

Running Head: MAGNITUDE DISCRIMINATION IN DEPRESSION

Spatial and Attentional Influences on Nonverbal Magnitude Discrimination in Depressed and
Non-Depressed Individuals

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degree

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Abstract

Numbers have been called the universal language. Yet the psychophysical properties of numerosity remain elusive, particularly as they relate to clinical disorders such as depression. It is known that the estimation and discrimination of magnitude remain a culturally unbiased phenomenon that could be used to negate the error associated with the use of linguistic or pictorial stimuli during assessments. Also, recent imaging studies have proposed that different processing streams are associated with the spatial perception of foreground and background image characteristics, with contextual binding of these two fields occurring in the right hippocampus. Using a novel three-dimensionally shadowed circularly concentric center-surround stimulus in which dot arrays were placed in either or both of the shadowed foreground and background fields, we hoped to ascertain whether depression can affect the performance on a magnitude estimation task. Changing dot arrays in either of the two fields across two time epochs, participants were required to accurately indicate which of the intervals had the greater number. In some blocks, a “red” coloured field was used to cue which of the two fields contained the changing dots. The inclusion of cue conditions allowed for the measurement of potential hippocampal and attentional dysfunctions in depressed individuals. Six depressed and 34 control (nondepressed) participants were recruited from psychology classes at Lakehead University. Dependent variables used to assess performance were Reaction Time (RT) and difference threshold (magnitude estimation accuracy). Our results showed that the depressed performed significantly worse than controls in overall accuracy, but that no RT differences were observed between the groups. Further, we noted some interesting increases in response latency relating to atypical vs. typical foreground/background arrangements. Finally, we found support for the theory that the dorsal visual stream can also process task-specific visual information typically associated with ventral visual pathway.

Spatial and Attentional Influences on Nonverbal Magnitude Discrimination in Depressed and Non-Depressed Individuals

Numbers have often been called a universal language that is free from cultural, racial and other biases. Where verbal language is prone to miscommunication, misinterpretation and misunderstanding, magnitudes or their representation seem to be universally appreciated across cultures and even across species (Brannon, 2006). This property of numerosity could be beneficial for those wishing to further their understanding of the often-debated characteristics of mental disorders such as depression. Using more robust and universal measures, such as magnitude estimation or discrimination, bias or error that is intrinsically associated with the processing of linguistic stimuli could be avoided.

The present study attempted to further our understanding of some of the possible mechanisms that underlie magnitude estimation processing, with specific emphasis towards understanding the relevant substrates found in clinical depression. We used a simple magnitude discrimination task in which depressed and nondepressed (control) participants were asked to detect which of two sequentially presented dot arrays contained a greater number of dots. Using a methodology similar to that recently employed by Goh et al. (2004), we altered the magnitude of the number of circular dots that were positioned either in the foreground or background of a compound spatial center-surround stimulus. In addition, we examined the influence of spatial cues on performance across clinical and control groups. This was accomplished either by presenting prior to testing no spatially-relevant stimulus cues, 100% valid cue stimuli or 50% valid cue stimuli. These paradigms helped determine the influences of clinical depression not only from a bottom-up perceptual perspective, but from a top-down “modulatory” perspective as well. In other words, we hoped to gain a more

comprehensive picture not only of the discrepancies that may exist between depressed participants and healthy controls, but also gain a keen insight into attentional processes (i.e., cueing, set-shifting), oculomotor control, retinotopic and visual field influences, and cognitive influences pertaining to magnitude discrimination. Further, the inclusion of depressed participants in the present study aided us not only to explore an as-yet-unidentified marker for depression, but also to verify the potential impact of hippocampal dysfunction in the performance of tasks containing three-dimensional (3D) information.

What follows is a review of the literature on numerosity and the spatial organization of numbers with an emphasis on the biological basis of numerosity and the distinction between magnitude estimation and counting. Key concepts regarding the processing of numbers are also addressed. We discuss target detection and attentional processes, with an emphasis on relevant visual parallel processing streams. We conclude by relating the above processes to depression and presenting hypotheses that relate to potential differences between depressed populations and healthy controls.

Numerosity

Many studies in the recent past have attempted to tease out the actual mechanism by which the human brain represents and codes for numbers and magnitude. It is now well established that the mechanisms underlying numerosity are developmentally-linked and evolutionary in nature (Brannon, 2006). The ability to discriminate magnitude has been found in a range of species, from monkeys (Cantlon & Brannon, 2007) to parrots (Pepperberg, 2006) and even domestic canines (Ward & Smuts, 2007), and seems to be an intrinsic neurocognitive system. Jordan and Brannon (2006) showed that even though 6-year-old children had acquired a verbal counting algorithm, they performed almost identically to

monkeys in a magnitude bisection task. In this task, human and non-human participants were required to select which of two dot arrays were closer in number to a target stimulus. Invariably, as the target stimulus was increased, so to was a bias toward the larger choice; however the reaction time (RT) of the children remained relatively unchanged. This led researchers to consider that a non-verbal counting strategy was being used despite the humans' ability to access verbal representation centers. Given the above evidence, we posit that the spatial (e.g., depth plane) and attentional (e.g., cueing) properties of our stimulus design, and their associated neurological pathways, could interact with the centers responsible for magnitude discrimination and potentially affect or modulate performance on a simple magnitude discrimination task.

Before describing the top-down influences on magnitude discrimination, a few key concepts need to be understood. Since Weber's law is posited to govern performance on magnitude discrimination tasks, it seems logical to begin with this concept. Weber's law states that the stimulus change in prothetic sensations needed for an organism to detect that change is a constant proportion of the stimulus' original prothetic level. Recent evidence states that this rule also holds true for magnitude estimation tasks and that the Weber proportion (or ratio) is dependent on age. In a review by Brannon (2006), humans and non-human animals, in accordance with Weber's law, showed a ratio-dependent magnitude discrimination performance (as defined by the ratio of the smaller numbered stimulus to the larger one). According to the same review, this ratio needs to be fairly extreme for younger infants (~6 months of age) where a presented test stimulus needs to be twice the magnitude of the original stimulus, or 100% greater. With development and training (9-month-old infants), however, discrimination sensitivity can improve to 2:3 ratios (the test stimulus being only

50% greater than the original). Most recently, even greater discrimination sensitivity was found with older adults who were capable of discriminating 10% ratio differences or less (Madon, Vanderleest & Wesner, 2008). In addition to discrimination sensitivity, RT and percent accuracy are systematically affected by both the absolute difference in the number of elements of the two compared stimuli (numerical distance) and absolute magnitude (total number of elements) of the stimuli (Ansari & Dhital, 2006; Moyer & Landauer, 1967.) For example, RT is inversely proportional to both absolute numerical difference and absolute magnitude, while percent accuracy is directly proportional to absolute number difference and unaffected by absolute magnitude (the total number of elements) but only if the age-dependent proportional ratios are maintained. RT effects are also discussed by Kadosh, Henik and Rubinsten (2007) who mentioned the size congruity effect. This effect refers to a phenomenon in which the size of a stimulus word or symbol can have a Stroop-like effect on RT at small numerical distances, meaning that when the relative size (the physical size of the stimulus) and its magnitude (the numerical magnitude) were incongruent, increases in response latency were noted. However, Kadosh and colleagues noted that if the relative size and magnitude of a symbol or word are congruent, decreases in RT are likely. According to the authors, however, this effect is diminished with increased numerical distance, and incongruent size:magnitude relationships were not effective at increasing RT. This supports the notion that increases in numerical distance is directly correlated with decreases in RT, regardless of physical stimulus size, or other confounding factors (e.g., colour, surface area, shape), and also speaks to the robustness of Weber's law as it relates to magnitude discrimination (Cantlon & Brannon, 2007). To directly test this, Cantlon and Brannon in the same study used a two-alternative match-to-sample task where one correct alternative was

based on numerical value and the other on another aspect of the stimulus (color, shape, physical size of stimulus). The study found that both number-trained monkeys (i.e., monkeys that have been previously conditioned to respond to numerical stimuli) and number-naïve monkeys preferentially responded to the numerical attributes of stimulus pairs despite the presence of a distracter attribute (color, shape or surface area/size), adding further support for the notion that numerosity is a biologically fundamental process.

The Difference Between Magnitude Estimation and Counting

It is important to note that the terms “magnitude estimation” and “magnitude discrimination” are not used interchangeably throughout this report. Based on the literature, magnitude estimation can be defined as the assignment of an approximate value to stimulus attribute (e.g. number, radius, surface area) that is not otherwise measurable or countable. Magnitude discrimination, on the other hand, is a slightly more complex process that involves attentional and working memory processes which enable participants to distinguish stimulus elemental numbers that are presented either in sequence or simultaneously at different spatial locations in their visual field.

Brannon (2006) showed that numerical set reconstruction and magnitude estimation operate from different neural systems. Set reconstruction relies on the ability of human subjects to “count”, which means there is a reliance on a verbal algorithm to identify exact numbers or stimuli. This process relies heavily on training and abstract symbols (such as Arabic numerals). On the other hand, magnitude estimation seems to follow Weber’s law, regardless of the human culture, age or species tested. As examples, rhesus monkeys have the ratio-dependent ability to spontaneously add (Flombaum, Junge & Hauser, 2005). The authors used a paradigm in which monkeys were shown four lemons, which were then

covered. Four lemons were then shown to the monkeys and added to those behind the screen, and when the screen was removed the monkeys were shown either eight lemons (the correct answer) or four lemons (an incorrect alternative). Their results showed that the monkeys maintained a longer fixation on the incorrect alternative, indicating that the incorrect result violated their expectations. Brannon (2006) also showed infants as young as 6-months of age are able to discriminate between different numbers of elements presented (i.e., set sizes) and between the surface area occupied by other stimuli, provided an appropriate age-dependent ratio was respected (see above). Further to this point, although set-reproduction tasks were difficult for two indigenous Brazilian tribes whose numbering systems did not surpass five (one tribe's system did not surpass two) the tribes were able to discriminate between large sets of dots (20-80) with performance similar to that of Western controls (Gordon, 2004; Pica, Lemer, Izard & Dehaene, 2004).

The above comparisons show that magnitude estimation can be construed as a lower-end reflexive process, whereas counting and the understanding of symbols related to numerosity are learned and a higher-end, verbally-tied phenomena. In fact, using a language interference task, Spelke and Tsivkin (2001) showed that exact calculation, but not estimation, were related to linguistic and semantic processes. This particular distinction is reasonable considering that counting, mathematics and arithmetic are reliant on an algorithmic system designed to distinguish exact quantities, whereas magnitude discrimination and estimation rely more on abstract knowledge of quantities (the actual meaning or measure of those quantities).

Another source of evidence for the linguistic link to counting comes from the *Spatial Numerical Association of Response Codes* (SNARC) effect (Dehaene, Bossini & Giraux,

1993), which posits that numbers in the brain are represented on a “mental number line”, and that certain values of those numbers, small vs. large, show preferential responding with the left or right hand, respectively. In other words, if shown two numbers and asked to select the greater of the two, a response bias would be noted for the right hand or button (and vice versa for small numbers), owing to the intuitive association of the right side with larger numbers in western culture. This argument does not reflect a hemisphericity difference in encoding – although such a difference does seem to exist (see below) – but rather it is thought that reading direction and intuitive associations of left to right are responsible for this numeric-value-with-handedness discrepancy. Indeed, after testing Iranian participants (who read right to left) in the same paradigms, a reverse preference was shown, and virtually no preference difference was shown in biliteral Persian and French participants, who were adept at reading in both languages, and thereby both directions (Fischer, Warlop, Hill & Fias, 2004).

The Biological Basis of Magnitude Estimation and Counting

The intraparietal sulcus (IPS), considered part of the high-end associative dorsal (vs. ventral) visual processing distinctions, has been repeatedly identified as the primary area for numerical and magnitude operations in the brain (e.g. Brannon, 2006; Cantlon, Brannon, Carter & Pelprey, 2006; Piazza, Mechelli, Price & Butterworth, 2006; Riviera, Reiss, Eckert & Menon, 2005). However its precise role, lateral functional characteristics, and linked associative processing areas are a source of debate and discovery among researchers in this field.

Based on neuroimaging studies, there appears to be age-dependent functional laterality in the processing of different aspects of numerosity in which the right IPS becomes more active when an individual is engaged in nonverbal magnitude estimation, and the left IPS

becomes more active when an individual is counting or undergoing concrete mathematical operations. Cantlon, Brannon, Carter and Pelphey (2006) provided evidence that the right hemispheric IPS is recruited by children as young as four years of age in the processing of non-symbolic magnitude differences. This supports the idea of an intrinsic laterality-based network in the IPS that is linked to magnitude estimation, and that this link is independent of levels of schooling. It is to be noted that the term “non-symbolic” refers to magnitude estimation relying on simplistic arrays, tone patterns or any other stimulus that is not easily associated with a specific number (such as “2”, “two” or the face of a die representing the number two). Of particular interest is the fact that adults show robust bilateral IPS activation during magnitude estimation whereas children show clear right-IPS biases while doing the same task. With symbolic mathematical operations, however, Riviera, Reiss, Eckert and Menon (2005) showed that the left IPS becomes increasingly active between the ages of 8 and 19 years, whereas the right IPS showed little to no change during the same developmental period. A neuroimaging (fMRI) study by Piazza, Mechelli, Price and Butterworth (2006) showed that estimation and counting (in a matching-to-sample paradigm) are controlled primarily by separate hemispheres in the brain. Estimation is fully right-lateralized in terms of activation and is also heteromodal in that there was no difference between accuracy using auditory or visual stimuli. No left activation was noted for this task. During counting tasks, however, the right-lateralized centers used in estimation were activated, and corresponding left-side areas were also activated, supporting previous conclusions that the left side of the brain is primarily responsible for more advanced mathematical functions. However, this may also reflect the fact that in order to count, one must have a counting algorithm, and that those algorithms are directly tied to language, which is predominately governed by left hemisphere.

Results from Piazza, Mechelli, Price and Butterworth (2006) were later supported by Piazza, Pinel, Le Bihan and Dehaene (2007), who showed hemispheric asymmetry in magnitude processing, and that the left IPS was more closely linked to the symbolic processing of numbers. Similarly, Ansari (2007) noted that there exists some IPS bilaterality when coding for magnitude using either words, Arabic numerals, or dot counts. Specifically, the left IPS seems to be specialized in coding for symbolic or enculturated numerical representations (e.g., words or Arabic numerals), possibly owing to a reciprocal connection with the left-prefrontal cortex (PFC) language centers, while the right IPS seems to be involved in coding for non-symbolic, non-enculturated magnitudes (e.g., dot arrays). Further support comes from damage and developmental studies as reviewed by Ansari, in that lower cell-counts, decreased volume and damage to the left IPS are all strongly associated with acalculia and other mathematical difficulties. Recent evidence also shows the left-lateralized fronto-parietal network to be responsible for more finely-tuned numerical representation such as exact count as opposed to making approximate estimations of number.

Kadosh, Henik et al. (2005) disagrees with the left/right distinction and states that it is in fact the individually-defined dominant IPS hemisphere that is responsible for numerical comparison. They do, however, go on to state that the IPS does not act only as a numerical comparator, but also serves other cognitive processes such as visuospatial analysis and general magnitude comparison, as stated above. The study also showed right temporal lobe activation, specifically in the middle temporal gyrus and superior temporal sulcus; however since the study involved the use of Arabic numerals, it was posited that these areas could be responsive to the semantic nature of these numeric stimuli.

To clarify the role of the IPS during magnitude estimation, Dehaene, Piazza, Pinel and Cohen (2003) proposed a tripartite parietal circuit that is activated during number processing. Dehaene, Piazza et al. assumed three separate cortical circuits centred on the parietal lobe for different magnitude and mathematical processes. The first is centered on the IPS and is the primary center for non-verbal numerical processing. It is closely tied to semantic/verbal processing centers (in the case of mathematics/arithmetic) but is more active during simple numeric approximation. It is likely that this site holds the key to what numbers actually mean, essentially allowing one to understand the concept of “twenty” vs. “ten”, in terms of representational magnitude. Further, the IPS is more active during estimation tasks than when people compute exact solutions. One explanation for this supports Piazza, Mechelli et al. (2006), in that the route of numerical processing could begin with the right IPS (magnitude estimation) and subsequently the processing signals could be forwarded to the left IPS for specific quantitative determination. Also, the right IPS is often not recruited when rote multiplication or addition problems are presented (Dehaene, Piazza et al, 2003). This is due to a heavier reliance on rote memory than actual quantity manipulation.

The second of the tripartite circuits includes the posterior parietal cortex (PPC), and seems to control higher-end attentional processes, specifically spatial attention and eye orientation. Dehaene, Piazza et al. (2003) also posited that this area and its projections are responsible for “number-based” attention, which is involved in the selection of one amongst several quantities or deciding which of two quantities is larger. The discrimination of quantities is the core of the present study, and as such we hypothesize the involvement of this circuit as well. In her review, Brannon (2006) noted activation in the PPC along with IPS activity during magnitude estimation tasks, leading to speculate multiple site involvement

with magnitude discrimination. The same study also noted anterior inferior temporal cortex activation and lateral prefrontal cortical activation. Impaired attention has been demonstrated in depressed patients (e.g., Sevigny, Everett & Grondin, 2003), and therefore we predict differences in magnitude discrimination accuracy and task RT when comparing depressed to non-depressed (control) groups.

The third of the tripartite circuits is centered on the left hemispheric angular gyrus and is involved in calculation and verbal number manipulations (Dehaene et al., 2003). This circuit could also be related to familiar symbolic processing (dice patterns, etc.), in that the processing of these symbols is algorithmic and does not rely on the right IPS except to confirm their relative magnitude. This circuit, although not essential to the non-symbolic task we employ, is described here because it needs to be treated as a potential confound in the present study.

