The Contributions of Spatial Processing and Selective Attention to the Deficits in Patients with Spatial Neglect and Neglect Dyslexia

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Abstract

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Patients with Spatial Neglect and Neglect Dyslexia

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Many patients with right hemisphere stroke fail to read words closest to the left margin of text and/or commit within-word errors on left-sided letters while correctly reading right-sided letters, a condition known as neglect dyslexia. These patients also show non-spatial deficits of selective attention, which may be a contributing factor to these errors. The purpose of this study was to determine the relative contributions of spatial processing deficits and selective attention deficits on reading errors in neglect dyslexia. In Experiment 1, we replicated studies that showed poorer reading accuracy for words when presented alongside a competitive distractor word than when presented solitarily. This deficit was larger for words on the left. In Experiment 2, we modified the paradigm so that the target word was positioned centrally at fixation in all conditions, in an effort to minimize spatial effects. We found that patients performed worse under conditions with a distractor word regardless of the side on which the distractor was presented. These findings suggest that the errors in neglect dyslexia are at least partly due to a selective attention deficit.

Dedication

To my mother and father,
who were just as proud of me on the day I was born
as they would be today

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Plain Language Summary

A right brain stroke can cause a variety of conditions that interfere with one's independence and ability to be successful with everyday tasks. One of those conditions, called spatial neglect, causes one to tend to ignore the left side of the world. Common examples include shaving only the right half of one's face, eating only the food on the right side of one's plate, or putting on only the right sleeve of one's shirt. There are many different manifestations of spatial neglect and each patient has a unique presentation which makes assessment and treatment quite challenging for rehabilitation clinicians.

When applied to reading, the condition is called neglect dyslexia and involves the person failing to read the words along the left margin or misreading the first few (left-sided) letters in an individual word. We completed a research study to determine if errors in neglect dyslexia are more due to their left/right position or to the distraction that other words nearby create. Patients with neglect were asked to read words presented on a computer monitor. Words were either presented alone or with a distractor word on its left or right side. Patients made errors that reflect contributions of both their position on screen and the presence of a nearby distractor word.

Assessment and treatment for spatial neglect present many challenges to rehabilitation clinicians. Unfortunately, clinicians tend not to complete comprehensive assessment, likely due to their complexity and lengthy administration. Options for treatment are limited and, of those available, none have been adequately researched. The effectiveness of interventions might be limited because they address only one aspect of this complex condition. The research reported here provides insights into opportunities for treatments that use virtual and augmented reality to address multiple underlying deficits to spatial neglect.

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Chapter 1

Spatial Cognition and Attention in the Spatial Neglect Syndrome: A Review of the Literature and a Framework for Conceptualizing its Various Subtypes

Spatial neglect, a complex and multifaceted syndrome commonly seen after right hemisphere stroke, affects a patient's ability to process stimuli located on their contralesional side or on the contralesional side of a group of objects. A patient with left-sided neglect might eat only the food on the right side of their plate, might search only the right side of the cabinet for a desired item, or might use only their right hand for a bimanual task even if their left hand functions properly. A different patient might bump into objects placed on the left side of a hallway, might fail to make left turns, or might omit words located along the left margin while reading.

The neglect syndrome has received much attention in neuropsychology and rehabilitation research over the past several decades for two reasons. First, systematic investigation of neglect has contributed much to our understanding of human spatial processing and selective attention in general through the triangulation of lesion sites with neglect behaviors. Second, spatial neglect has debilitating and long-term effects on a patient's daily functioning, independence, and quality of life (Jehkonen et al., 2000, 2006; Katz et al., 1999). Rehabilitation clinicians face challenges with assessing and treating patients with spatial neglect because it is poorly understood and presents inconsistently between patients and even within the same patient at different times.

This chapter has three primary objectives. The first is to provide an overview of spatial neglect. The syndrome can be difficult to conceptualize without first-hand observation of patients and is often misunderstood even by those with first-hand observation. Therefore, it is critical for the reader to understand what spatial neglect is and is not before proceeding to discussions of underlying neurocognitive deficits underlying the syndrome. The second objective is to make clear the relative contributions of spatial processing deficits and selective attention deficits to the behaviors observed in patients with spatial neglect through a review of the literature on spatial processing and selective attention in general and specific to those with spatial neglect. The third and final objective is to organize the various subtypes of the syndrome into a structured taxonomy based on spatial frames of reference, sensorimotor modality, and neuroanatomic correlates. All subtypes with the exception of neglect dyslexia are described in this chapter to avoid redundancy as neglect dyslexia is covered in detail in Chapter 2. A concise summary of the subtypes described can be referenced in Table 1.1, located at the end of the chapter.

