphere may also be important for shifts of attention in either direction.

In the contrast, the left cerebral hemisphere supports shifts of attention in the rightward direction (Shulman et al., 2010). Different from the right hemisphere, the left hemisphere presents local bias or focuses on the components of the picture (Gotts et al., 2013; and au.af.mic-lesson 5). The left hemisphere tends to be specialized for processing language, numbers, logic, sequential tasks, and fine motor coordination (Gotts et al., 2013; and au.af.mic-lesson 5; and Wright, Stamatakis, & Tyler, 2012). It mainly processes at the upper perceptual stream (Verleger et al., 2013).

For the present study, I wanted to investigate whether these functional cerebral asymmetries would extend to working memory tasks. It was hypothesized that the left hemisphere (i.e., information flashed to the right visual field) would have more advantage for accurate responses to a Number-based memory task, whereas the right hemisphere (left visual field) would be relatively advantaged for accurate responses on a Color-based memory task. Further, when participants recognize the stimulus accurately, I hypothesized that they would be faster for stimuli flashed to the visual field contralateral to the cerebral hemisphere that seems to be specialized for the corresponding type of processing (i.e., left hemisphere = words and numbers, right hemisphere = shapes and colors).

Method

Participants. Undergraduate students (n = 39) volunteered to be tested. They received experiment-participation credit for completing the study.

Apparatus and Task. Participants were tested on two computer-based working-memory tasks: one with colors as to-be-remembered stimuli, and one with Arabic numerals as stimuli. The Color-memory task was inspired by the Corsi-block task (Corsi, 1972) with 4x4 grid. Participants pressed a key to initiate a trial, whereupon the 4-cell x 4-cell grey grid appeared in the middle of the screen. After a brief random pre-stimulus interval, one cell of the grid changed color. Once per second, one randomly selected square changed to a different randomly selected color briefly, and returned to grey after 1 second. This continued until between 3 and 5 squares had illuminated sequentially in different colors, such that the participant had to remember the locations and the colors of each grid as it appeared over time. No single cell changed to two different colors within a trial. Participants did not know how many grid cells would change color on any particular trial. One second after the final cell was presented on the trial, the screen cleared and a multicolored grid was flashed for 150 msec on the left or right edge of the screen. Given the distance between the participants and the screen, the inner edge of this flashed grid was at least 4 degrees of visual angle from fixation. The flashed stimulus was either the exact same stimulus that was presented sequentially in the middle of the screen, or was different from this to-be-remembered stimulus by one cell (i.e., one color moved to an incorrect location). The flashed stimulus was immediately masked with a black and white dot pattern to disrupt visual persistence. The participants were instructed to choose S for same and D for different to indicate whether the flashed stimulus was identical to the to-be-remembered stimulus, as it would have appeared if it had been shown all at once rather than sequentially (such that the memory had to be constructed and maintained one colored cell at a time). The participants had to remember the color and location of each block in this array.

The Number-memory task was similar to the Color-memory task. After the trial-initation response and pre-stimulus interval, a line containing a string of 8 digits (zeroes) appeared in the middle of the screen. Once per second, a randomly selected position would change to a randomly selected numeral (1 to 9), and then disappear from view (return to a zero) after 1 second. The trial continued until between 3 and 5 digits had been presented, and again the memory load (number of digits) was randomized on each trial and unpredictable by the participants. One second after the final digit was presented, the screen cleared and either the same string or a string that differed at just one position would flash quickly (150 msec) on the left or right edge of the screen, 4 degrees of visual angle from fixation. The participants then chose S for same and D for different to indicate whether the flashed stimulus was identical to the target string. Again, to-be-remembered number strings did not appear all at once, but rather the non-zero digits would be added sequentially and in random order, such that working memory was required to construct and maintain the correct answer. The participants had to remember the identity and location of each number in the array.

Each task had three levels of memory load: 3, 4, and 5, corresponding to the number of to-be-remembered colors or Numerals. For instance, in the load=3 condition of Number-memory task, there were 3 to-be-remembered numerals embedded in the string of 8 zeroes. By flashing comparison stimuli briefly and parafoveally as described above, I was able to test whether working memory for numeral strings or color grids varied as a function of hemisphere of processing, and whether this varied as a function of memory load.

Procedure. Participants were individually tested on separate laboratory computers. After completing consent and demographics forms, each participant received instructions and was asked to finish the two working-memory tasks. The tasks were assigned in different order across participants, in order to counterbalance for possible learning or fatigue effects.