Further to the involvement of the tripartite model, other neuroimaging and electrophysiological studies have been performed that refine our knowledge of numerosity processing. For example, Sawamura, Shima and Tanji (2002) used fMRI data to show that specific neurons encode for specific cardinal values in the IPS, and that these are independent of other stimulus attributes such as density, perimeter and surface area. Further, when the elemental numbers of the stimulus is increased, this cluster of specialized neurons shows a representational overlap with the area responsible for magnitude estimation, leading researchers to postulate a physiological basis for the magnitude and numeric distance effects noted above. In other words, even within the IPS, certain functional distinctions can be found relating quantity to magnitude. A related model was recently posited by Ansari (2008) and supported by Roitman, Brannon and Platt (2007). In Ansari's model, individual cardinal

number values are represented by single neurons, each containing its own “tuning curve” that preferentially responds to a narrow range of values centered on one cardinal value. According to the authors, this tuning curve is evident in infancy, but its association to symbolic numerals (e.g. Arabic numerals) must be learned. In either case, these results show that even tasks as simple as magnitude discrimination may be susceptible to top-down control or developmental factors, and if this is the case, then these performance measures may be susceptible to clinical disorders such as depression.

Roitman, Brannon and Platt (2007) posited functional distinctions within the IPS, specifically the ventral and lateral intraparietal areas (VIP and LIP, respectively). The authors made electrophysiological recordings of the right and left LIP while monkeys performed an implicit (non-directed) numerical discrimination task. Two monkeys were trained to saccade to a target while a dot array was placed in the opposite visual field from the target position. By varying stimulus attributes (e.g., colour, element size, element density, etc.) other than number, the authors were able to isolate a population of neurons that seemed to code for cardinal numerical values within the LIP. The results of this study suggested that LIP, in addition to coding for spatial location of saccade targets, also coded for numerical magnitude in the contralateral peripheral visual field. Previous research has shown that neurons in the VIP do the same for the foveal visual field (e.g. Avillav, Deneve, Olivier, Pouget & Duhamel, 2005). Roitmann et al. (2007) also noted a hierarchical processing of other stimulus attributes, such as colour within the dorsal visual stream, provided those attributes were being used in the identification of a numerosity target. The theory that the dorsal visual stream can code for stimulus attributes typically associated with the ventral visual stream was supported by Toth and Assad (2002), who made electrophysiological recording of single cells in the LIP

while monkeys were trained to saccade to a target (left or right) based either on its location or its colour. The authors found that colour, and by extension other arbitrary stimulus characteristics, although typically associated with ventral visual stream operations, can be processed in the dorsal visual stream (specifically in the LIP in this case) when related to a goal-directed behaviour, such as identifying the greater of two non-symbolic magnitudes. The authors also mentioned that LIP and VIP regions contain neuron populations that code for cardinal numerical values, and thus goal-directed magnitude discrimination could be entirely dorsally-mediated, regardless of other presented stimulus conditions.

Based on the above findings, we postulate that although the left and right IPS can individually code for numerical stimuli, the left IPS is more intrinsically linked to linguistic centers. We argue that the discrimination of magnitude without the aid of verbal algorithms or symbolic representations will focus more exclusively on the right IPS. Supporting this laterality is a transcranial magnetic stimulation (rTMS) study by Snyder, Bahramali, Hawker and Mitchell (2006) in which the left anterior temporal lobe was inhibited by using a 1.0 Hz field directed magnetic field. The results showed that the inhibition simulated “savant”-like numerosity skills in normal participants, giving them the ability to accurately guess, within 5 units, the amount of dots in an array varying from 50 to 150 elements. The authors suggested that the magnetic field inhibited our tendency to assign meaningful patterns to meaningless stimuli (such as dots arrays) and this tendency interferes with our ability to accurately estimate magnitude. In other words, the magnetic field inhibited the noise-producing left anterior temporal lobe, thus yielding an enhanced “savant-like” nonverbal performance by the participants. This finding is an example of how the dorsal and ventral visual streams interact in the estimation of magnitude, and lends weight to our use of a stimulus design that will

incorporate a pictorial, monocular three-dimensional design, which would require cooperation or activation of both these streams to accurately perform the task. If this cooperation represents strictly semantic and/or linguistic components, the lack of these dimensions in the present study allows us to directly probe the involvement of visual streams without invoking higher-ordered linguistic confounds.

Ansari and Dhital (2006) proposed that a developmentally-dependent activation of areas other than the IPS are necessary to aid in magnitude estimation. They stated that children recruit the right dorsolateral prefrontal cortex during magnitude estimation, and that this recruitment wanes with age. This may reflect an attentional or working memory mechanism that is required for younger children and dissipates with age-related experience. Children also show a markedly longer RT than adults across the same task, perhaps reflecting the need for extended integrative processing that is not necessary for older adults.

A few rTMS studies have shown complementary evidence to the above findings. Gobel, Calabria, Farne and Rossetti (2006) used rTMS over the right PPC or over the right occipital lobes in an attempt to show their involvement in the processing of numeric spatial representation. rTMS over the right PPC significantly disrupted the subjects' ability to bisect, or name the number falling exactly between, a pair of three-digit, aurally-presented numerical values without calculation. No disruptions were noted during an occipital rTMS. This supports a spatial representation of numerical values or magnitudes occurring in the PPC. Kadosh, Kadosh, Schuhmann et al. (2007) used neuronavigated rTMS over the right and left IPS, and showed that right IPS magnetic disruption lead to disruption of automatic magnitude processing assessed using a size-congruity task, in which participants were asked to attend to a relevant dimension (in this case the selection of the greater of two arabic numerals) while

ignoring an irrelevant dimension (relative size of the stimulus). The authors suggested that both hemispheric IPS sites were responsible for magnitude processing, but only disruptions to the right IPS lead to increased deficits in magnitude processing. Kadosh, Kadosh, Schuhmann et al. further speculated that this effect was due to inefficient processing of the verbal component of the numbers. In other words, although the IPS in both hemispheres is responsible for some part of numerical processing, the left IPS cannot perform numerical discrimination without the aid of the right IPS, positing a hierarchical pathway beginning with the right IPS. Cappeletti, Barth, Fregni, Spelke and Pascual-Leone (2007) found, however, conflicting but intriguing results using rTMS over the right and left IPS. In their study participants were asked to discriminate both numerical (e.g. Arabic) and non-numerical (e.g. dots). Left rTMS disrupted a numerical processing task while right rTMS actually *enhanced* it. They posit that an interhemispheric (transcallosal) inhibitory control system is the likely culprit for this effect. Given the above evidence, the likelihood that the IPS is hemispherically redundant is low; however it still needs to be considered in light of the present study's task.

To summarize, it seems that the right IPS and PPC are the primary centers involved in magnitude coding, and that the left IPS (perhaps in conjunction with linguistic centers) is the primary center for exact counting and enculturated, symbolic numerosity. These systems are interdependent, but unidirectionally so. To explain, a sense of magnitude is required to appreciate numbers (numbers being an abstract representation and sophistication of basic magnitude). However the reverse apparently is not true; one can appreciate magnitude without knowing number.

Spatial Representation of Numbers – Evidence from the SNARC Effect

Studies have shown that the parietal cortex codes for spatial information related to target detection as well as numerosity (e.g., Roitman, Brannon & Platt, 2007). What follows is an example of how these very distinct neural substrates can interact, and the resultant behavioural consequences of that interaction.

As previously mentioned, Dehaene, Bossini and Giraux (1993) showed evidence of the SNARC effect, which states that numbers in the brain are represented on a “mental number line”, with certain magnitudes (large vs. small) showing preferential orientation from right to left, respectively, in western cultures. Nuerk, Wood and Willmes (2005) provide further evidence that the SNARC effect is replicable with both auditory and visual stimuli, supporting that a spatial representation of numbers is not solely reliant on visual representations. The cross-modality of this phenomenon is further demonstrated by Fischer, Warlop, Hill and Fias (2004) who tested congruent and incongruent saccadic eye movement in response to Arabic numerals. Results showed that left saccades were faster for responding to relatively small digits (within the range used) and right saccades were faster for responding to relatively large digits. In this study, only a latency difference in saccades was found, and magnitude of saccades appeared to be constant across conditions. Besides supporting the SNARC effect, Fischer et al. showed that the left/right distinction or organization of varying Arabic numerals is present irrespective of the task-defined effector used (i.e., key-press, verbal or saccadic.)

Two other studies have shown how this phenomenon could impact RT depending on the automatic spatial representation associated with certain numbers (Gevers, Lammertyn, Notebaert, Verguts & Fias, 2006; Gevers, Verguts, Reynvoet, Cassens and Fias, 2006). These

studies showed that the SNARC effect is present in the vertical dimension as well, with “up” responses biased to large numbers and “down” responses biased to small numbers. In the same articles, the authors postulated that a dual-route system exists for spatial numerical processing, and that these systems are independent, though convergent. To explain, conditional, target-oriented processing streams (“identify whether the stimulus is odd or even”) are activated at the same time as irrelevant, spatial processing streams (left or down for small digits, up or right for large digits.) In the valid cue condition (i.e., when the stimulus is a relatively small number and requires a down or left response, and vice versa), these two routes will converge, leading to shorter latencies in making an accurate choice. In the invalid cue tasks (i.e., when the stimulus is a relatively large number and requires a down or left response, and vice versa), these will diverge, leading to the need to abort the irrelevant process and focus on the relevant one, leading to longer latencies. The SNARC effect, when conditions are reversed (e.g., press right button for a small digit, left for a large), is a perfect example of this.

The current study controlled for the SNARC effect by using sequentially presented stimuli consisting of equally distributed, randomly positioned elements within a circular field. Elements were distributed from the center of the screen outward, with no bias to any specific direction (see Methods section for exact details.) The participants were required to press the left button if the first stimulus presented is larger, and the right button if the second is larger. The SNARC effect predicts that response latencies and accuracy could be affected by this design, in that participants may incorrectly press (or be tempted to press) the top key if the second stimulus is greater. However, we avoided some of this bias by using randomly

positioned neutral dot elements and fast presentation times that void linguistic or counting associations.

In line with the above precautions, a few other considerations were made in order to obtain accurate, unbiased data. The first consideration dealt with cognitive load, in that a fine balance must be struck between task difficulty and ensuring that the task is still representative of the lower-end neural substrates we wished to explore (i.e., “lower” with respect to numeric linguistic associations). Using fMRI and event-related potentials, Kadosh, Kadosh, Linden et al. (2007) showed that differences in cognitive load may have an impact on the neural resources used in magnitude estimation tasks. Low-load scenarios may be served by distinct neural substrates, whereas high-load situations may require pooled and/or shared resources. Such a discrepancy could affect the performance of depressed participants relative to non-depressed controls in large-number/small-difference trials, in that depressed individuals may plateau at a certain cognitive load because of deficits in executive function. Alternatively, if the task were to be considered too easy by the control and/or clinical groups, there would be an inadequate sampling of performance measures to measure thresholds with all performances approaching near-perfect correct responses.

Another factor that was considered was in the recruitment of semantic processes. Although semantic processing in numerosity is fairly basic, the above studies do reveal a functional link between linguistic centers and numerosity judgements. To that end, and to avoid the potential confound of semantic processing, this study refers to Dehaene (1995), which showed that the first point at which semantic processing occurs is approximately 250-280 ms after stimulus delivery. A caveat to this is that the stimuli used were words, not dot

arrays, so the generalizability of this phenomenon is questionable. In accordance with this, and erring on the side of caution our stimulus presentations were limited to 250 ms.

Since no research to date has explored the effects of depression on magnitude estimation, the present study consisted of two separate experiments. The first part of the experiment required participants to perform a sequential magnitude discrimination task using a pictorial, 3D shadow depth cue design, in which only one of the two stimulus areas contained a dot array. The second part of the experiment required a higher cognitive load in which the participants were required to detect which of two field dimensions within a concentric, center-surround stimulus (i.e., center circle or annular surround) were showing changing dot numbers. The participants were then required to discriminate between the magnitude of two sequentially presented center-surround stimuli. Further details of this second part are outlined below.

Foreground vs. Background Spatial Discrimination

The proposed paradigm of this study not only required participants to discriminate magnitude, but also to note which of two sets of magnitude stimuli (dot arrays) in a two-field, center-surround stimulus were changing during any given trial. These two sets of arrays were positioned in a foreground or background (as defined by monocular shadow depth cues). The foreground or background was either the center or surrounding annular field in the center-surround stimulus (for stimulus illustrations, see Fig. 4). This stimulus not only controlled for such directional biases as the SNARC effect (except as noted above), but also allowed us to test for the effects of attention and clinical performance as it relates to structures in the brain known to be influenced by foreground or background context images (Chee, Goh, Venkatraman et al., 2006; Goh, Chee, Tan et al., 2007; Goh, Siong, Park et al., 2004).

The cortical areas involved in the discrimination and integration of foreground and background object cues have been extensively researched during the past decade. The following is a summary of some of current theories of neural involvement in these processes.

Malach, Levy and Hasson (2002) reviews the retinotopographical routes associated with object perception. Generally, images that require analysis of fine detail, such as faces, letters or words, are more centrally-biased in terms of visual field position (i.e., foveal), whereas landscape or background information requires less resolution or information and entails large-scale integration found in the peripheral visual fields. The terms foveal and peripheral refer to the retinal eccentricity associated with the placement of stimulus objects. Malach and associates also describe different cortical areas involved in the higher-end processing of various objects and scenes, with such specific distinctions as to include areas for tools, faces and animals. The foveal and peripheral fields also tend to map to different areas in the cortex, and the organization of these areas is critical for effective image processing throughout the entire visual field. For example, the lateral-occipital area is primarily responsible for close inspection of fine detail and subtle individual variations within a category and is tied to foveal vision. The area located around the collateral sulcus (in the ventromedial temporal lobe) and extending into the parahippocampal gyrus, however, is more closely linked to the broad, coarse mapping of the peripheral visual fields, and is related to navigational processing and texture segregation. These data are supported by Goh, Siong, Park et al. (2004) and Aminoff, Gronau and Bar (2007). Both foveal and peripheral brain processes may be recruited when analyzing the stimulus in the current study (see above, Roitman, Brannon & Platt, 2007), depending on the difficulty of the task and the ability of the participants to shift their attention from foreground to background during trials. The

identification of small differences in magnitude may require a finer analysis of detail, whereas the detection of larger differences, or the ability to detect change in the overall stimulus, could call for a broader and more integrative strategy. Also, with the difference between foreground and background operations characteristic of occipitotemporal and parahippocampal activity, respectively, it makes sense to use a foreground and background image context to study the possible dysfunction in clinical depression, particularly in areas association with hippocampal regions given their vulnerability to stress-related pathologies (e.g., Caspi et al., 2003; Duman, Malberg & Thome, 1999; Laifenfeld, Karry, Grauer, Klein & Ben-Shachara, 2005; Sapolsky, 2000). Another source of potential variability is in the “crossing” of the two streams called upon by our current design. Since magnitude in the peripheral field is coded by the LIP and that perception associated with that field seems to be governed by the medial temporal region, it was interesting to note any differences in performance when the peripheral annular surround was made into a “foreground” plane by virtue of a shadowed depth cue. Similarly, since the LOC and VIP are both responsible for foveal coding (of objects and magnitude, respectively), a similarly incongruent process could affect performance when the center of the image is in the background.

A recent article by Ratinckx and Fias (2007) discusses the involvement of the occipito-temporal area (bilateral) in the recognition of numbers; however they specify that this area is more related to the processing of Arabic numerals more so than in a magnitude discrimination task. Further, although not surprisingly, they discussed that the bilateral IPS and occipito-temporal cortices (all of which were active during the task) are transcallosally linked.

Culham and Valyear (2006) posited the involvement of the anterior IPS in the coding of 3D information that was defined by pictorial cues, much like those in the current stimulus design. This area was also involved in mechanisms relating to action planning and attention, both of which are going to be manipulated as an independent variable in the present study. An fMRI study by Pollmann and von Cramon (2000) showed right IPS activation during a visuo-spatial orienting task using abstract visual stimuli. A recent study by Tsutsui, Taira and Sakata (2005) also claimed the involvement of the caudal intraparietal area (CIP) in the perception and integration of texture and three-dimensional stimulus features (such as shadows); its location and function is analogous to Culham and Valyear's anterior IPS.

Goh, Siong, Park et al. (2004) performed vegetative fMRI recordings (i.e., recordings during which no task was to be performed) while altering objects in the foreground, backgrounds and both using naturalistic scenes. The authors found that object processing was primarily centered in the lateral occipitotemporal region and background processing was primarily centered in the ventromedial temporal area with connections to the parahippocampal gyrus. "Binding" which is the contextual association of the object and the background, occurred in the right hippocampal area. The authors defined contextual association as the presentation of a novel stimulus and novel background during the same trial. Since the current study will make use of novel stimuli varying across one of two dimensions, an implicit contextual association between the two dot arrays, via the figure-ground relationship, should involve the right hippocampus. Again, because hippocampal formations are susceptible to dysfunction in depression (e.g., Caspi et al., 2003; Duman, Malberg & Thome, 1999; Laifenfeld et al., 2005; Sapolsky, 2000) we believe the concentric center-surround stimuli offered a precise probe into the operating pathways affected by depressive

pathophysiologies. Supporting this, Manns and Squire (2001) demonstrated that when cortical damage is restricted to the hippocampal formation, non-declarative, perceptual memory was unaffected in an implicit contextual cueing task. However, the authors stated that damage to the medial and lateral temporal lobe did impair performance on the same task. Because the present study involved perceptual memory, we posited that dysfunction those areas surrounding the hippocampal formation, including the parahippocampus, will relate to a decrement in performance with the clinically depressed group. Ongur, Zalesak, Weiss et al. (2005) used a recognition memory paradigm using previously reinforced and novel stimuli. The authors showed supporting fMRI evidence for the right hippocampus to be involved in “binding” alone – specifically, that it codes for associations between stimuli and not for the detection of individual stimuli. Further, the right hippocampal activation was not related to speed or accuracy on the task, in which participants had to identify which of two presented pairs of visual stimuli matched a previously presented pair of stimuli. The authors posited that another area of the brain must be responsible for any discrepancies found.

Overall, it seems that both the dorsal and ventral visual streams are influenced by the IPS/PPC circuit and the parahippocampal-lateral occipital regions, respectively, in the detection, orientation to and manipulation of 3D pictorial information. Also, it seems that many areas involved in the basic processing of magnitude information are closely associated with the dorsal pathways. Proposed models of the two relevant pathways are shown in Figs. 1 and 2.