Overview of Spatial Neglect

Spatial neglect can be defined as a syndrome that occurs after neurologic incident in which the patient fails to respond to, orient to, or attend to contralesional stimuli. Its incidence following acute right hemisphere stroke has been reported as 43% in one study and 83% in another (Ringman et al., 2004; Stone et al., 1993). Neglect has been defined as a syndrome because it encapsulates a wide range of phenomena that occur in different combinations for each patient and are dissociable from one another (Hillis, 2006; Kerkhoff, 2001; Vallar, 1998). Neglect research has traditionally been interpreted from the perspective of spatial processing, attentional, and representational accounts. Given the diversity of behaviors, it is possible that these interpretations are all correct and simply reflect different aspects of the syndrome.

Patients most often face numerous additional neurocognitive and sensorimotor impairments related to their stroke that exacerbate neglect behaviors. Commonly comorbid conditions include homonymous hemianopia, hemiparesis, cognitive impairment, and anosognosia (Hillis, 2006; Kerkhoff, 2001). Cases of “pure” neglect, in which no other neurologic impairments are present, are quite rare (Mort et al., 2003). The interaction of spatial neglect with comorbidities related to their stroke contribute to the difficulty that rehabilitation clinicians face in deciphering the true impairments that underlie observed behaviors in this patient population.

It is important to emphasize that the distinction between neglect and common comorbidities is that neglect does not include any disturbance to sensory systems (e.g., visual fields, tactile sensation, proprioception) or motor systems (e.g., upper extremity movement and coordination). A patient with intact visual fields and/or intact tactile sensation might still fail to process or attend to those stimuli. Likewise, a patient with intact motor systems might be able to move their left arm and hand without issue but may neglect to use it even for tasks that are very difficult to complete unilaterally. For these reasons, the naïve observer and the seasoned clinician alike may misinterpret neglect behaviors as sensorimotor impairments.

The neuroanatomical epicenter of spatial neglect has been shown to be in the parietal lobe, along the angular gyrus near the temporoparietal junction (Gillebert et al., 2011), though it also occurs after infarcts to frontal or temporal lobes, thalamus, or the basal ganglia (Corbetta & Shulman, 2011; Karnath et al., 2002). It is also seen following infarct to the subcortical white matter tracts connecting these regions. The diversity of cortical and subcortical lesion sites suggests that neglect might be more accurately understood as a disconnection syndrome, in which critical cortical areas are unable to effectively coordinate to affect behavior. Neglect after right hemisphere lesions, resulting in leftward neglect, is more common, severe, and chronic than rightward neglect after left hemisphere lesions (Ringman et al., 2004; Stone et al., 1991).

The behaviors of spatial neglect have been divided in many ways in the literature. Some behaviors involve perception of sensory stimuli while others involve intention and motor output. Some occur in the egocentric contralesional hemispace while others occur in the contralesional side of an allocentrically framed group of objects even if positioned in the ipsilesional hemispace. Some behaviors affect personal space while others affect far extrapersonal space. In the following paragraphs, these divisions will be made clear. Then, these divisions are used to organize neglect behaviors into a taxonomy of subtypes.

Perception Versus Intention in Spatial Neglect

Prior to discussion of the differential effects of spatial processing and attention, the emphasis of this chapter, it is important to first highlight a different way to divide neglect behaviors. Some deficits are related only to the patient's perception of external sensory stimuli and others to the patient's motoric action to accomplish tasks. That is, one patient with primarily perceptual deficits might not respond to visual, auditory, or tactile sensory stimulation, while another patient with primarily deficits of action or intention might show decreased use of their contralesional body, might have difficulty performing tasks in contralesional space, or might have difficulty moving their body or body parts into contralesional space.

Deficits of perception in individuals with spatial neglect involve the processing of various external sensory stimuli – vision, hearing, touch – to both build accurate representations of contralesional space and respond to stimuli that is positioned in contralesional space. These processing deficits occur in a unique array for each individual, often affecting one sensory modality while leaving others intact (Buxbaum et al., 2004).

Deficits of intention or action have to do with the individual's use of their body to accomplish tasks. In the acute stages of severe neglect many individuals show a strong ipsilesional gaze preference. In the case of left-sided neglect, the individual's eyes and neck are pointed toward the right and they face great difficulty directing their gaze leftwards. Later, after some period of recovery, they might have more neutrally aligned gaze but also show a bias in directing their gaze to the right at the expense of the left. For another individual, a deficit of intention presents as an underutilization of their contralesional arm and hand. When faced with a task that demands the use of both hands, they struggle for some time using only their ipsilesional hand. Once prompted, however, they realize their mistake and finish the task with both hands.