Results

Response Accuracy. Table 1 displays mean proportions of correct responses (with range and deviation statistics) for both tasks as a function of visual field of presentation and memory load conditions. Recall that chance accuracy on these tasks would be 0.50, so in general participants found this task to be very difficult across conditions. Although some participants were able to respond very accurately in some conditions (note that the range for each variable includes means as high as 100% accuracy), others got no trials correct in particular conditions. Overall, mean accuracy across conditions and participants was just 51%.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Left1.3	39	.13	1.00	.5641	.19219
Left1.4	39	.08	.89	.4908	.16845
Left1.5	39	.20	.89	.5418	.14887
Right1.3	39	.33	1.00	.5628	.15226
Right1.4	39	.00	1.00	.4697	.19401
Right1.5	39	.17	.80	.5338	.12873
Left2.3	39	.00	.86	.5231	.18655
Left2.4	39	.00	.88	.4985	.18772
Left2.5	39	.14	.89	.5115	.18557
Right2.3	39	.13	.83	.5026	.18285
Right2.4	39	.09	.70	.4767	.13971
Right2.5	39	.14	.80	.5051	.17535
Valid N (listwise)	39				

Table 1. Proportion correct as a function of experimental conditions (with sample size, range, and standard deviations): “Left” indicates that the stimulus appeared in the left visual field. “Right” indicates that the stimulus appeared in the right visual field. “Left1” and “Right1” are the results for the Color-memory task. “Left2” and “Right2” are the results for the Number-memory task. The numbers 3, 4, and 5 after the period refer to the memory-load condition (e.g., “Right2.5” corresponds to right visual field presentations of Numeral-memory stimuli with load=5).

No significant differences were observed in the accuracy of responding as a function of task (*p* = .11) or visual field (*p* = .42). Figure 1 shows means for these two conditions, although the differences suggested here were not statistically reliable. A curious main effect of memory load on accuracy was observed however, *F*(2,76) = 4.12, *p* = .02, with poorer accuracy in the Load = 4 condition (Mean = 49%) than in the Load =

3 or Load = 5 conditions (Mean = 57% and 54%, respectively). No significant interactions were observed between these variables.

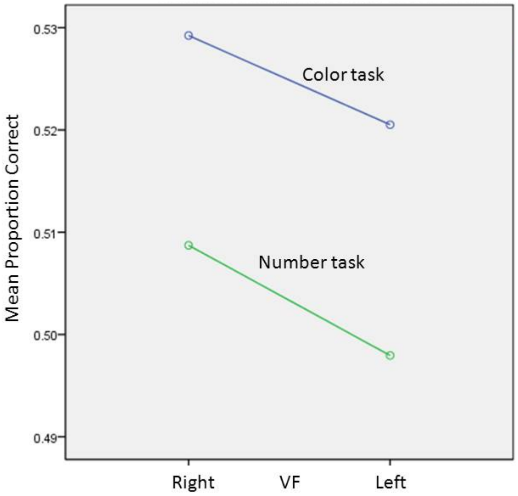

Figure 1: Proportion correct as a function of Task and Visual Field (VF)

Response Time. Mean response time (the interval from presentation of the flashed probe stimulus until a same/different response was recorded) was computed for each experimental condition, but response times were only analyzed for trials in which a correct response was observed. These means, together with other descriptive data, are displayed in Table 2.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Left1.3	39	409.00	2614.00	1265.0000	517.37597
Left1.4	39	615.00	2350.00	1333.6410	446.11525
Left1.5	39	855.00	2566.00	1467.4359	371.54633
Right1.3	39	454.00	2153.00	1238.2821	471.45262
Right1.4	37	218.00	2736.00	1266.1081	566.89881
Right1.5	38	304.00	2928.00	1393.5526	577.44370
Left2.3	37	237.00	2287.00	1212.6486	505.52993
Left2.4	38	251.00	2895.00	1263.0000	618.25605
Left2.5	39	176.00	2552.00	1242.0000	565.69375
Right2.3	38	135.00	2847.00	1333.0789	534.86555
Right2.4	38	275.00	2936.00	1370.5526	593.58825
Right2.5	38	384.00	2524.00	1344.8158	570.86477
Valid N (listwise)	31				

Table 2. Mean response time, in milliseconds: “Left” indicates that the stimulus appeared in the left visual field. “Right” indicates that the stimulus appeared in the right visual field. “Left1” and “Right1” are the results for the Color-memory task. “Left2” and “Right2” are the results for the Number-memory task. The numbers 3, 4, and 5 after the period refer to the memory-load condition. So, for example, “Left1.3” refers to color-memory stimuli presented in the left visual field with memory load=3.

As with the accuracy data, analysis of correct response times revealed significant main effects for memory load, *F*(2, 60) = 4.40, *p* = .02. Responses took significantly more time in the Load = 5 condition (Mean = 1356 msec) than in the Load = 3 or Load = 4 conditions (Mean = 1264 and 1269 msec, respectively).