Attention and Perceptual Memory

The link between the use of memory and attentional processes is indisputable, however their functional link seems to be very task dependent. Since attention and memory

are both limited resources, their efficient cooperation is required to accomplish specific tasks. For example, in a recent review by Chun and Turk-Browne (2007), it was stated that the lateral-occipital complex (LOC) – described above as the area responsible for object recognition and foveal operations – is only activated if the experimental task requires that responses be based on features of those objects. If the experimental paradigm in the current study differentially activated the LOC and ventromedial temporal area, the foreground field should have been considered an object, and its dot array a feature, leading to postulate once again that the ventral and dorsal visual fields will be required to perform our task.

A study by Majerus et al. (2007) showed a link between the left IPS and both attentional modulation and short-term memory for faces. These findings further support the notion that the IPS is involved in both the encoding of, and the attending to, visual stimuli. The tasks in the current study, however, were preferentially selecting the right IPS, and we expected the design of the tasks was able to selectively probe for attentional processes related to magnitude. The IPS also seems to be involved in target detection, along with the anterior cingulate cortex and the PFC (Brazdil, Mikl, Marecek, Krupa & Rektor, 2007). The PFC involvement in target detection could potentially be an attentional control process, whereby it becomes active as an attentional modulator when a target is embedded within a larger stimulus, such as the dots embedded within the larger foreground “objects” in the current study.

Another variable to consider is the time it takes for attentional processes to complete a search of a visual area. In Hayakawa, Fujimaki and Imaruoka (2006), the temporal sequence of activation was noted for brain areas thought to be responsible in both target detection and evaluation. Hayakawa et al. used a simple target detection paradigm in which the participants

had to locate a slightly rotated bar from a matrix of upright bars. They found that within latencies of 215 ms following stimulus onset, event-related potentials (ERPs) were noted over the superior temporal sulcus, calcarine sulcus and IPS. In the same study they discussed the existence of feed-forward and feedback systems between all of those areas and the visual cortex, supporting findings on the functional connectivity of the dorsal and ventral visual streams in low-difficulty tasks.

Depression, Attention and Memory

The current study primarily examined susceptible brain regions that are important for perceptual navigation and binding, coupled with magnitude estimations which does invoke both attentional and working memory processes. Porter, Bourke and Gallagher (2007) reviewed and more clearly defined these working memory and attention constructs. Attentional mechanisms are divided into three distinct categories: Selective attention, sustained attention and divided attention. Porter et al. noted that global assessments of attentional deficits in depression are common, but that the differentiation of these processes is not often found in the literature. The present study does theoretically differentiate between these three processes. Selective attention, defined as attending to relevant information while ignoring competing information, were assessed in terms of percent accuracy on the cued attention tasks (see below). Continuous attention, defined as the ability to maintain attention over a period of time, were tested by comparing accuracy and RT from earlier to later trials across Depressed and Controls. We hypothesize that if the two groups do not differ in their performance, then any deterioration in mutual group responses is an indication of fatigue rather than attentional deficits. Finally, divided attention, which refers to attending more than one task at a given time were examined when no foreground or background spatial cues were

presented that predict field position of differing dot numbers. Participants divided their attention between the two fields in the concentric circular stimuli. The Porter et al. review goes on to define memory and executive dysfunctions in depression, which was investigated in this study by using a temporal two-alternative forced-choice (2AFC) method requiring the retention of sequentially presented nonverbal element number stimuli. Meyer and Blechert (2005) performed a study on persons judged to be at risk for developing bipolar disorder and found no difference between them and a control group on tests of attention. The authors postulated that no attentional biases are present prior to disorder onset, which limits the potential impact of these attentional discrepancies to clinical groups, thus refining the scope of the present study. Gualtieri, Johnson and Benedict (2006) showed that depressed patients, both on and off medication, have particular problems in areas of executive control and in tasks that demand effortful attention based on a neuropsychological test battery. This deficit was also noted in an earlier study during a continuous attention task in which depressed participants were asked to detect a target letter from a sequence of letters (Sevigny, Everett & Grondin, 2003). These results suggest that depressed individuals have more difficulty in maintaining attention during long periods. This was considered in the analysis of our results by examining response trends for both accuracy and RTs over the course of the experiment. Sevigny et al. study also used a time estimation task to discern deficits in temporal processing. Results showed that the depressed group had more difficulty when cognitive mediation was required to supplement a basic process. Although time estimation is not directly related to the current study, it is interesting to note that the top-down mediation of a basic magnitude task seems to be more difficult for people suffering from depression. Further, Brannon, Lutz and Cordes (2006) noted that beginning at 6 months of age, Weber's law holds true for

discrimination of surface area, magnitude and time, and suggest that the same underlying mechanisms are responsible for all three attentional processes.

The ability to switch attention from one task (or aspect of a task) to another was examined in a recent study by Wilkinson and Goodyer (2006) and showed that adolescents suffering from depression had significantly more difficulty in task-switching compared to controls. This was posited to have an influence on the 50-percent invalid cue task of the current proposed study (see below), which will demand the shifting of attentional resources from one center-surround field to another. In this study, participants were presented with a 50-percent valid cue block, the goal being to get the participants to learn to disregard the cue once they realized that half the time it is invalid. Additional, albeit conflicting, literature also demonstrates that depressed adults have difficulty learning new rules compared to controls (Purcell, Maruff, Kyrios & Pantelis, 1997; Beats, Sahakian & Levy, 1996). This evidence further supports our hypothesis that depressed participants were to have more difficulty than non-depressed controls during the 50-percent valid cue condition, owing to their need to learn to ignore previously relevant information.

The actual mechanisms by which these attentional processes modulate performance are hotly debated. A recent study by Pardo, Pardo, Humes and Posner (2006) showed that although sustained attention performance did not differentiate depressed from control participants, RT was slower for the depressed group, suggesting that psychomotor retardation and/or the slowing of other related processes could account for the discrepancies once thought to be attributable specifically to attentional mechanisms associated with higher-load cognitive tasks. This data was partially supported by Egeland, Rund, Sundet et al. (2002), who stated that reduction in performance on attention tasks are due to non-specific cognitive slowing in

depression, and by Smith, Brebion, Banquet and Cohen (1995), who stated that cognitive slowing, not psychomotor retardation, was the cause of delays in RT in depression. This lack of psychomotor retardation as a consideration in increased response latency should allow for more accurate probing of the proposed pathways in the current study, namely those associated with magnitude processing in perceived 3D space. Indeed, the current study noted no RT differences between depressed and non-depressed participants, leaving the authors to postulate that psychomotor retardation was not a factor in depressive performance in the current study's paradigm (see results). The Smith, Brebion, Banquet and Cohen (1995) study, however, also showed that depressed individuals can benefit from cues prior to stimulus presentation, and showed appropriate RT shifts during a valid-cue condition. This was not the case in a study by Koster, Leyman, De Raedt and Crombez (2006) however. The cues offered in this study were emotionally salient facial expressions, suggesting perhaps a different process was enhanced by the cues. The former Smith et al. study suggests that top-down, compensatory or strategy-forming processes could be effective in further subdividing the attentional paradigms tested in this study.

Other researchers have posited a two-dimensional model (severity of depression and psychomotor retardation) for biases in depressive attention and memory. For example, Brebion, Smith and Widlocher (1997) showed that severity of depression negatively affects discrimination capabilities, whereas psychomotor retardation is more closely associated to response bias. It is to be noted that these results were gathered using a word-recognition paradigm, and therefore these effects likely do not apply to our nonverbal experimental paradigm.

Recent biological evidence from animal models have shown that both stress and depression can systematically affect spatial cognition and memory. Li, Wang, Wang, Murakami and Matsumoto (2006) showed impairments in both spatial learning and memory in two models of depression (learned helplessness and chronic mild stress) in rats, further suggesting that these faculties, akin to their human counterparts, are affected by depression.

Some studies have shown differences in performance depending on presence of melancholia (Even, Monier, Thuile, Rouillon & Guelfi, 2006). However since the current study is using a university student population, we considered stress factors as a potential confound to our psychophysical measurements. Therefore, we used the State-Trait Anxiety Inventory (STAI) as a covariate to the collected results to ensure differential performance on this task could be more reliably applied to depression.

Graver and White (2005) demonstrated that with minimal distractions, depressed individuals are capable of performing cognitive tasks at comparable levels to controls; however after stress induction, marked decreases in the performance of the depressed group were noted. The current study is designed to keep distraction to a minimum, and as such, any differences noted were assumed to be characteristic of the pathology of depression.

Two Proposed Models of Three-Dimensional Magnitude Discrimination

Given the above evidence, we propose two potential models for the discrimination of non-symbolic numerical magnitude in a monocular-cued, three-dimensional arrangement: a hierarchical, stimulus-oriented model (see Figure 1) and a dorsal, goal-directed model (see Figure 2). Since the integration of magnitude discrimination and 3D perception has yet to be investigated in the literature, the support for the aforementioned models was considered equivocal, however for simplicity's sake we based our hypotheses on the stimulus-oriented

model. It is to be noted that we defined the dorsal and ventral visual streams as the processing areas beyond V4, owing to the need for the visual system to establish a primal sketch prior to performing the task.

A Model for Hierarchical, Stimulus-Oriented Processing

The hierarchical, stimulus-oriented model we designed proposes that the information related to depth plane (i.e., foreground/background), stimulus arrangement (center/annular surround), and cueing (0/50/100% validity), would be processed *prior to* the magnitude discrimination task. In this model, the inclusion of a foreground-background should invoke the ventral visual stream to process and “bind” these fields in the right-hippocampus (e.g., Goh, Siong, Park et al., 2004) before forwarding that information to the right-IPS for magnitude discrimination. This hierarchical staging (illustrated in Figure 1), posits that after being processed by the primary and associative visual areas (V1 to V4 in the model), the 3D nature of the stimulus will invoke the ventral visual stream, specifically the LOC and VMT for foreground and background, respectively. Following this, the two fields would have to be contextually “bound” in the right hippocampus to allow for a full appreciation of the image, and this information would subsequently be forwarded to the right-IPS for operations related to magnitude discrimination. This model also proposes a functional connectivity or follow-through between the LOC and VIP during foveal or foreground magnitude operations, and the VMT and LIP during peripheral or background processing. This model is particularly of interest since it invokes the hippocampus, which may directly verify stress-dependent dysregulation with depression.

A Model for Dorsal, Goal-Directed Processing

Complex perceptual processes (such as 3D perception and the segregation and processing of objects relative to backgrounds) are typically a function of the ventral visual stream, however recent studies have proposed that areas associated with the integration and processing of task-relevant information are, in fact, task-specific (Ansari, 2008; Toth & Assad, 2002; Tsutui, Taira & Sakata, 2005). In other words, this model posits that both the dorsal and ventral visual streams can process information such as depth equally, and that the “selection” of proper processing stream is entirely task dependent.

The dorsal, goal-directed model we designed proposes that the evaluation of the stimulus configuration is secondary to the performance of the task, and as such most stimulus information would have to be processed in the primary and associative visual areas before being directed to the pathway most appropriate to the performance of the task; in the case of magnitude discrimination, the dorsal visual stream. This model (shown in Figure 2) posits that information will first be processed in the primary and associative visual areas (V1 to V4 in the model). Following this the caudal intraparietal area (CIP) will perform the necessary integration of monocular depth cues (Tsutui, Taira & Sakata, 2005), and that this information will then be forwarded to the ventral and lateral segments of the right-IPS for foveal and peripheral magnitude discrimination, respectively. This model assumes that only the dorsal visual stream will be involved, and as such the ventral visual stream and its hippocampal connections would be bypassed, thus possibly negating any hippocampal deterioration associated with clinical depression.

Summary

Foreground and background dot arrays were used to represent magnitude, in a sequentially-presented 2AFC discrimination task. This task is expected to involve the IPS and PPC (right lateralized) in processing these magnitudes, and also recruited either the lateral-occipital complex or the ventral-medial temporal area (and the parahippocampal gyrus) depending on whether or not the magnitude of elements to be estimated lie within the foreground or background of the stimulus. The monocular depth cues used were either shaded around the edges of the center “white” circular field relative to the darker “gray” annular background or around the edges of the surrounding annular “white” field relative to the darker “gray, sunken” center circular background. This reversal is to control for the possible confounding effects of the foveal vs. peripheral visual fields as well as to investigate the cortical associations discussed earlier with respect to foveal/background binding and shifting (Aminoff, Gronau & Bar, 2007; Goh, Siong, Park et al., 2004; Malach et al., 2002). We also used 100-percent and 50-percent valid cues (defined on the basis of cueing field position of changing dots either in the foreground or background) to simultaneously test for the top-down modulation of magnitude discrimination and attentional deficits noted in depression.

Hypotheses

We first hypothesized that, in line with Weber’s law and the numeric distance effect, as the number of dots in the array increased and the difference between the two arrays to be discriminated decreased, RT would increase and accuracy would decrease for both groups. Additionally, due to possible deficits in working memory and attentional processes, we posited that depressed participants will perform less accurately in the discrimination task

overall. Because of depressive psychomotor retardation, we also predicted a significant increase in RT for depressed participants. We predicted that during the initial, non-cued trial block, depressed individuals would have greater difficulty shifting attention to the correct stimulus area (foreground or background; indicated by a greater shift to the right along the x-axis of their psychophysical response curve), owing to perseveration and the need to contextually “bind” the two fields, which will involve activation of a hypoactive hippocampal formation. The 100-percent valid cue condition also promised to offer some interesting data, in that we predicted a lowering of threshold (increase in sensitivity) for magnitude estimation in the control group, owing to the elimination of one field option to be examined for the task. In this condition, we also expected that the difference between clinical groups at threshold would be reduced from the naïve trial block, with the exception that the depressed participants (due to attentional deficits) will show less of a sensitivity shift compared to non-depressed controls. Finally, in the 50-percent valid cue condition, we expected the controls would readily adapt to the novel cue condition even with 50-percent increases in error rates, while depressed participants would persevere based on the cue-validity of the previous task.

Methods

Pilot Study

Participants

Participants were 25 university students, 6 male and 19 female, recruited from Psychology classes at Lakehead University and given extra credit toward their class mark as an incentive. Ages ranged from 17 to 31 years (age $M=19.32$ years, $SD=3.02$ years).

Apparatus and Stimuli

Visual functioning screening: Visual function screening was performed using two instruments: a Freiburg visual acuity task (FrACT; Bach, 1996) and automated perimetry. Stimuli from the FrACT were presented on a 24 cm CRT monitor positioned 75 cm from the participants. Participants were required to choose, on the number pad of a standard keyboard, the orientation of a Landolt 'C' gap that varied in size. A total of eight possible orientations were presented and the test was adaptive to the responses of the user. Participants were positioned with a chin rest to ensure constant viewing distance and stimulus visual angles.

Visual field screenings were also made using an automated perimeter (Model no. AP200BY, Opto-Global, Adelaide, South Australia). Participants were seated and their chair and chinrest adjusted to a comfortable height. A patch was then placed over their left eye and the lights turned off. A standard five-minute dark-adapt and three-minute light-adapt followed. Note that the perimeter is designed for monocular visual field assessment and each eye was tested separately. We used a full visual field threshold screening strategy to ascertain retinal sensitivity in the present study. This strategy consisted of 165 green (570 nm wavelength) test points (Goldmann size III, 0.43 degrees) on a white background arranged from 0 to 50 degrees (parametric angles) centered on a red fixation point. The stimulus dots appeared randomly at each of the positions 3 times. Background illuminance is constant at 10 apostolibs (asb) and the green stimulus dots range in intensity from 0.03 asb to 1000 asb in adaptive steps. Participants were to click the response button when they perceive a green dot anywhere in the test area. The exposure times used by the perimeter were also adaptive, with typical exposure time ranging from 500 to 1100 ms. RT windows were fixed at approximately 800 ms.

Main psychophysical testing. The main testing stimuli for the pilot study were presented using Superlab 4.0 Stimulus Presentation Software (Cedrus Corporation, San Pedro, CA). The space-averaged luminance level of the display was $\sim 100 \text{ cd/m}^2$, with peak luminance levels under 130 cd/m^2 . For more information on stimulus design, see below. Stimuli will be monochrome (with the exception of the cue) and will be projected on a 24 cm CRT monitor. Participants will be positioned with a chin rest 75 cm from the CRT. The spatially averaged intensity of the screen was $\sim 100 \text{ cd/m}^2$.

Two concentric center (9° dia) -surround (9° inner - 18° outer dia) fields were used. Both fields were “white” in colour ($\sim 127 \text{ cd/m}^2$). In this part of the study, one of the two fields was filled with a randomly varying number of 41.6 cd/m^2 , 0.5° dia. “black” dots. The base number of dots for all trials was 30, with comparison stimuli ranging from 29-20 dots in one-dot steps.

Procedure

Recruitment of Participants. Participants were recruited from Introductory Psychology classes. Informed consent was obtained prior to participation in the experiment.

Experimental session – psychophysics experiment. Participants were seated in front of the experimental monitor and the chinrest height adjusted for comfort. Participants were dark-adapted for seven minutes and light-adapted for three minutes prior to testing. Participants were asked to use their dominant hand to respond to the tasks using a Superlab multi-directional response pad.

In the main psychophysics experiment, a trial consisted of an outline of the stimulus area (fixation) for 1000 ms, followed by the first stimulus image for 250 ms, a blank screen (interstimulus interval: ISI) for 500 ms, the second stimulus image for 250 ms then a blank

screen to await participant input. RT was measured immediately following the disappearance of the second stimulus. Participant response signalled the end of a trial, and 200 ms intertrial interval preceded the next trial.

The experiment began by offering 10 practice trials; three in which the center field was filled, three in which the annular field was filled, and four in which the center and annular field changes were interleaved. Participants were to press the top button of the response pad if the first stimulus image contained more dots, and the bottom button if the second stimulus image contained more dots.

The experiment consisted of 12 trials at each of the 10 assigned resolution levels (30 vs. 29-20 dots) for each presentation condition (center- or annular-field), for a total of 240 trials. Changes in presentation condition and resolution level were randomized throughout the experiment.

Participants were debriefed upon completion of the experiment, and the experimenter was available to answer any questions.

Results

Data were analyzed using paired t-tests between the center and surround fields, with accuracy and RT as the dependent variables. All significance values were compared to $\alpha=0.05$. No significant differences were found when analyzing the accuracy data. A significant difference was found in the RT data, in which the annular field showed an increase in RT compared to the center field at the lowest level of resolution, $t(23)=2.258, p<0.05$.