Of course, perception and action are inextricably linked for function. For example, an inaccurate perception of a contralesional stimulus affects the motor program that directs eye movements towards it. Likewise, ineffective oculomotor exploration of contralesional space influences perception and, subsequently, the individual's internal representation of space as well as the objects positioned within it. Therefore, in many observed neglect behaviors it can be challenging to distinguish whether the underlying deficit is one of perception or action.

Spatial Processing Deficits in Neglect

Patients with neglect demonstrate deficits in spatial processing of contralesional stimuli. The lateralized nature of the deficit is what differentiates spatial neglect from a more general impairment of visual perception. The visual system uses multiple, often overlapping, frames of reference to organize and process the stimuli it receives. Egocentric frames of reference include coordinates that are viewer-centered, anchored to the midline of the individual. Allocentric frames of reference include coordinates that are object-centered, anchored to the midline of a single object or group of objects. Spatial processing deficits in neglect are dependent on the frame of reference being called upon by the visual system for the task at hand.

Spatial Deficits Within Egocentric Frames of Reference

Egocentric space, anchored at the midline of the individual, can be further divided into three distinct delineations of space. Extrapersonal space refers to space beyond arm's reach, the area in which we locomote and navigate. Peripersonal space refers to space within arm's reach, the area in which we complete most of our tasks. Personal space refers to the body itself. These delineations are supported by the dissociations observed in neglect (Butler et al., 2004; Committeri et al., 2007; Halligan & Marshall, 1991).

Personal Egocentric Spatial Deficits

First, consider the personal area of egocentric space, involving the patient's body itself. Following the division of perception versus action, neglect of this type involves either a deficit in responding to information incoming from sensory systems (light touch, deep touch, proprioception) or a deficit in initiating premotor and motor systems (e.g., movement of the extremities, head) to carry out tasks.

The first specific subtype covered here is called *hemiasomatagnosia*, also known as "body neglect." The deficit within this subtype involves a decreased spontaneous awareness of one's contralesional body. It can be considered a deficit of both perception and intention. A patient with this presentation might allow their left arm to dangle off the side of their wheelchair, or they might forget to wash the left side of their body or shave the left side of their face. In severe cases, patients deny ownership of one or more contralesional body segments, which is known as somatoparaphrenia. There is evidence that hemiasomatagnosia is a result of an infarct to the inferior parietal lobule (Committeri et al., 2007) where sensory information is interpreted and body image is constructed (Catani & Thiebaut de Schotten, 2012).

Somatosensory neglect, the next subtype within personal egocentric space, can present similarly to hemiasomatagnosia, but differs in that it is a purely perceptual deficit rather than a combination of perceptual and intentional. Somatosensory neglect involves a diminished response to touch, proprioception, temperature, pain, or other sensations of the body. A patient with somatosensory neglect, for example, might not respond to a tap on their shoulder or they might allow the fingers of their neglected arm get caught in the spokes of their wheelchair.

Hemihypokinesia, the final neglect subtype within peripersonal egocentric space, is purely intentional in nature. Also known as “motor neglect,” it has been described as a spontaneous underutilization of one side (Catani & Thiebaut de Schotten, 2012). Just as in other subtypes, hemihypokinesia is independent of a motor impairment and is seen in those with intact and hemiparetic limbs alike. Those with this subtype may fail to incorporate their contralesional hand in typically bimanual tasks. Even with great difficulty the patient with hemihypokinesia uses only one hand for the task until it is brought to their attention. Frequently after this is brought to their attention, they provide a confabulated excuse as to why they hadn’t incorporated it, representative of a lack of insight and awareness.

Peripersonal and Extrapersonal Egocentric Spatial Deficits

The other two delineations of space, peripersonal and extrapersonal, concerns the space external to one’s body. Peripersonal egocentric space exists within arm’s reach of the individual and is the area in which most tasks are completed. Most clinical tests are completed in peripersonal space with paper and pencil tasks. Extrapersonal space is the area beyond arm’s reach. Deficits of extrapersonal space may involve issues with mobility or scanning the distant environment for a particular item.

The medial and lateral intraparietal areas have been identified as the regions that process peripersonal and extrapersonal space, respectively (Chokron, 2003). Neurons in these areas are retinotopic, representative of the egocentric frame of reference, and respond preferentially to salient rather than novel stimuli.