No main effects of visual field or task were observed on the response time data; however, a significant interaction of these two variables was obtained, *F*(1, 30) = 4.65, *p* = .05. As is shown in Figure 2, responses were significantly faster on the Color-memory task when stimuli were flashed in the left visual field, but were significantly faster on the Number-memory task when the probe stimuli were flashed in the right visual field.

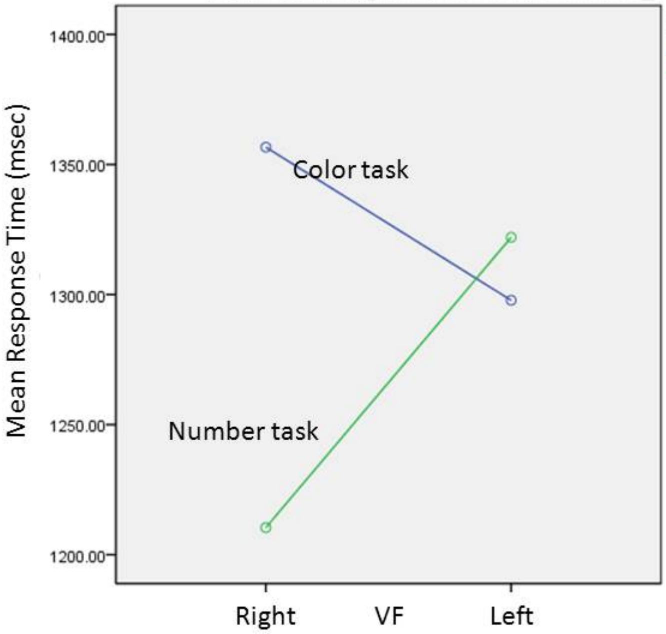

Figure 2. Mean response time (in msec) as a function of memory task and visual field (VF)

No other significant main effects or interactions were observed for these data.

Discussion

With respect to response accuracy, it was surprising that participants performed so poorly on these tasks. Although the memory-load conditions and the presentation duration (i.e., 150 msec flashes) made both tasks quite difficult, prior pilot testing had suggested that participants should have been better than chance on these working memory tasks.

In light of the high error rate, it is not surprising that no meaningful differences were observed in the accuracy data as a function of the experimental variables. Of course, this might mean that the hemispheres do not differ with respect to processing specialization on Color- or Number-memory tasks. As mentioned in the introduction, Adam and Gunturkun (2009) showed that sometimes the cerebral hemispheres are not specialized for certain tasks. It seems more likely, however, that the hypothesized hemispheric differences were masked by the overall low accuracy rate for all conditions. Although there was a significant effect of memory load on accuracy, it was not in the predicted direction (i.e., lower accuracy as load increased), but rather showed an unexpected pattern where the accuracy was better with Load=3 and Load=5 than with Load=4. Nevertheless, the general low accuracy of responses across all conditions challenges any interpretation of these data.

It is possible that participants merely guessed on every trial, and thus that all of these data (accuracy levels *and* response times) are meaningless. However, the response time data do suggest another interpretation. When participants responded correctly, their responses took longest for the Load=5 condition, and showed the Memory Task X Memory Load interaction that was hypothesized. This suggests that rather than guessing on all trials, participants did remember the stimuli on some trials and misremembered the stimuli on other trials. If this is true, then the patterns of responding on those trials in which participants were correct may indeed be interpreted as meaningful reflections of processing in the two hemispheres.

In this case, it is interesting that the present data suggest functional cerebral asymmetries in working memory for a Corsi-type Color-memory task and a similar Number-memory task. It appears that participants constructed a memory representation of color-block arrays or digit-sequence stimuli, updating the representation when each new stimulus was presented. If a same or different probe stimulus was flashed briefly to the left visual field, such that the right cerebral hemisphere had preferential access to the information, accurate responses were faster for the Color-task stimuli but slower for the

Number-task stimuli. The opposite pattern was observed with probe stimuli flashed to the right visual hemifield / left hemisphere: faster responses were observed if the two-be-remembered information consisted of numerals but slower responses were obtained for color-block stimuli.

Thus, the hypothesis for this study was supported by the response time data. The left hemisphere appears to be advantaged for accurate responses when the memory stimuli are numerical in nature, whereas the right hemisphere has more advantage for accurate responses on the Color-memory task. What remains unanswered in this study is whether these functional cerebral asymmetries indicate the hemisphere in which the respective memory representations are held, or are simply advantages for the rapid and accurate processing of the probe stimuli that are compared to those memory representations. Future research should be designed to investigate these possibilities, as well as to replicate the present findings under conditions that facilitate better accuracy across experimental conditions.

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