Implications

The pilot study findings support the notion that magnitude discrimination is invariant at up to 18° retinal eccentricity, although some slight reaction times discrepancies were noted at subthreshold levels.

Main Experiment

Participants

Participants were 40 university students, 6 depressed (6 female, mean age 28.32 years) and 34 nondepressed (22 females and 12 males, mean age 20.02 years), recruited from Psychology classes at Lakehead University and given extra credit toward their class mark as an incentive.

Psychological Screening Measures

Hamilton Depression Rating Scale (HAM-D; see Appendix A). The Hamilton Depression Rating Scale (HAM-D) was used to select potential candidates during the screening for the depressed and control groups. The current literature was divided as to the efficacy of HAM-D in diagnosing depression. However, the HAM-D is designed to assess severity of depressive symptoms, and was used only as a screening tool (Bagby, Ryder, Schuller & Marshall, 2003; Williams, 2001). Participants with a HAM-D score greater than 16, or less than 10, was classified, respectively, as potential Depressed or non-depressed Control. The HAM-D consists of 29 questions corresponding to typical and atypical depressive symptoms, each answered using a 5-point scale corresponding to mood variables in the last two weeks. Total score on the HAM-D is calculated by adding up all the responses to the various questions. Higher scores on this scale are indicative of higher depression

severity. This measure has shown good psychometric properties and is a reliable and valid measure of depression severity.

Beck Depression Inventory – II (BDI-II). The BDI-II (Beck, Steer & Brown, 1996) is also a measure of the severity of depressive symptoms. It was used during the experimental session to confirm the clinical group assignment of participants, either to the Depressed or Control group, done during a previous screening session. Sevigny, Everett and Grondin (2003) suggest an *a priori* cut-off score of 14 or higher for the Depressed group and 8 or lower for the Control group on the BDI-II. The decision to use the HAM-D for the screening and the BDI-II for experimental session was undertaken deliberately to avoid a practice effect that could bias the group classifications during psychophysical testing. The BDI-II contains 21 items which reflect mood functioning in the past two weeks. Each item is rated on a 4-point scale, from 0-3, and overall score is calculated by adding up the responses from each question. The psychometric properties of the BDI-II are good, with the test showing good internal consistency, reliability and validity. A copy of this scale was not included for copyright reasons.

State-Trait Anxiety Inventory (STAI). The STAI (Spielberger, Gorsuch & Lushene, 1970) is a measure of both state and trait anxiety. The participants' scores on the state anxiety were used in covariate analyses to control for the possible confounding or exacerbating effects of state anxiety on performance in experimental psychophysical tasks. The scale consists of 40 questions; 20 of which measure current anxiety level (state anxiety) and 20 that measure general anxiety level (trait anxiety). The questions consist of statements which are endorsed on a 4-point scale, with approximately 50% of the questions being reversed-scored. The STAI has shown good reliability and validity when compared to other measures of anxiety

(Spielberger, Gorusch & Lushene, 1970). A copy of this scale was not included for copyright reasons.

Computerized structured clinical interview for DSM-IV Axis I disorders (SCID). A computerized screening version of the SCID was used to determine if participants met the diagnostic criteria for major depression (see Appendix B). The software used was the SCID Screen Patient Questionnaire (SSPQ; First, Gibbon, Williams & Spitzer, 2001).

Apparatus and Stimuli

Visual functioning screening: Visual function screening was performed using two instruments: a Freiberg visual acuity task (FrACT; Bach, 1996) and automated perimetry. Stimuli from the FrACT were presented on a 27 cm CRT monitor positioned 75 cm from the participants. Participants were required to choose, on the number pad of a standard keyboard, the orientation of a Landolt 'C' gap that varied in size. A total of eight possible orientations were presented and the test was adaptive to the responses of the user. Participants were positioned with a chin rest to ensure constant viewing distance and stimulus visual angles.

Main Psychophysical Testing: Stimuli were delivered using a VisionWorks 4.0 psychophysics stimulus package (Vision Research Graphics, Durham, NH). The space-averaged luminance level of the display was $\sim 100 \text{ cd/m}^2$, with peak luminance levels under 130 cd/m^2 . For more information on stimulus design, see below. Stimuli were monochrome (with the exception of the cue) and were projected on a 30 cm CRT monitor. Participants were positioned with a chin rest 75 cm from the CRT. The spatially averaged intensity of the screen was $\sim 100 \text{ cd/m}^2$.

Two concentric center-surround circular fields with either a 9° inner diameter (i.d.) circular field or 9° i.d. – 18° outer diameter (o.d.) annular field were "raised" via a monocular

shadow depth cue (8 pixel shadow with a 5 pixel Gaussian blur; 41.6 cd/m^2). The “background” field (i.e., the one that is not raised) was “gray” in colour (64.1 cd/m^2) and the foreground, or raised field was “white” (127.7 cd/m^2). In the first condition (single field presentation), one of the two areas was filled with a randomly varying numbers of 41.6 cd/m^2 , 0.5° dia. “black” dots. The dots were randomly positioned within each of the areas using a variable radial grid with a number of divisions equal to the number of elements. This ensured maximum center-to-center spacing between elements. This controlled for density, perimeter and total surface area. The randomization and radial grid also controlled for possible automatic processing of familiar numerical stimuli, such as dice or domino patterns (Dehaene, Piazza, Pinel & Cohen, 2003; Neurk et al, 2005). Threshold numerical salience data derived from a pilot study was used to set the number of dots in the array. Examples of the different foreground/background stimulus designs are shown in Figure 3.

The following three conditions of the psychophysical task used the same template 3D design, with the exception that both fields, the foreground and the background, contained dot arrays with, of course, only one showing change in number.

Procedure

Recruitment of participants. Research participants were recruited from Lakehead University Introductory Psychology classes. A research screening questionnaire package was distributed to the students with the request that they return it within 2 days of completion. The package consisted of a cover letter (see Appendix C) that explained the reason for the screening, a description of the experiment, and details covering the ethics of both the screening and experimental processes. A screening consent form (see Appendix D) was also included along with the HAM-D and a list of therapy resources in Thunder Bay for the

participants' information and use. Questions on the use of prescribed psychoactive medication or other compounds that could affect results on a psychophysical task were asked to weed out participants who could present confounds in the experiment. Participants who had scores of HAM-D >19 or HAM-D <10 were deemed, respectively, to be potentially depressed or nondepressed (for the control group) and invited to the experimental session.

Experimental session – psychological assessment. Participants who were invited to the experimental session were first required to undergo group (Depressed or Control) classification. They were reminded of the nature and procedure of the experiment, and were given a consent form to sign (see Appendix E). A copy of the therapy resources in Thunder Bay was also provided. Afterwards, they were administered the BDI-II, the STAI, and the computerized SCID, and then led to another room where they underwent visual screening and the psychophysics experiment. The results of the psychological tests were forwarded to a clinical psychologist for classification of participants into either the Depressed or Control group. The Depressed group had a BDI-II score of at least 14 and met the diagnostic criteria for major depressive episode on the SCID. The Control group had a BDI-II score of 12 or less and did not meet the diagnostic criteria for major depressive episode. The experimenter and the participants were blind to group assignment and did not receive any feedback on the results of the psychological assessment. The participants were accorded anonymous number codes that were used for their collected psychophysical and psychometric data.

Experimental session – psychophysics experiment. Participants were seated in front of the experimentation monitor and the chinrest height adjusted for comfort. Participants were dark-adapted for 7 min and the practice sessions (outlined below) also served as the 3 min light-adaptation session prior to testing. In accordance with the SNARC literature, participants

were asked to use their dominant hand to respond to the tasks using a standard track-ball mouse.

The trial events during the main psychophysics experiment were as follows: 1) a unique fixation outline of the center-surround stimulus area, designed to prevent afterimage confounds, was presented for 750 ms, followed by the first 2-field stimulus for 250 ms, a blank screen (interstimulus interval: ISI) for 500 ms, the second 2-field stimulus for 250 ms, then a blank screen to await participant response. RT was measured immediately following the disappearance of the second stimulus. Response signified the end of the trial, and a 200 ms intertrial interval preceded the next trial.

Participants received two practice blocks, consisting of 20 trials each prior to testing. The first practice block consisted of two concentric circles with no shading, with only one of the two fields containing a dot array. The second practice block consisted of both fields being filled, with only one field changing. The participants were required to press the top key if the magnitude in the first image is greater or the bottom key if the magnitude in the second image was greater. This response key configuration was kept for all trials.

The first trial block (Single Field Presentation; defined as elements presented in only one field as opposed to both concentric fields) consisted of nine trials at each of the six assigned resolution levels (40 vs. 41 to 46 dots) for each presentation condition (center-foreground, center-background, annular-foreground and annular background), for a total of 216 trials. Resolution levels and foreground-background changes were randomized for all experimental blocks. Also, stimuli with the center foreground and annular foreground were interleaved throughout each of the trials (temporal presentation order are shown in Figures 4-

Single-Field Presentation; 5-- Dual-Field No Cue; 6-- Dual-Field With 100% Cue; and 7-- Dual-Field With 50% Cue).

Following the first block, three blocks of trials in which both fields contained dot arrays (Dual-Field Presentation) were presented in the following order: naïve (no cue; Fig. 5), 100- percent valid cue (Fig. 6), 50-percent valid cue (Fig. 7). Each of these blocks contained 9-10 trials at each of 9 assigned resolution levels (40 vs. 41 to 49 dots) for each presentation condition (center-foreground, center-background, annular-foreground and annular background), for a total of 324 in the “no cue” and 100-percent valid cue blocks, and 360 trials in the 50-percent valid cue block. The “naïve” block consisted of the magnitude discrimination task with no instruction other than “indicate which of the two stimuli has a greater magnitude.” This order is illustrated in Fig. 5. The 100% valid cue block followed, with the addition of a 500 ms cue interval as shown in Fig. 6. In this case, participants were told that in an image following fixation and preceding test presentations, a “red” field will highlight either the foreground or background within the concentric, two-field arrangement indicating which of the two fields will contain a magnitude change across presentations. The 50% valid cue block presented the same arrangement with the exception that only 50% of the trials showed dot changes in agreement with cue position (see Fig. 7). The spatial design and temporal sequencing of this block was the same as the previous blocks. Naïve and cued trials were not interleaved in accordance with a study by Jaffard, Benraiss, Longcamp, Velay and Boulinguez (2007), that found mixed-block sequence designs (those in which cued and non-cued trials were interleaved) had greater error rates than “pure”-block sequences, and that these error rates were not related to attentional processes. Rather, they were due to competitive response processes and as such could prove a source of error in interpretation.

Upon completion of the experiment, participants were debriefed. The experimenter went over the debriefing sheet (see Appendix F) to make sure participants understood the experiment, and answered any questions. Throughout the experiment, participants were given the opportunity to arrange to speak to someone about any psychological difficulties. The experimenter reminded the participants of the therapy resource list provided to them in the event that they, or anyone they know, might find the list useful.

Statistical Design and Analysis

Separate analyses were used to compare the data from the various conditions. Since we used only six levels of difference (1-6 elements) during the single field presentation, we compared these six levels to the first six levels of difference from dual field presentation with no cue. Therefore, a 2 (Group: depressed, control) X 2 (Field: center, surround) X 2 (Arrangement: Foreground, Background) X 2 (Presentation: single field, dual field) X 6 (Percent Element Difference) mixed factorial ANCOVA was used with one between-subject factor (Group), four within subject factors (Field, Arrangement, Presentation, Element Difference), one covariate (State Anxiety) and the dependent variables being accuracy and RT.

For the second analysis, only the dual-field presentation blocks were included, and a 2 (Group: depressed, control) X 2 (Field: center, surround) X 2 (Arrangement: Foreground, Background) X 3 (Cue: no cue, 100% valid cue, 50% valid cue) X 9 (Percent Element Difference) mixed factorial ANCOVA was used, with one between-subject factor (Group), four within subject factors (Field, Arrangement, Cue, Element Difference), one covariate (State Anxiety) and the dependent variables being accuracy and RT.

Thresholds were established using logarithmic plots drawn with KaleidaGraph Version 4.03 (Synergy Software, Reading, PA) and analyses were performed using SPSS Version 16 for Windows (SPSS, 2006).

Results

The data were analyzed in keeping with the models outlined above, with assumptions of sphericity (verified by Mauchly's W) and equality of error variances (verified by Levene's test of equality of error variances) being met for most conditions. Where these assumptions were not met, a Greenhouse-Geisser correction was used before interpretation. All significance values were compared to $\alpha=0.05$.

Participants

A total of 111 potential participants were included in the screening process. They ranged in age from 18 to 51 years (age $M=21.96$, $SD=6.3$), with HAM-D scores ranging from 0 to 39 (HAM-D $M=11.91$, $SD=9.03$). Of the 111 potential participants, 7 participants were excluded; two due to self-reported visual illness and five due to self-reported visual problems. Participants identified as potentially depressed ($n=21$; HAM-D $M=26.81$, $SD=6.13$) and non-depressed ($n=56$, HAM-D $M=5.25$, $SD=2.44$) were called back to participate in the main study.

Of the 77 potential participants, 40 (28 female, 12 male) participated in main psychophysical study. These participants ranged in age from 18 to 36 years (age $M=21.35$, $SD=6.16$). Of these 40 participants, six were identified as depressed (6 female) and 34 were identified as control (22 females, 12 males).

The depressed groups' BDI scores ranged from 20 to 34 (BDI $M=28.67$, $SD=6.80$), and the control groups' BDI scores ranged from 4 to 19 (BDI $M=7.35$, $SD=4.75$). A significant group difference was noted on this measure, $t(38)=9.49$, $p<0.001$.

The depressed groups' STAI scores ranged from 34 to 73 (STAI $M=57.17$, $SD=13.67$) and the control groups' STAI scores ranged from 20 to 52 (STAI $M=32.28$, $SD=7.90$). A significant group difference was also noted on this measure, $t(36)=6.27$, $p<0.001$.

Covariate

Pearson correlations were computed between the covariate and the dependent measures to ascertain whether STAI scores had any significant relation to those dependent measures. STAI scores showed negative correlations with both accuracy, $r=-0.12$, *n.s.* and RT, $r=-0.15$, *n.s.* Though these correlations were not significant, the covariate was nonetheless included in the analyses below to ensure we accounted for that any variance explained by the STAI scores.

First Analysis

The first analysis consisted of a 2 (Group: depressed, control) X 2 (Field: center, surround) X 2 (Arrangement: Foreground, Background) X 2 (Presentation: single field, dual field) X 6 (Percent Element Difference) mixed factorial ANCOVA, with one between-subject factor (Group), four within subject factors (Field, Arrangement, Presentation, Element Difference), one covariate (State Anxiety) and the dependent variables being accuracy and RT.

Accuracy Data

When considering within-subject factors, a main effect of Presentation type was noted when comparing the single- and dual-field presentations, in which accuracy was significantly

greater during single presentation, $F(1,38)=19.35, p<0.001, \eta^2=0.34, \text{power}>0.99$. A main effect of the Percent Element Difference was also noted, with accuracy increasing as the difference between the test and base stimulus number increased, $F(5,190)=20.48, p<0.001, \eta^2=0.35, \text{power}>0.99$ (see Figure 8). No other significant main effects were found.

The data also showed a between-subject factor difference, in which the control group performed significantly better overall than the depressed group, $F(1,38)=5.87, p<0.02, \eta^2=0.13, \text{power}=0.65$. The inability of the depressed group to attain threshold detection in most cases is illustrated in Figure 10.

Finally, a Presentation by Percent Element Difference by Group interaction was found, in which the control group showed significantly higher accuracy at greater numerical differences, $F(5,190)=3.43, p<0.014, \eta^2=0.08, \text{power}=0.81$. No other significant interactions were found.

Reaction Time Data

When analyzing the RT data, we noted a main effect for Presentation type, $F(1,38)=9.08, p<0.005, \eta^2=0.19, \text{power}=0.84$, in which the single field presentation showed longer reaction times overall. There was a main effect for Plane, in which the foreground showed significantly slower reaction times, $F(1,38)=1138.8, p<0.001, \eta^2=0.968, \text{power}>0.99$. There was also a main effect for Eccentricity, in which the annular field showed significantly longer reaction times, $F(1,38)=790.29, p<0.001, \eta^2=0.95, \text{power}=0.95$. No other significant main effects were found. No significant between-subject effects were found.

The above main effects seem to have been driven by a substantial Plane by Eccentricity interaction, in which RTs were significantly longer in the annular-foreground

paradigm, $F(1,38)=658.9$, $p<0.001$, $\eta^2=0.95$, power >0.99 (see Figure 9). No other significant interactions were found.

Second Analysis

The second analysis consisted of a 2 (Group: depressed, control) X 2 (Field: center, surround) X 2 (Arrangement: Foreground, Background) X 3 (Cue: no cue, 100% valid cue, 50% valid cue) X 9 (Percent Element Difference) mixed factorial ANCOVA, with one between-subject factor (Group), four within subject factors (Field, Arrangement, Cue, Element Difference), one covariate (State Anxiety) and the dependent variables being accuracy and RT.

Accuracy Data

A significant main effect for Plane was noted, with accuracy being higher overall in the foreground, $F(1,38)=6.60$, $p<0.014$, $\eta^2=0.15$, power=0.71. A significant main effect was also found for Percent Element Difference, with accuracy increasing as the difference between the test and base stimulus number increased, $F(8,304)=50.55$, $p<0.001$, $\eta^2=0.57$, power >0.99 (see Figure 8). No other significant main effects were found.

A Cue by Plane by Eccentricity interaction was also found, with the center-foreground field in the cued condition showing significantly higher accuracy than all other conditions, $F(2,76)=8.59$, $p<0.001$, $\eta^2=0.18$, power=0.96. No other significant interactions were found.

Reaction Time Data

When analyzing the RT data, we noted a main effect for Cue, $F(1,38)=9.08$, $p<0.005$, $\eta^2=0.19$, power=0.84, in which the uncued presentation showed longer reaction times overall. There was a main effect for Plane, in which the foreground showed significantly slower reaction times, $F(1,38)=83.27$, $p<0.001$, $\eta^2=0.69$, power >0.99 . There was also a main effect

for Eccentricity, in which the annular field showed significantly longer reaction times, $F(1,38)=89.07, p<0.001, \eta^2=0.70, \text{power}>0.99$. No other significant main effects were found. No significant between-subject effects were found.