Visual-sensory neglect involves a deficit in responding to contralesional visual stimuli. It has been called “pseudo-hemianopia” because it is easily and often confused with the sensory impairment (Kooistra & Heilman, 1989). Assessments such as visual field perimetry testing will often show a false-positive of hemianopia for those with visual-sensory neglect. It is not only difficult to differentiate between pure visual neglect and pure hemianopia but, for those with both, it is difficult to precisely determine the degree of influence each has on performance.

Visual-sensory neglect may be expressed differently in the peripersonal and extrapersonal delineations of egocentric space. Peripersonal visual neglect distorts the visual space within arm's length which, in turn, influences subsequent motor outputs of reaching for and interacting with objects in the contralesional hemispace. Far extrapersonal visual neglect likewise influences representation of far space and influences one's ability to accurately and safely locomote and navigate the environment. Visual-sensory neglect has been attributed to lesions in the inferior parietal lobe, especially near the supramarginal gyrus with extension into the white matter, and a secondary area in the frontal lobe suggesting involvement of the frontoparietal network (Verdon et al., 2010).

Auditory neglect is less studied than other subtypes of neglect, likely because it has fewer obvious consequences in daily life. Hearing nonetheless contributes to our spatial construction of space based on the timbre and reverberation of the sounds. Hearing also provides information about spatial relationships between the self and the object of interest by calculating the interaural time difference. In auditory neglect, one might not respond to a greeting from a friend standing on her left side or may have a diminished ability to localize sounds.

Oculomotor-directional hypokinesia is a deficit of eye movements. In severe cases, patients with presenting with this subtype can show a strong ipsilesional deviation of the eyes and head and may have great difficulty moving their eyes contralesionally. Those with this subtype demonstrate limited saccades into the contralesional visual space or in a contralesional direction. In fact, they display a "magnetic gaze attraction" toward the ipsilesional side (Gainotti et al., 1991). Lesions to frontoparietal areas including the frontal eye fields and the frontoparietal superior longitudinal fasciculus can induce this hypokinesia (Bourgeois et al., 2015). Oculomotor exploration is, however, heavily influenced by bottom-up attention as salient stimuli moderate subsequent intentional exploration of the visual environment.

Motor-directional hypokinesia is often grouped with the personal egocentric space subtype *hemihypokinesia* and termed "motor neglect" but the two are quite different phenomena and should be measured separately. Recall that hemihypokinesia is a type of "body neglect" in which the patient shows a decreased use of their contralesional limbs. Motor-directional hypokinesia, on the other hand, impacts the direction of attention while exploring or acting on the environment in some way. This subtype is also differentiated between the peripersonal and extrapersonal delineations of space. In peripersonal space, this manifests as a decreased reaching for and interacting with objects in the contralesional hemispace or in a contralesional direction within the ipsilesional hemispace. In extrapersonal space, individuals have difficulty making left turns or walking to the left side of the room.

Spatial Deficits Within Allocentric Frames of Reference

Allocentric frames of reference are anchored to the midline of an individual object or group of objects rather than to the individual. This means that an allocentric frame might be perceived around a group of objects that all reside in the individual's subjective right hemispace. The cardinal directions within the allocentric frame (e.g., left and right, top and bottom) are consistent with the egocentric perspective, however.

Spatial deficits within allocentric frames of reference follow a left-to-right gradient of accuracy just as in egocentric frames. Within a framed group of objects, the contralesional side is processed more poorly than the ipsilesional side. Viewer-centered coordinates still determine which side is left and right within the allocentric frame, but processing within that frame is independent of egocentric spatial position.

Lesions in the temporal lobe, particularly the medial and lateral temporal cortex (Verdon et al., 2010) and the superior temporal gyrus (Hillis et al., 2005) have been implicated in allocentric spatial neglect. Though Mort et al. (2003) did not dissociate subtypes of neglect, their lesion analysis study of 11 subjects with right hemisphere stroke showed that all five subjects with neglect had infarcts in the inferior medial temporal lobe, more specifically, the parahippocampal area. All six subjects without neglect lacked a lesion to that area. Citing the dense connections between the temporal lobe and the critical regions for neglect in the parietal lobe, Mort et al. hypothesized that the presence of neglect in those with infarcts to the temporal lobe may be attributable to temporoparietal diaschisis rather than to the cortical parahippocampal lesion itself. However, other studies that compared lesion sites to specific subtypes of neglect found that a more temporal distribution resulted in distinct allocentric deficits (Hillis et al., 2005; Verdon et al., 2010) suggesting a key role in processing object-based representations of space.