The above main effects seem to have been driven by a substantial Cue by Plane by Eccentricity interaction, in which RTs were significantly longer in the annular-foreground paradigm during the uncued condition, $F(2,76)=177.7, p<0.001, \eta^2=0.82, \text{power}>0.99$ (see Figure 9). No other significant interactions were found.

Discussion

The goal of the present study was threefold: 1) to test the limits of human perception during a sequential magnitude discrimination task, 2) to determine whether or not magnitude discrimination within our specific foreground/background paradigm could be used as a potential marker for depression, and 3) to ascertain whether spatial and/or attentional factors had any effect on both accuracy and RT related to magnitude discrimination, and in so doing, attempt to comprehend the perceptual and cognitive networks associated with this task.

Hypotheses and Significant Findings

The first hypothesis, in which we predicted an inverse (direct) relationship between RT (accuracy) and magnitude difference, was partially supported, with accuracy increasing significantly with magnitude difference between dot array presentations. RTs were significantly affected by changes in magnitude, however, the plotted trends (see Figure 9) revealed apparent little-to-no effects with magnitude difference. The significance appears to be a product of a rather surprising Arrangement by Field by Cue interaction (see below).

With regards to the performance of the depressed participants, we hypothesized that they would show overall poorer accuracy and overall longer RTs. These predictions were

only partially supported. The depressed group did show poorer accuracy overall, however this result was only apparent when the data from the single-field and dual-field presentations (first analysis) were used; when considering only the data from the second analysis, the performance difference only approached significance. We did not find RT differences between the two groups, refuting our hypothesis that the psychomotor retardation typically associated with depression would be a factor in the performance of magnitude discrimination tasks.

It is possible that the small sample size for the depressed group ($n=6$) was a mitigating factor in these findings. The range of magnitude ratios was predetermined from pilot data that used slightly lower base numbers, and as a consequence produced the truncated data set, with the control group only just attaining difference threshold levels for the Dual-Field condition, and the depressed group typically not attaining difference thresholds for most conditions. Fig. 10 shows the frequency of accuracy percentages obtained from both groups, the most notable feature of which was the inability of the depressed group to attain threshold in the majority of cases. This limited range did not allow for supra-threshold performance analysis, which is where the majority of the differences between groups were expected to be found.

Due to our truncated data, many of the other predictions outlined in our initial hypotheses were not verifiable. There were no significant group by condition or group by presentation interaction effects demonstrating that no verifiable gain/efficiency changes existed relative to the control group.

Despite the inconclusiveness of the results with respect to the group comparisons, some very interesting effects and interactions were noted during analysis. The first of which was a significant decrease in accuracy in the dual field presentation compared to the single

field presentation. Figure 8 illustrates these accuracy changes as a function of the different depth plane and eccentricity combinations. This rather large discrepancy in accuracy suggests that the addition of a second field of unchanging, unmoving dots produces a masking effect which hinders an individual's ability to discriminate magnitude, despite RT evidence that the two fields in any given stimulus arrangement were processed separately.

Another interesting finding was a significant increase in accuracy during “foreground” relative to “background” discrimination when both fields were filled (dual-field presentation). Figure 8 shows, when comparing the two bottom graphs, a distinct advantage for the processing of foreground information, which is especially evident when comparing the two curves representing single field presentation performance. This selectivity for foreground information could reflect a preferential processing pathway for magnitude discrimination.

A rather surprising finding was a significant increase in RT when subjects were called upon to discriminate magnitude in the foreground of the “annular-foreground” stimulus template (see Figure 9). This discrepancy was evident during the single field and uncued dual field presentations only, with latencies returning to levels comparable to the other stimulus templates when fields were properly cued. This finding could be demonstrative of preferential processing for “typical” foreground/ background arrangements. Further implications of this curious interaction are discussed below.

Magnitude as a Weberian Construct

When comparing our pilot study data to the data collected from the present study, we noted that a very narrow operating range seems to exist when considering factors such as the base number of elements (Madon, Vanderleest & Wesner, 2008). To illustrate, we noted that during the pilot study, which used a base element number of 30 and decremented to 20

elements in single element steps, a single element difference of 3.33% produced a better-than-chance accuracy of 60% correct. Conversely, with the present study, we noted that differences of 2.5% were no longer detectable at better than chance levels. Although magnitude discrimination has been shown to follow a Weberian function (Brannon, 2006), we posit that the discrimination of large magnitudes is also mediated by the numeric distance effect (Ansari & Dhital, 2006; Moyer & Landauer, 1967), in which not only the ratio of base number to target elements are important, but also the actual magnitude base number. It is possible that magnitude discrimination is, in fact, subject to its own “numeric distance effect”, which could complement earlier Weberian-based theories. A recent review by Ansari (2008) suggests that the numeric distance effect is linked to the “tuning curves” of individual neurons; neurons representing cardinal values that are relatively close to one another have a great deal of functional overlap, leading to increased processing latencies and decreased accuracy when discriminating these values. Conversely, neurons representing cardinal values that are further apart operate on very distinct tuning curves, thus making discrimination easier. This review also mentioned that neurons used to encode for higher numerical values typically have a wider tuning curve, and are thus less capable of fine distinction than those engaged when comparing smaller values. The analogous “numeric distance effect” shown in the present study suggests that these large-value tuning curves are invoked during non-symbolic magnitude discrimination tasks, and our findings could indicate that as the base number of elements in a given set of trials is increased, the amount of time needed for an accurate assessment also increases, and the accuracy of that assessment decreases dramatically. Further investigation into the properties of varying base numbers should be conducted (see below).

We noted that humans are capable of quite incredible feats of discrimination. During the single field presentation condition, participants were able to accurately detect a 7.5% difference in magnitude (equivalent to a difference between 40 and 43 elements.) This level of discrimination is exceptional when compared to the 100% difference needed for accurate discrimination in infants. When comparing these findings to those noted in previous studies describing the difference ratios needed to for accurate magnitude discrimination in infants, this finding supports Brannon's (2006) hypothesis that the human ability to process and discriminate between large quantities is developmentally dependent.

Implications for Depression

The results do tentatively support the hypothesis that magnitude discrimination can be used as a potential marker for depression. Despite our truncated data set, our results did conclusively show that persons suffering from depression have significantly greater difficulty in discriminating magnitude compared to non-depressed controls. Although we expected a significant gain change in the depressed group compared to the controls (i.e., a shift of the depressed psychometric functions to the right along the x axis), when comparing the change in accuracy between single- and dual-field presentation conditions, no significant change was noted. Again a significant change would have been evidenced by an increase in the distance between the depressed and control group curves, when changing from Single- to Dual-Field presentation paradigms. As this distance did not increase significantly, we posit that this finding rescinds the notion of a hierarchical pathway in magnitude processing, in which the foreground/background information is processed first in the ventral visual stream, then contextually "bound" into a whole image in the right hippocampus (e.g., Goh, Siong, Park et al., 2004) – an area susceptible to depressive dysregulation, and then forwarded to the parietal

areas (specifically, the right-IPS) for magnitude processing. In other words, because there was no significant interaction between group and presentation block, we argue that magnitude information processing “bypasses” this hippocampal operation, with foreground-background integration occurring exclusively along the dorsal stream (specifically, in the CIP). This finding is to be considered with caution, however, since the current study lacked the supraliminal data necessary to draw definite clinical, and therefore pathway conclusions.

Our findings also support the notion that the difficulty which depressed participants showed on this task were related to a diminished ability to process magnitude-related information, illustrated by their overall poorer performance on the task regardless of the number of fields filled or the cueing conditions. Another explanation for this poor performance is that the task might have been particularly taxing for depressed individuals, who were required to attend to relevant areas of the stimuli, remember the first stimulus presented to compare it to the second, and take into account cueing information that guided performance in the latter trials blocks. All of these functions relate to executive function and attention, and depressed individuals have been shown to be deficient in these areas (e.g., Gualtieri, Johnson & Benedict, 2006).

Spatial and Attentional Properties

The findings from the present study did show some intriguing effects relating to spatial and attentional parameters. First, in concordance with the findings from our pilot study, we found that the human ability to accurately discriminate magnitude does not vary within visual eccentricities up to 18°. That said, our ability to discriminate magnitude does vary with regards to depth plane, with higher accuracy noted in the foreground compared to the background, independent of eccentricity. Though this could have been the result of a

greater luminance contrast between dots and field in the foreground relative to the “gray” background, we posit that the interaction between foreground viewing and magnitude discrimination more than likely reflects activity within a synergistic cognitive pathway that is independent of retinotopic eccentricity.

This finding, in concert with the above finding that the hippocampus (and by extension, the higher-order processing areas in the ventral visual stream) is not involved in the processing of spatial information related to this task, supports the notion that higher-order areas in the dorsal visual stream, specifically the CIP, can process monocular depth information such as the shadowing used in the present study (Tsutsui, Taira & Sakata, 2005), provided that these cues are being used to guide task responses. Furthering this line of reasoning, we also noted a dramatic increase in RT when participants were made to discriminate magnitude changes in the annular foreground, whereas no such increases were found in any of the other stimulus conditions. This could be perceptually analogous to a “keyhole” effect in which, while looking through a keyhole one has to process information situated on the surrounding door. We argue that although the CIP is adept at integrating textures and depth cues for operations in the dorsal visual stream, it is plausible that it is only capable of such operations when information is presented foveally or when the foreground/background arrangement is “typical” (i.e. when the foreground is presented foveally and the background presented peripherally). When information is presented atypically, the dorsal visual stream may be required to recruit the ventral visual areas for further processing, leading to longer RTs. These longer RTs were no longer observed when a covert cue identifying the changing field position was added prior to the first stimulus presentation. The cue effectively reduced RT to levels comparable to the other three stimulus conditions, which in itself

suggests an additional property of this paradigm; that even at pre-attentive levels, a covert cue was effective at lowering RT. In the case of the foreground annulus, the cue might have allowed the top-down operations of attention to dismiss the atypical arrangement of the changing foreground annulus, and allow the participant to “ignore” the irrelevant field. We plan to investigate this puzzling result further by comparing the use of the foreground annulus arrangement to a “typical” foreground- background arrangement and to a “flat” field arrangement in which depth information is not implied, specifically focusing on performance in the annular field.

Support for a Goal-Directed, Dorsal-Stream Model of Magnitude Discrimination

The above findings support the notion that magnitude discrimination, even within the context of monocular-cued three-dimensional space, is primarily dorsal-stream mediated. The absence of any significant gain/efficiency changes when comparing depressed and control groups across different conditions, which would have been characteristic of hippocampal foreground/background binding operations in the ventral visual stream, suggests that the present study did not invoke the ventral visual stream, with the exception of the “annular-foreground” configuration noted above. This finding, in concert with the recent finding that the CIP (dorsal-stream) can discriminate texture and three-dimensional cues (Tsutui, Taira & Sakata, 2005), supports the notion that magnitude discrimination is entirely dorsally mediated. Our findings also support previous claims that the dorsal visual stream can single-handedly process all the relevant spatial and attentional information needed to direct behaviour in a magnitude discrimination task (e.g., Ansari, 2008; Toth & Assad, 2002). However, this single-stream model does not fully explain the increase in RT, which occurred during the “annular-foreground” condition. A possible explanation for this curious interaction is that

prior to being processed by the dorsal visual stream, an as-yet-unidentified system “labels” the task and forwards this information to task-appropriate areas, in this case, the CIP and right-IPS for depth and magnitude processing, respectively (Toth & Assad, 2002; Tsutui, Taira & Sakata, 2005). In this circumstance, a longer integration time may have been needed to process the conflicts between eccentricity and depth plane associated with our annular-foreground stimulus design. Another possibility is that the dorsal visual stream’s ability to process stimulus information is “trained” by the ventral visual stream to the point of being automated—analogue to trained open loop systems associated with coordinate motor activity and the cerebellum. When “atypical” stimulus configurations are perceived, specific, time-consuming activities in a ventral stream network may need to be invoked to compensate for the dorsal stream’s inability to “open-loop” decipher the conflicting object/background relationship. This potential “recruiting” of the ventral stream was implied in a recent study by Ansari, Lyons, van Eimeren and Xu (2007), in which they compared stimulus-driven versus goal-directed visual stream activation in magnitude estimation. The authors noted that in cases of large-magnitude estimation, there was an increase in activity in the dorsal visual stream and a suppression of activity in the temporo-parietal junction compared to smaller-magnitude size estimations within the subitizing range (1-4 elements according to Ansari, Lyons et al.). This finding suggested dissociation between the dorsal and ventral visual streams when automatic, semantic processing of stimuli is not possible during a goal-directed task. That said, this temporo-parietal junction could be the locus of exchange between the dorsal and ventral streams during a task that requires the processing of atypical foreground-background arrangements, such as those in the present study.

Strengths, Limitations and Future Directions

Despite certain caveats, the findings from the present study can be considered fairly robust. The stimulus configuration and presentation strategy used was designed to prevent basic visual processes such as pattern recognition or after-images from artificially enhancing performance, enabling us to be confident that our findings are related to the discrimination of numerical magnitude. Further, the use of a compound, center-surround stimulus allowed us to control for potential directional issues associated with the SNARC effect, as well as explore potential interactions between retinal eccentricity and foreground-background processing. We also included a measure of anxiety as a covariate, to ensure that any results obtained were specifically applicable to depression and its pathologies rather than other commonly comorbid factors.

There exist some cautions in the interpretation of the present findings. First, since we opted for a double-blind design in the verification of clinical group membership, we were unable to control for the number of depressed and control participants ultimately included in the study. This unfortunately led our groups to be quite uneven (depressed $n=6$ and control $n=34$), and as such we must use caution in the interpretation of any of our clinical findings. Second, we based ourselves on pilot data to define the elemental range of the current study. Because we assumed magnitude discrimination ratios to conform to Weber's law, and not to be subject to the numeric distance effect, the discrimination task became more difficult than originally anticipated. Therefore most of our conclusions are drawn from threshold and subthreshold data only. This truncated data range did not allow us to evaluate supra-threshold eccentricity, depth plane, cueing or clinical group effects, which could have shed additional light on some of the potentially telling interactions that we noted. Third, because our study

relied on a specified order of cueing conditions to maintain proper cue validity, we could not control for practice/learning effects. This may have led to greater error rates in the initial sets of trials, owing to the naivety of the participants to the task. Finally, it would be beneficial to test whether luminance contrast of the fields relative to the dots influence accuracy or RT without the benefit of a shadowed cue, to rule out stimulus saliency as a confounding factor.

With all of the above limitations considered, there are still many potential avenues for discovery using this experimental paradigm. A first and obvious direction is the widening of the range of element differences, which would offer greater accuracy in determining threshold detection ratios in humans. Following this, in order to test the hypothesis that there exists an analogous “numeric distance effect” for magnitude, a future study could modify the base number of elements across trials and keep the ratios of compared elements constant. This would allow for a direct verification of the effect of the posited numeric distance effect on the Weberian nature of magnitude discrimination. Third, in order to verify whether the top-down modulatory effects are indeed universal in sequential magnitude discrimination, a cue could be added to the single-field presentation condition and determine whether performance is subsequently improved. Fourth, to verify the claim that the dorsal visual stream can, in fact, process arbitrary stimulus information in goal-directed tasks, this study could be repeated using stereopsis to establish a true binocular foreground-background stimulus arrangement. Fifth, explore the possibly conflicting pathways that are associated with the annular-foreground stimulus configuration by comparing performance in this arrangement to other, more typical arrangements (see above). Finally, to verify whether the decrease in performance shown here in the depressed group is actually related to magnitude discrimination, it is necessary to compare their performance to that of participants with

developmental dyscalculia, the latter of whom have been shown to have a marked decrease in IPS activity, and as a result, a loss of sensitivity for magnitude discrimination (Price, Holloway, Rasanen, Vesterinen & Ansari, 2007).

Conclusions

The present study demonstrated that magnitude discrimination, although an ability shared across cultures and even species, is subject to a great many modulators. We have shown that clinical depression can negatively affect one's ability to discriminate magnitude, regardless of the spatial and attentional properties related to the task. Also, our findings support the theory that an analogous "numeric distance effect" exists when comparing non-symbolic magnitudes, with different base numbers of elements showing differing threshold detection levels, leading us to postulate that a similar mechanism to the "tuning-curve" that exists for cardinal numerical identification is also involved in magnitude processing. These findings complement the Weberian ratio theory for magnitude discrimination, in that Weberian theory could be used to predict threshold discrimination values, and the numeric distance effect could predict performance at sub- and supraliminal levels. Further, we found support for the idea that magnitude discrimination is a primarily a high-ordered dorsal-stream-mediated process (e.g., beyond V5), and that most stimulus information relevant to the task could also be processed along this pathway, with little-to-no reliance on the alternative high-order ventral stream operations. Finally, we noted the "keyhole" effect, in which stimulus configurations that present the periphery as the foreground are more difficult to process along the dorsal stream, and likely require the aid of the ventral stream's superior object processing power to decipher.

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Figure Captions

Figure 1. Graphical representation of a hierarchical, stimulus-driven neural model of magnitude discrimination. LGN, Lateral Geniculate Nucleus; LOC, Lateral Occipital Complex; VMT, Ventromedial Temporal Area; RH, Right Hippocampal; IPS, Intraparietal Sulcus; VIP, Ventral Intraparietal Area; LIP, Lateral Intraparietal Area.

Figure 2. Graphical representation of a dorsal, goal-directed neural model of magnitude discrimination. LGN, Lateral Geniculate Nucleus; CIP, Caudal Intraparietal Area; IPS, Intraparietal Sulcus; VIP, Ventral Intraparietal Area; LIP, Lateral Intraparietal Area.

Figure 3. Stimulus Configurations. Upper left and upper right images illustrate the center foreground/annular background arrangement, without and with dot arrays, respectively. Lower left and lower right images illustrate the annular foreground/center background arrangement, without and with dot arrays.

Figure 4. Presentation sequence for single field presentation. The unique fixation image will be presented for 750 msec followed by the first stimulus image for 250 ms, a 500 ms interstimulus interval (ISI), the second stimulus for 250 ms, and a blank screen until response is given. Note that the response keys will only become active during the “wait for response” phase of each trial.

Figure 5. Presentation sequence for uncued trials. The unique fixation image will be presented for 750 msec followed by the first stimulus image for 250 ms, a 500 ms interstimulus interval (ISI), the second stimulus for 250 ms, and a blank screen until response is given.

Figure 6. Presentation sequence for a valid cue. Same sequence as Fig. 5, with the exception that an image is inserted between the fixation image and the first stimulus image. In valid

cues, this image will paint “red” the area (center or surround) in which a change in magnitude will occur.

Figure 7. Presentation sequence for an invalid cue. Same sequence as Fig. 5, with the exception that an image is inserted between the fixation image and the first stimulus image. In invalid cues, this image will paint “red” the area (center or surround) in which a change in magnitude will occur 50% of the time, with the other 50% indicating the wrong field position.

Figure 8. Accuracy plots. The four plots grouped in the top left of the matrix represent accuracy in each unique eccentricity by plane configuration. The two graphs below and to the right of the four unique graphs represent the combinations of data for changes in the center or annular surround (defined by rows) or changes in the foreground or background (defined by columns). In each graph, the red curve represents the single field presentation, the blue curve represents the No-Cue Dual Field presentation, the green curve represents Dual Field presentation with 100% cue validity, and the black curve represents Dual Field presentation with 50% cue validity. The horizontal pink dashed line in each graph represents threshold (75% accuracy). Error bars at \pm SEM.

Figure 9. Reaction times within different unique combinations of foreground/background and eccentric fields. Of note is the large increase in latency noted in the “annular-foreground” (lower-left) graph. Error bars at \pm SEM. * denotes a significant interaction ($p < 0.001$).

Figure 10. Frequency plot comparing accuracy ranges by group. The red bars represent the control group, the blue bars represent the depressed group. The horizontal pink dashed line in each graph represents threshold (75% accuracy). Of note is the overall shift of the depressed group toward lower accuracy scores when compared to control and the lower frequency of trials actually attaining threshold detection.

Figure 1.

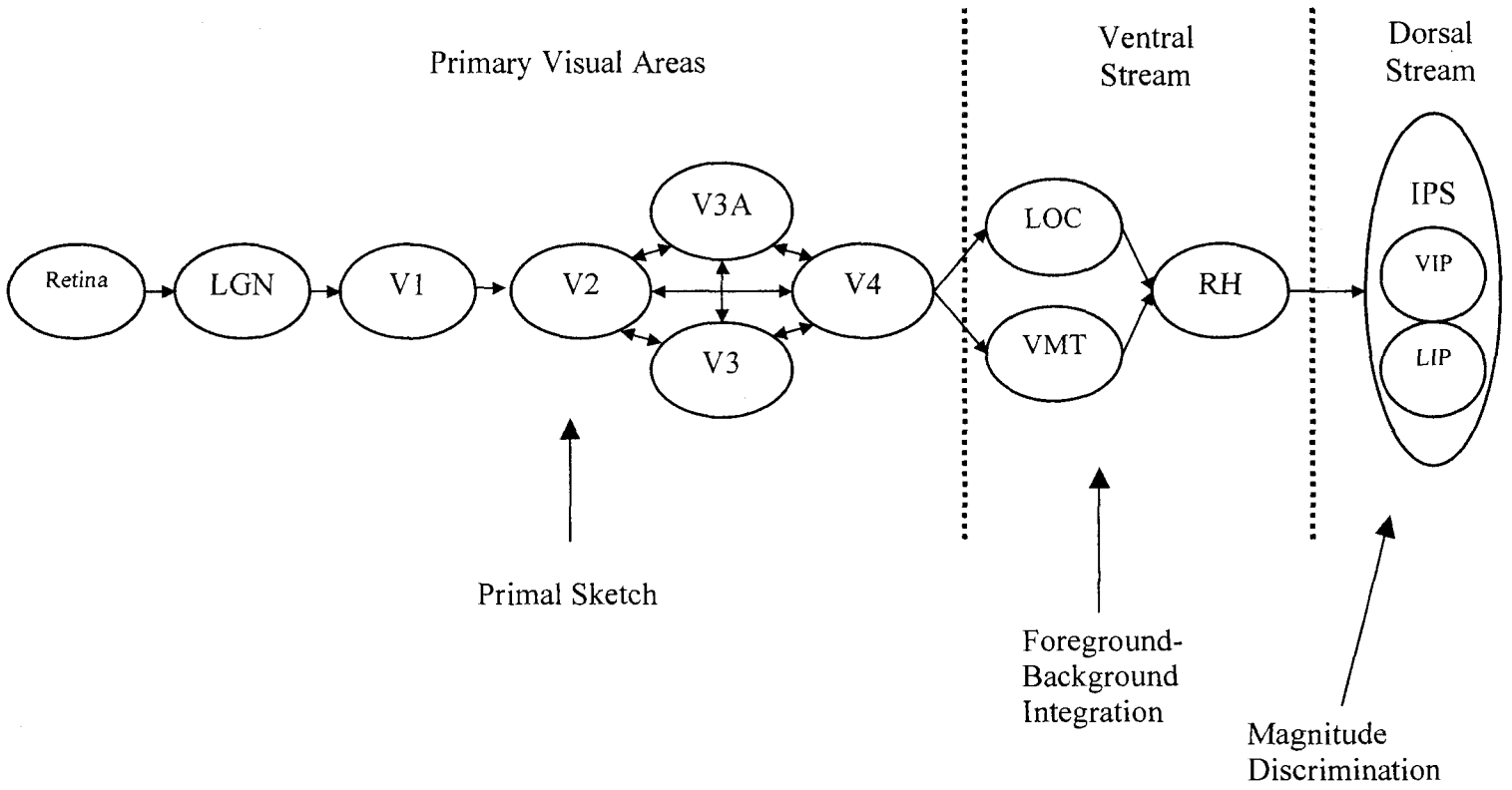


Figure 2.

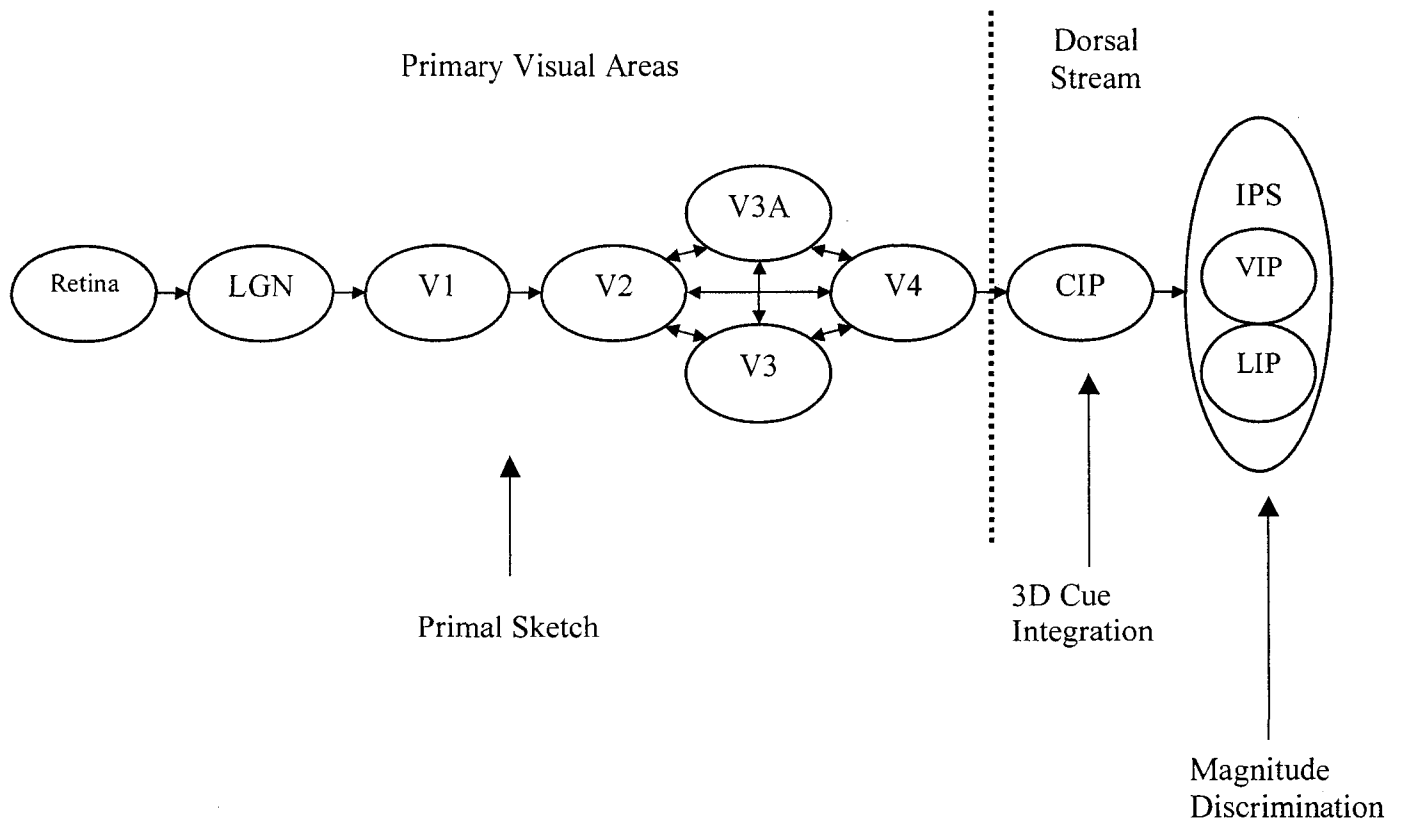


Figure 3.

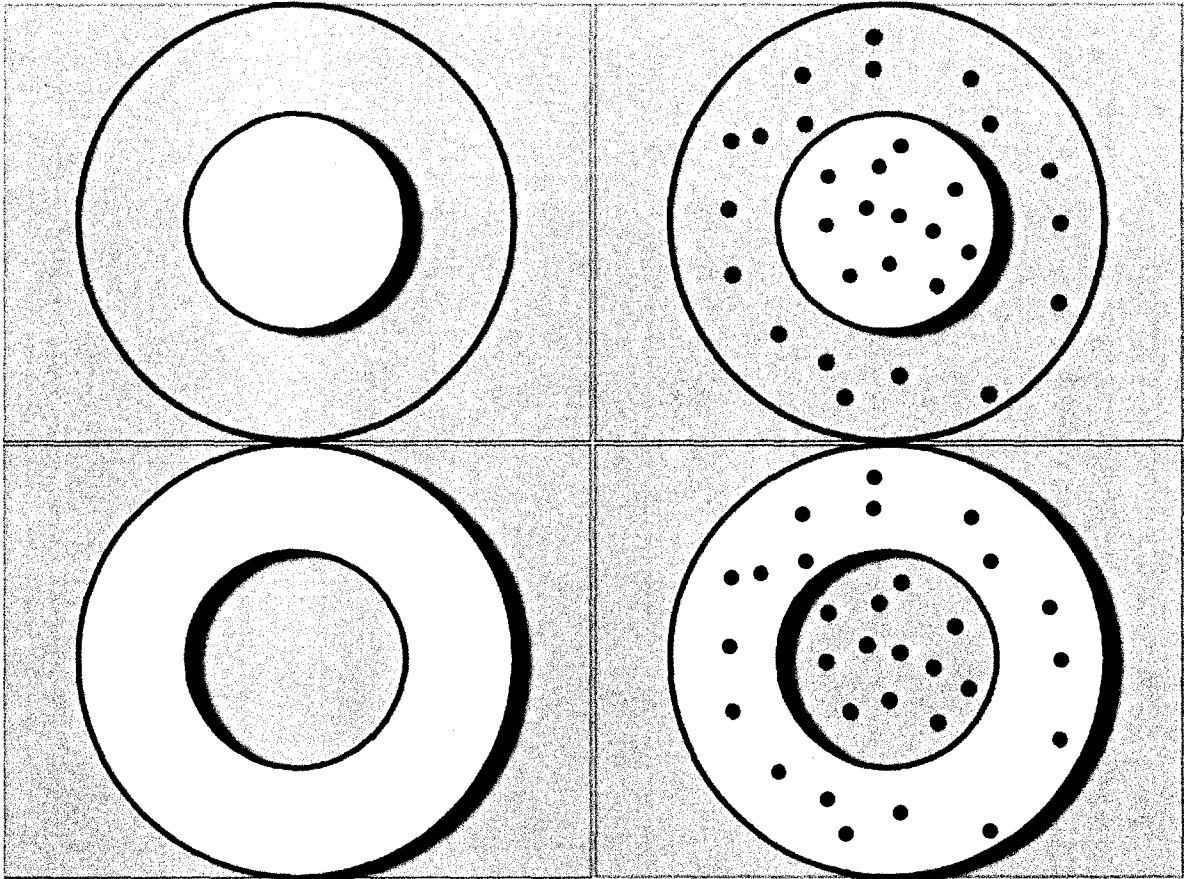


Figure 4.

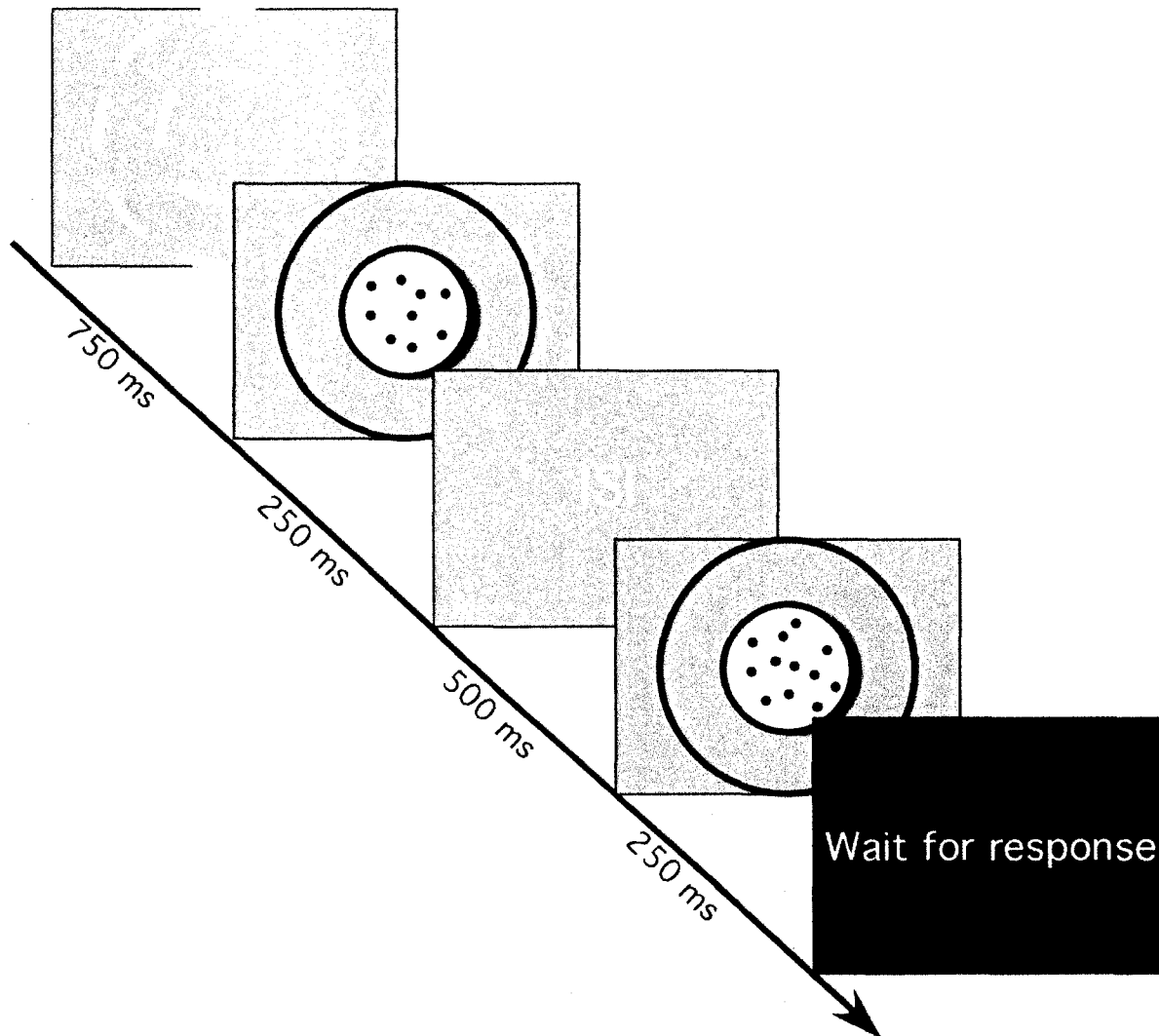


Figure 5.

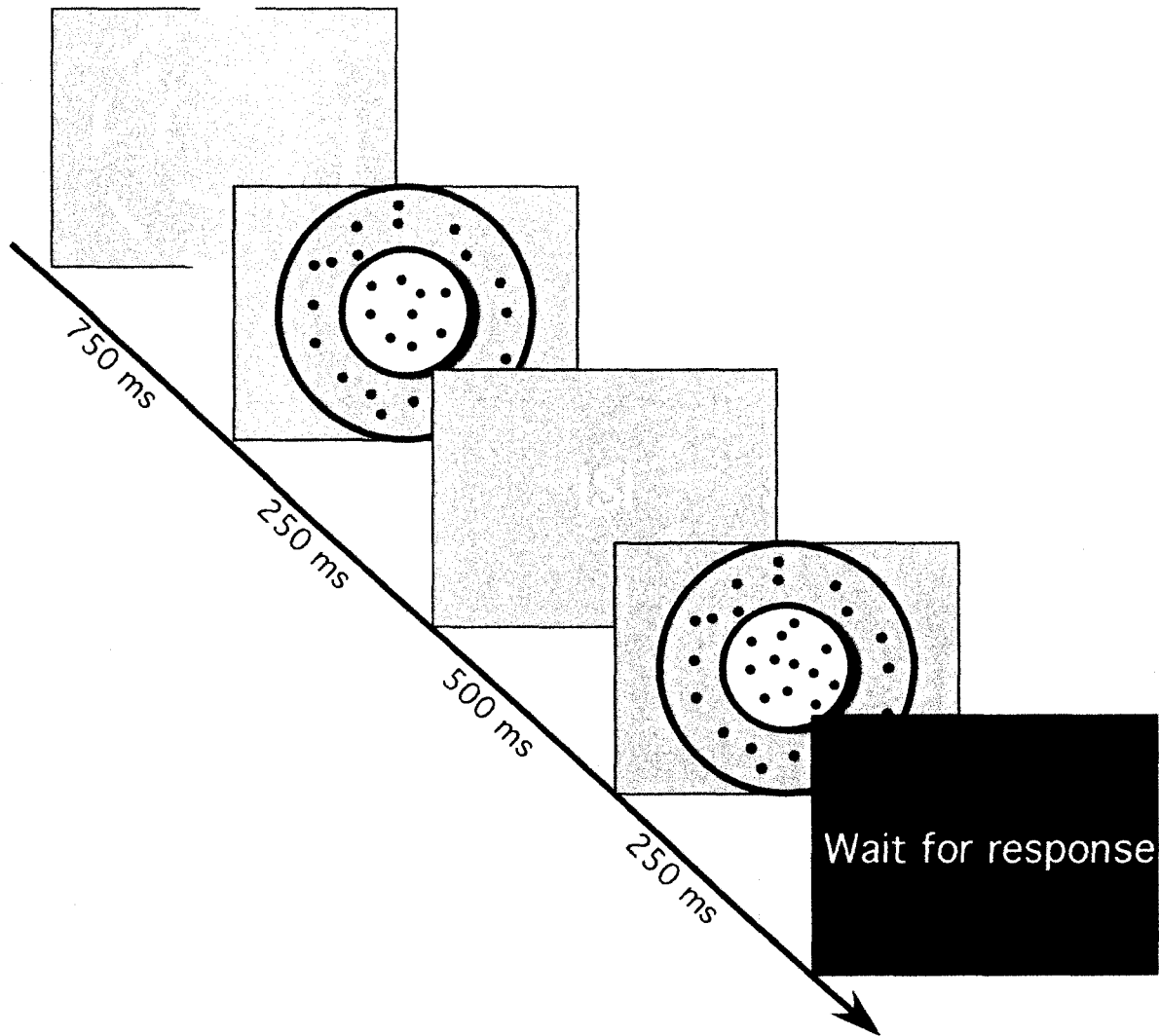


Figure 6.

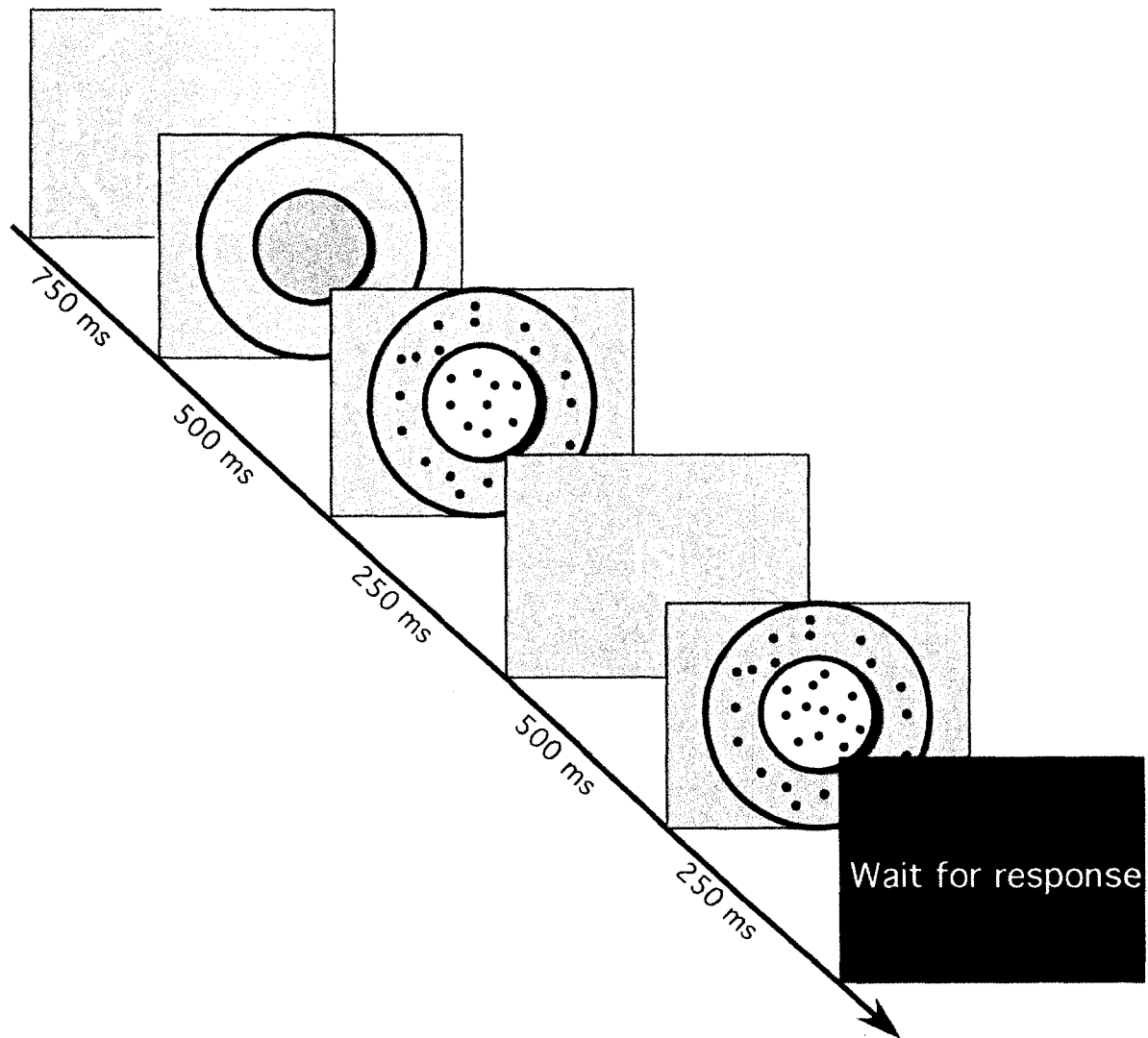


Figure 7.

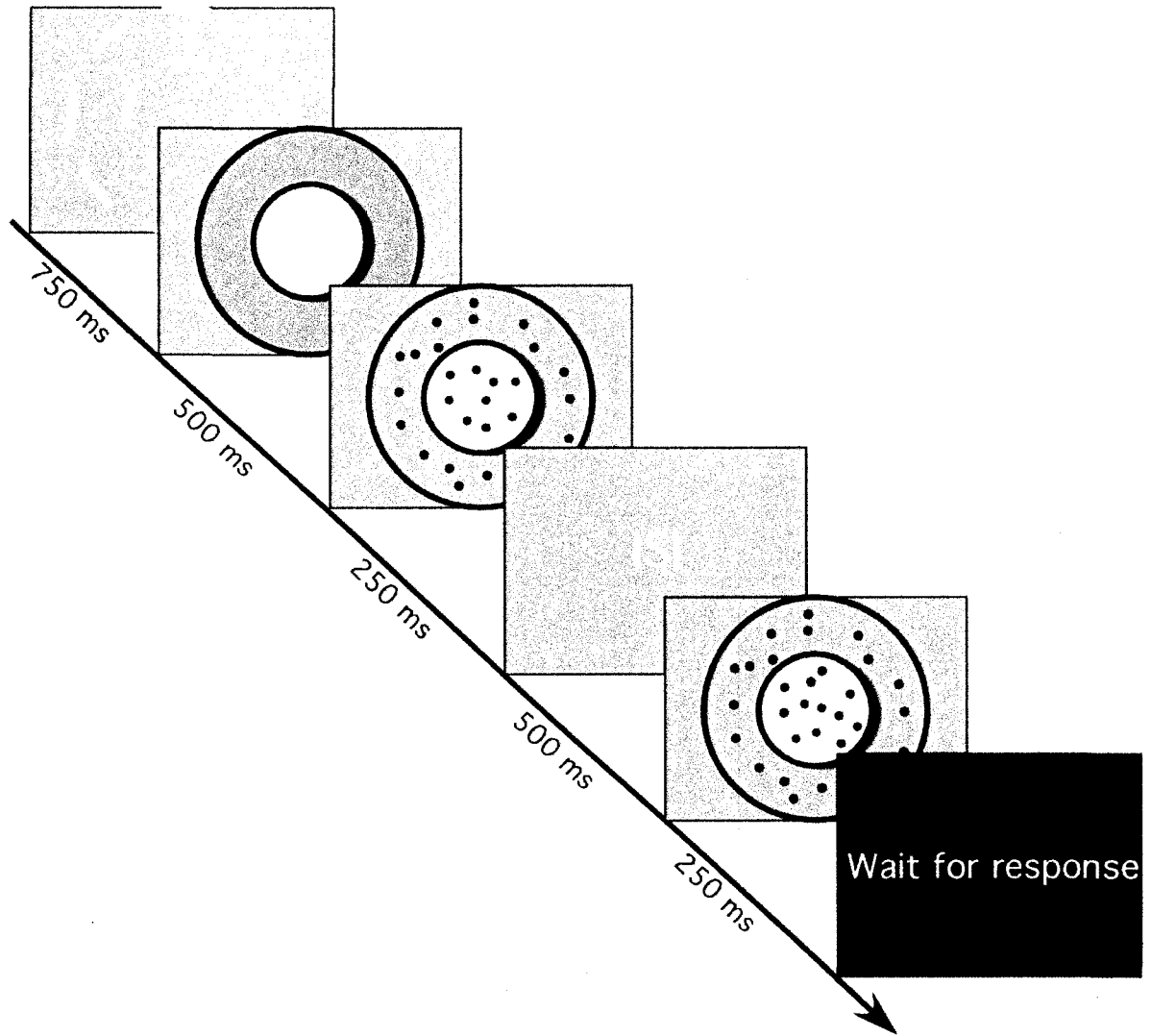


Figure 8.

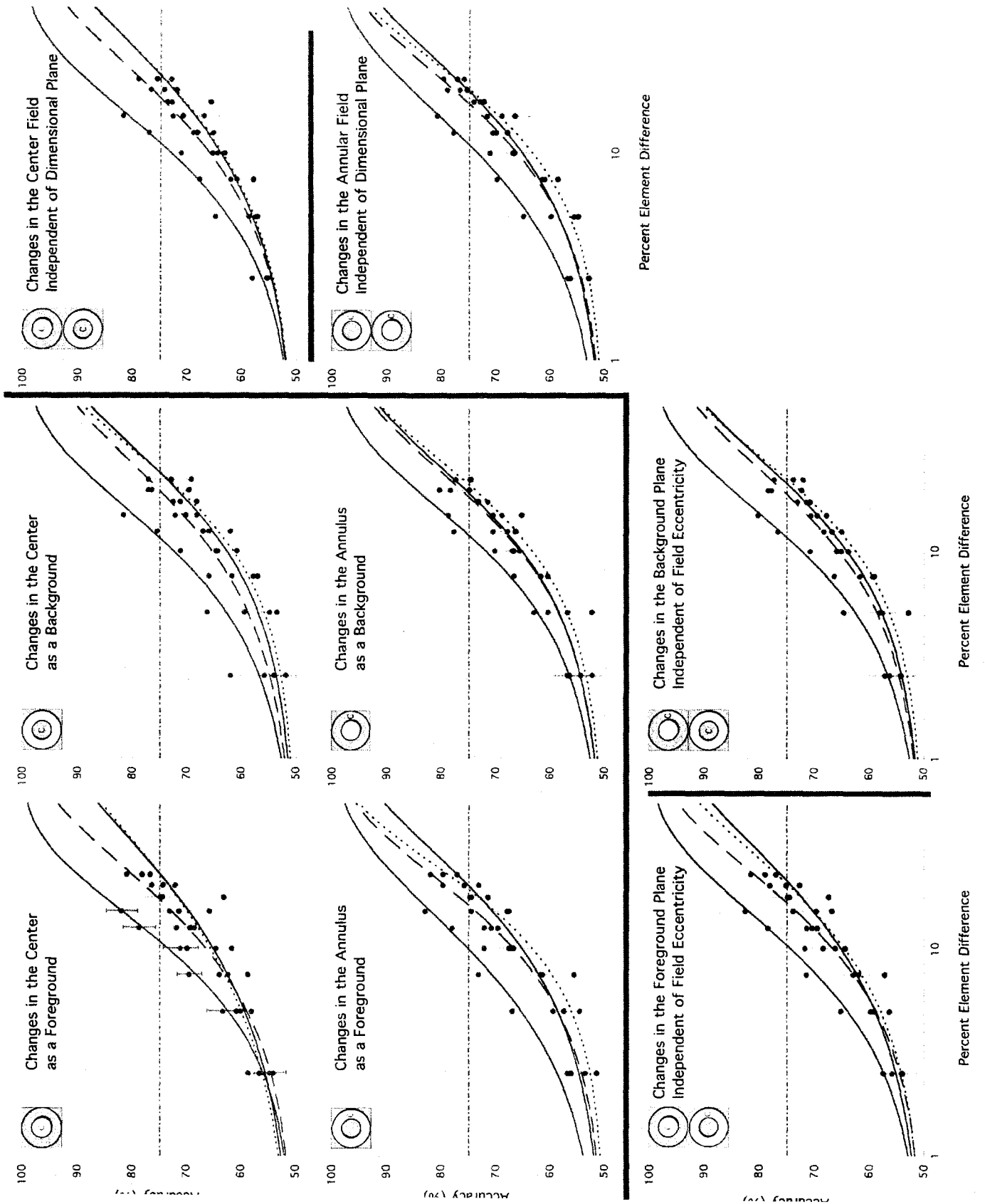


Figure 9.

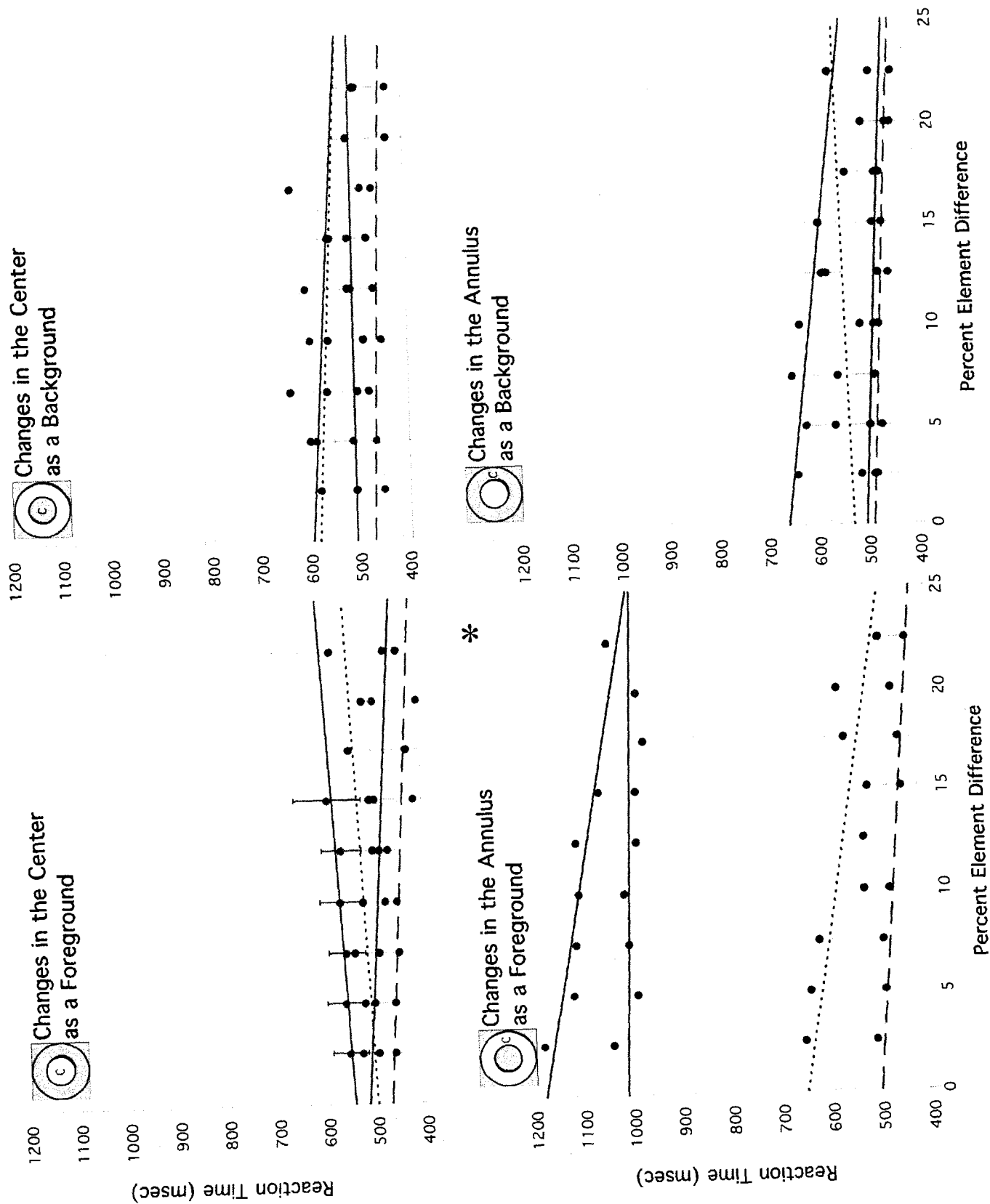
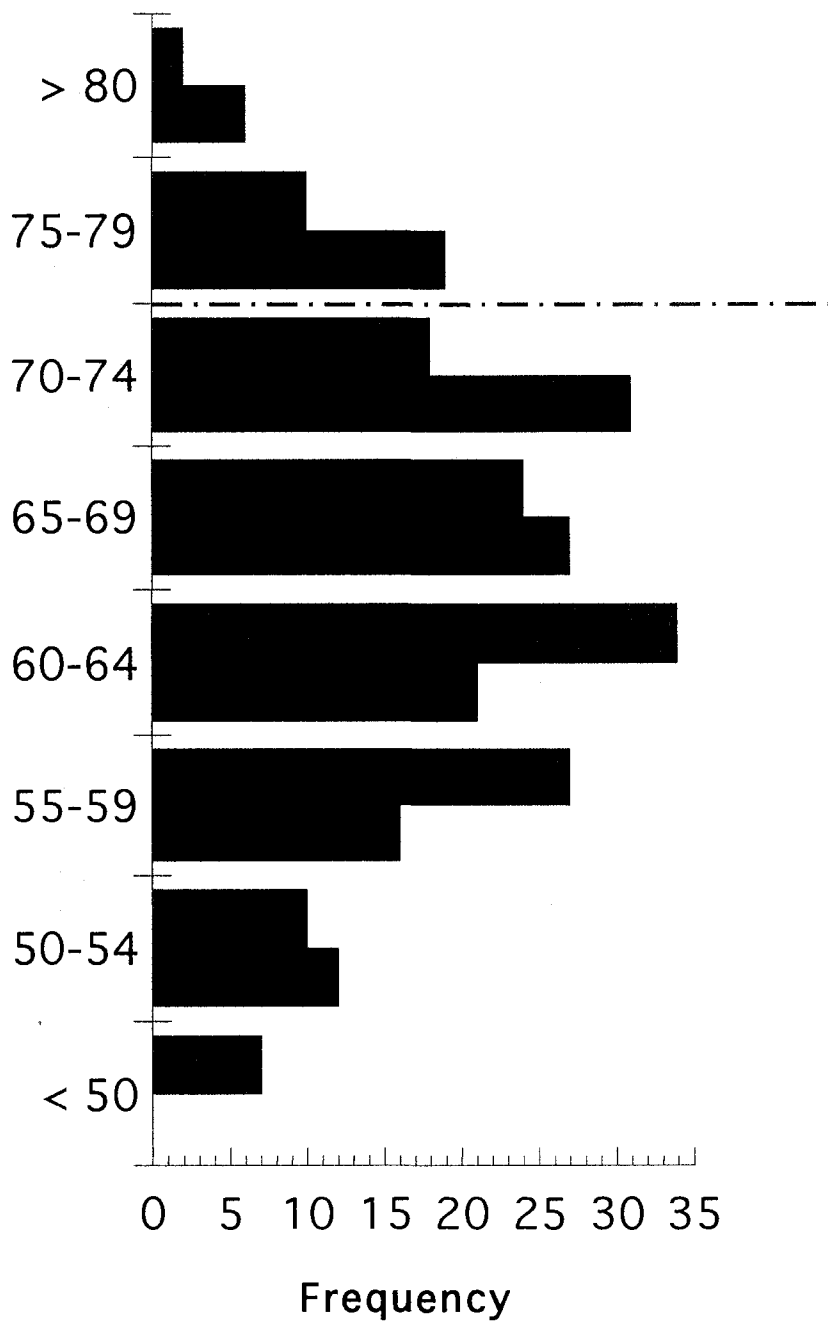


Figure 10.



Appendix A

Hamilton Depression Rating Scale (HAM-D)

Compared to how you feel when you are in an even or normal mood state, how would you rate yourself on the following items during the past 2 weeks?

	Not at all	Just a little	More than just a little	Quite a bit, moderately	Marked or severely
	0	1	2	3	4
I have been feeling	0	1	2	3	4
1. down and depressed	0	1	2	3	4
2. less interested in doing things	0	1	2	3	4
3. less interested in sex	0	1	2	3	4
4. less interested in eating	0	1	2	3	4
5. that I've lost some weight	0	1	2	3	4
6. that I can't fall asleep at night	0	1	2	3	4
7. that my sleep is restless	0	1	2	3	4
8. that I wake up too early	0	1	2	3	4
9. heavy in my limbs or aches in back, muscles, or head, more tired than usual	0	1	2	3	4
10. guilty or like a failure	0	1	2	3	4
11. wishing for death or suicidal	0	1	2	3	4
12. tense, irritable, or worried	0	1	2	3	4
13. sure I'm ill or have a disease	0	1	2	3	4
14. that my speech and thoughts are slow	0	1	2	3	4
15. fidgety, restless, or antsy	0	1	2	3	4
16. that morning is worse than evening	0	1	2	3	4
17. that evening is worse than morning	0	1	2	3	4
18. unreal or in a dream state	0	1	2	3	4
19. suspicious of people/paranoid	0	1	2	3	4
20. preoccupied/obsessed that I must check things things a lot	0	1	2	3	4
21. physical symptoms when worried	0	1	2	3	4
22. like socializing less	0	1	2	3	4
23. that I have gained weight	0	1	2	3	4
24. that I WANT to eat more than usual	0	1	2	3	4
25. that I HAVE eaten more than usual	0	1	2	3	4
26. that I crave sweets and starches	0	1	2	3	4
27. that I sleep more than usual	0	1	2	3	4
28. that my mood slumps in the afternoon or evenings	0	1	2	3	4
29. less energetic and more lethargic than usual	0	1	2	3	4
<i>Please do not write below this line</i>					
<i>Score (1-21)</i>					
<i>Supplemental Score (22-29)</i>					

Appendix B

DSM-IV-TR Criteria for Major Depressive Episode, Current

- A. Five (or more) of the following symptoms have been present during the same 2-week period and represent a change from previous functioning; at least one of the symptoms is either depressed mood or (2) loss of interest or pleasure. **Note:** Do not include symptoms that are clearly due to a general medical condition, or mood-incongruent delusions or hallucinations.
1. Depressed mood most of the day, nearly every day, as indicated by either subjective report (e.g., feels sad or empty) or observation made by others (e.g., appears tearful). **Note:** In children and adolescents, can be irritable mood.
 2. Markedly diminished interest or pleasure in all, or almost all, activities most of the day, nearly every day (as indicated by either subjective account or observation made by others)
 3. Significant weight loss when not dieting or weight gain (e.g., a change of more than 5% of body weight in a month), or decrease or increase in appetite nearly every day. **Note:** In children, consider failure to make expected weight gains.
 4. Insomnia or hypersomnia nearly every day
 5. Psychomotor agitation or retardation nearly every day (observable by others, not merely subjective feelings of restlessness or being slowed down)
 6. Fatigue or loss of energy nearly every day
 7. Feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) nearly every day (not merely self-reproach or guilt about being sick)
 8. Diminished ability to think or concentrate, or indecisiveness, nearly every day (either by subjective account or as observed by others)
 9. Recurrent thoughts of death (not just fear of dying), recurrent suicidal ideation without a specific plan, or a suicide attempt or a specific plan for committing suicide
- B. The symptoms do not meet criteria for a Mixed Episode.
- C. The symptoms cause clinically significant distress or impairment in social, occupational, or other important areas of functioning.
- D. The symptoms are not due to the direct physiological effects of a substance (e.g., a drug of abuse, a medication) or a general medical condition (e.g., hypothyroidism).
- E. The symptoms are not better accounted for by Bereavement, i.e., after the loss of a loved one, the symptoms persist for longer than 2 months or are characterized by marked functional impairment, morbid preoccupation with worthlessness, suicidal ideation, psychotic symptoms, or psychomotor retardation.

Appendix C

Sample Recruitment Cover Letter

Dear Potential Participant,

We are currently recruiting participants for our project, entitled *Spatial and Attentional Influences on Nonverbal Magnitude Discrimination*. What follows is a series of screening questions designed to assess your eligibility to participate. We are looking for individuals across a range of scores on a psychological measure that assesses emotional functioning. This screening questionnaire takes only 5-10 minutes to complete, and if you meet the research criteria, you may be invited to participate in the main study. We assure you that any data collected during the screening process will be kept strictly confidential, and no identifying information will be associated with any of your scores. Instead, a code number will be used to identify all participants and potential participants. Also, completing the screening questionnaire does not oblige you to participate in the study.

The use of psychophysical experiments to assess specific functioning in a variety of populations is one of the cornerstones of psychological research. Using the knowledge gained from these experiments, we hope to further our understanding of how the human brain functions and how that functioning translates into behaviour.

Our study proposes to assess differences in performance based on the use of a novel, non-verbal magnitude discrimination task and different cueing conditions. The experiments pose no risk to participants and will take between 120 minutes total. You will be asked to complete a series of questionnaires that assess emotional functioning and undergo basic visual function screening tasks. Dr. Tan, a clinical psychologist, will evaluate all the emotional assessments, and at no time will the researchers be aware of any of your scores on these measures. Once these tasks are completed, you will be required to discriminate between dot arrays presented on a computer screen and, using a response pad, indicate which of the two arrays is greater. Participation in this study will earn you two bonus marks towards your introductory psychology course mark.

In some cases, with your consent, you may be invited to participate in an optional experiment, in which brain activity recordings (using an electroencephalograph or EEG) will be taken during the dot array discrimination task. The EEG poses no risk, although cap fitting does require the application of a gel to the scalp at certain points, and will require the participants to wash their hair after relatively soon after the experiment. The EEG option will take an additional 30 minutes (approximately), and as such a further bonus mark (for a total of three bonus marks) will be awarded to those who participate.

Participation in this experiment is strictly voluntary, and you may withdraw at any time without bias or penalty. If at any time you feel discomfort during the experiment, you will not be required to continue. The principle investigator or trained research assistants will be present at every stage of the experiment to ensure that you are not experiencing any adverse effects.

Information collected for this experiment will be held in strict confidentiality. At no point will any identifying information be released to individuals who are not part of the research team. All information will be securely stored in Dr. Wesner's laboratory at Lakehead University for a period of seven years. Findings from the projects will be made available to participants upon completion of the project.

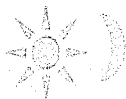
If you have any questions or concerns regarding the experiment, please do not hesitate to contact me directly. I can be reached by phone (807) 343-8418 or through e-mail (smadon@lakeheadu.ca). You may also contact Lakehead University's Research Ethics Board at (807) 343-8283.

Please return this package to the box marked "Magnitude Discrimination Study" in the psychology department mailroom (SN1042) within two (2) days of completion, or as soon as possible.

Thank you for your interest in our project,

Stewart Madon, B.A. (Hons.)
M.A. Clinical Psychology Candidate

Dr. Michael Wesner
Supervisor



Appendix D

Sample Recruitment Consent Form, Screening Questionnaire and Therapy Resources

CONSENT FORM

Spatial and Attentional Influences on Nonverbal Magnitude Discrimination

I, _____, the undersigned, hereby consent to participate as a subject in the research project entitled *Spatial and Attentional Influences on Nonverbal Magnitude Discrimination* conducted at Lakehead University under the direction of Stewart Madon and Dr. Michael Wesner. The procedures in this research project have been explained to me and are as follows:

1. This study is examining whether differential characteristics of a three-dimensional stimulus design affect performance on a sequential magnitude discrimination task. The study is designed to ascertain whether differential stimulus configuration and cueing techniques will affect performance on a magnitude discrimination task across a broad sample of the population.
2. The main study will consist of one session lasting 120 minutes. First, I will complete some questionnaires and engage in a computer task that will ascertain my present behavioural and emotional functioning. Then my visual functioning will be assessed using a Freiberg Acuity Test and automated perimetry measurements. Based on these preliminary assessment, I may then be asked to participate in the experiment. The experiment begins with me sitting in the dark for 5 minutes and then viewing a white computer display for 3 minutes. After that, I will be positioned in a head/chin rest in front of a computer screen and given a computer task. In this task, I will be asked to view sequences of images containing dot arrays in two concentric circles and asked to identify the larger of two images by pressing the correct key on a response pad.
3. I may be offered the option of also having my EEG or brain activity recorded at the same time as I undergo the experiment to confirm hypotheses about the involvement certain brain areas during the task. The EEG poses no risk, although cap fitting does require the application of a gel to the scalp at certain points, and will require me to wash my hair after relatively soon after the experiment. The EEG option will take an additional 30 minutes (approximately).
4. My consent is given of my own free choice without undue inducement or any element of force, fraud, deceit duress, or any form of constraint or coercion. I understand that I am free to withdraw my consent at any time without prejudice to me. Participating in one stage of the study does not oblige me to participate in later stages. I further understand that all results obtained from this research will be kept confidential and remain in secure storage at Dr. Wesner's lab at Lakehead University for 7 years. An impartial reference code will be used for all data files, figures and sign-up sheets. These codes also will be incorporated into any published works that come from this research effort. None of my responses in the computer tasks can be traced back to me. In return for my participation without the EEG recording, I will be given 2 credits toward my introductory psychology course mark. If I participate in the study and have the EEG recording, I will be accorded 3 credits. If I wish to have a summary of the results, I can request a copy from the investigators.

Name of Participant (Print)

Signature

Date

Name of Witness (Print)

Signature

Date

Contact Information – Please Complete Before Returning

Email: _____

Phone: _____

Please ANSWER THE FOLLOWING QUESTION...

- 1) Are you currently experiencing any illness or infections that are affecting your eyes? **Yes / No**
- 2) Do you have normal or corrected-to-normal vision? **Yes / No**
- 3) Are you currently taking any prescription medication that could affect your performance on this task? **Yes / No**

Age: _____

Gender: _____

Please complete the survey on the following page before returning package.

Questions or concerns?

Stewart Madon

Lab: (807)343-8418

Email: smadon@lakeheadu.ca

Dr. Michael Wesner

Office: (807)343-8457

Email: mwesner@lakeheadu.ca

Do you want a copy of the results of this study?

Yes / No

If yes, enter your permanent mailing address below:

Please return completed packages to SN1042 (the copy room in the psychology department) within 2 days of completion. Deposit it in the box marked *Magnitude Discrimination Study*.

Resources for Counselling and Therapy

- LU Student Health and Counselling Services – free to all Lakehead students: 343-8361.
- Thunder Bay Counselling Centre: 626-1880
- Catholic Family Development Centre: 345-7323
- Crisis and suicide response 346-8282
- Emergency services are available from the Thunder Bay Regional Health Sciences Centre
- See your physician for a referral or refer yourself to any mental health professional in private practice (look up the Yellow Pages under *Psychologists and Psychological Associates; Psychotherapy; or Marriage, Family & Individual Counsellors*).

Appendix E

Sample Experiment Consent Form

CONSENT FORM

Spatial and Attentional Influences on Nonverbal Magnitude Discrimination

I, _____, the undersigned, hereby consent to participate as a subject in the research project entitled *Spatial and Attentional Influences on Nonverbal Magnitude Discrimination* conducted at Lakehead University under the direction of Stewart Madon and Dr. Michael Wesner. The procedures in this research project have been explained to me and are as follows:

1. This study is examining whether differential characteristics of a three-dimensional stimulus design affect performance on a sequential magnitude discrimination task. The study is designed to ascertain whether differential stimulus configuration and cueing techniques will affect performance on a magnitude discrimination task across a broad sample of the population.
2. The study will consist of one session lasting 120 minutes. First, I will complete some questionnaires and engage in a computer task that will ascertain my present psychological state. Then my visual functioning will be assessed using a Freiburg Acuity Test, in which I will have to identify which of 8 positions on a ring contains a gap, and automated perimetry measurements, in which I will have to respond when I see a dot of light presented. Based on these preliminary assessments, I may then be asked to participate in the experiment. The experiment begins with me sitting in the dark for 5 minutes and then viewing a white computer display for 3 minutes. After that, I will be positioned in a head/chin rest in front of a computer screen and given a computer task. In this task, I will be asked to view sequences of images containing dot arrays in two concentric circles and asked to identify the larger of two images by pressing the correct key on a response pad.
3. I may be offered the option of also having my EEG or brain activity recorded at the same time as I undergo the experiment to confirm hypotheses about the involvement certain brain areas during the task. The EEG poses no risk, although cap fitting does require the application of a gel to the scalp at certain points, and will require me to wash my hair after relatively soon after the experiment. The EEG option will take an additional 30 minutes (approximately).
4. My consent is given of my own free choice without undue inducement or any element of force, fraud, deceit duress, or any form of constraint or coercion. I understand that I am free to withdraw my consent at any time without prejudice to me. Participating in one stage of the study does not oblige me to participate in later stages. I further understand that all results obtained from this research will be kept confidential and remain in secure storage at Dr. Wesner's lab at Lakehead University for 7 years. An impartial reference code will be used for all data files, figures and sign-up sheets. These codes also will be incorporated into any published works that come from this research effort. None of my responses in the computer tasks can be traced back to me. In return for my participation without the EEG recording, I will be given 2 credits toward my introductory psychology course mark. If I participate in the study and have the EEG recording, I will be accorded 3 credits. If I wish to have a summary of the results, I can request a copy from the investigators.

- I have been offered the option of an EEG recording as outlined in #3 above and I accept the option.
- I have been offered the option of an EEG recording as outlined in #3 above and I decline the option.
- The option of an EEG recording as outlined above has not been offered to me.

Name of Participant (Print)	Signature	Date
Name of Witness (Print)	Signature	Date

Appendix F

Sample Debriefing Letter

Debriefing

Thank you for your participation in this study. We'd like to take this opportunity to tell you a little more about the study you were participating in. We are conducting this study to confirm certain attributes and dysfunctions in mood disorders, and trying to find a non-biased method of assessing them. To this end, we chose to use magnitude estimation/discrimination as our base. It has been shown that the ability to discriminate between sets of numbers (or representations of them, like the dot arrays that we used) changes over time, and is developed in infancy. This ability has been shown to be present in monkeys and other species of non-human animal, and it seems to adhere to certain principles that make it a reliable and culturally unbiased measure of performance.

Further, we use three-dimensional stimuli to assess the functioning of certain pathways and centers in the brain. The hippocampus, long-thought to be the center of memory, has shown to be involved in other processes as well, such as relating the foreground and background of an image and making sense of the image as a whole. This last function seems to be a property of the right hippocampus. Since it is speculated in current literature that the hippocampus shows certain decreases in functioning during depression, we designed this stimulus to optimally and without bias confirm and/or measure the degree to which it could affect performance on a relatively simple task.

Ultimately, we are attempting to produce a non-verbal, culturally-unbiased way to test for prodromal depression. This type of research will undoubtedly aid us in further understanding an illness that will affect approximately 8% of persons in Canada in their lifetime.

For our study, we were interested in comparing the psychophysical responses of individuals with low and high scores on a measure of psychological distress. That is why we needed to conduct a screening during our recruitment process.

Thank you again for your participation in this study, and you have any further questions, concerns or comments about this research, please do not hesitate to contact me at the email address or telephone number below.

Sincerely,

Stewart Madon, B.A. (Hons.)
M.A. Clinical Psychology Candidate
Sensory Neuroscience and Perception Laboratory
Center for Biological Timing and Cognition (CBTC)
Lakehead University
Phone (Lab): (807) 343-8418
Email: smadon@lakeheadu.ca