Attention Deficits in Neglect

It is clear that there is a spatial processing deficit involved in neglect, whether it be within an egocentric or allocentric frame of reference. However, many patients with right hemisphere stroke exhibit additional spatial and nonspatial attentional deficits. As a basis for more complex attention, an adequate level of alertness and sustained attention is necessary. Typically, right hemisphere damage induces greater changes in alertness and sustained attention than left hemisphere (Corbetta & Shulman, 2011), increasing its overlap with neglect. Some authors conclude that impaired alertness and sustained attention is a feature of spatial neglect (e.g., Adair & Barrett, 2008).

Selective and Divided Attention in General

Selective attention can be defined as the allocation of neural processing to one stimulus at the exclusion of another. Selective attention is what allows a neurologically healthy person to clearly hear the voice of their partner through the aural chaos of a busy restaurant, colloquially known as the “cocktail party effect”. In order to accomplish this, the brain must attenuate the sensorineural signal of the background noise of the restaurant and boost the signal of their partner’s voice. Selective attention is also involved in serial processes such as reading, in which one word must be selected at a time in sequence.

Early selective attention research used a paradigm called dichotic listening to examine healthy subjects’ processing of two conflicting auditory signals (e.g., Broadbent, 1958; Cherry, 1953; Treisman, 1964). The task includes two auditory messages played simultaneously to the left and right ears through headphones. Subjects are to attend to only one of the messages and ignore the other. Some tasks involve reporting content or characteristics of the message and others involve ‘shadowing’ tasks in which subjects repeat back the message in real time. Subjects find shadowing to be quite easy but interestingly are unable to report anything about the contents of the ignored message. In one study, subjects do not notice when the language of the ignored message changed or when it was played in reverse but did notice when the speaking voice changed gender or was replaced by a 400 Hertz tone (Pashler, 1998).

Divided attention is defined as occurring when there is more than one relevant stimulus for the visual system to process at the same time. Limitations in capacity for divided attention can create a bottleneck at some point in the sequence of processing. It is debated at what stage of processing a bottleneck occurs. Cherry’s (1953) dichotic listening paradigm is an early example of a filtering paradigm from which bottleneck theories of attention emerged. Early and late selection theories are most concerned with the locus of selective attention — where on the stimulus-decision sequence a bottleneck of selective attention occurs. Early selection proponents such as Broadbent (1958) and Treisman (1964) believed that selection occurs before stimulus identification. Broadbent's (1958) Filtering Theory put forth that sensory stimuli first undergo a stage of preattentive processing in which filtering of irrelevant stimuli occurs. From this all-or-nothing view, filtered stimuli are not analyzed semantically and do not reach awareness. Treisman's (1964) Attenuation Theory challenged the all-or-nothing premise and suggested that filtered stimuli are processed at the level of crude physical characteristics but attenuated (Pashler, 1998). In contrast, late selection models, such as posed by Deutsch and Deutsch (1963), suggest that unconscious semantic analysis of all available stimuli occurs prior to a selective response.

The presence of a bottleneck implies that the system faces capacity limitations under conditions of divided attention. The study of perceptual capacity concerns the influence of the number of competing relevant stimuli on accuracy and response times (Scharff et al., 2011). Perspectives that represent the two opposite ends of a capacity continuum are the unlimited capacity, and the fixed capacity models of divided attention. Under unlimited capacity models, perception of simple features in a display is accomplished with parallel processing and is unaffected by the number of stimuli presented. Fixed capacity models, in contrast, state that there is a limited amount of processing that occurs at one time. Capacity may either be dedicated to stimuli one-at-a-time in a sequential, serial fashion or may be pooled and divided between competing stimuli.

Flanker tasks challenge capacity limitations through a manipulation of distractors that surround a target item. Manipulations include target-distractor similarity and spatial configuration of distractors. In Eriksen and Eriksen's (1974) flanker task, a target letter was briefly presented in the central position. Subjects responded to targets S versus C or H versus K with a right or left lever press. The target was flanked by three “noise letters” on either side. They were either of the same or different perceptual category (i.e., the target letter as flankers or distractor letters as flankers). In addition to the effects of the noise letters themselves, the spacing between adjacent letters was also manipulated. They found that response times were slowed with tightened spacing, suggesting greater noise interference with decreasing spacing/eccentricity. Response times were fastest when distractors were the same letter as the target and slowed as distractors become more dissimilar. Shaffer and LaBerge (1979) conducted an experiment with a flanker paradigm in which a target word was displayed sandwiched between identical distractor words. Similar to Eriksen and Eriksen (1974), results of this study showed that response times were faster when flanking words were of the same semantic category than when they represented a different category (Pashler, 1998).

Visual search is a task in which the subject actively scans, with or without eye movements, for a target among several distractors (Heinke & Humphreys, 2004). Task complexity of visual search lies between simple detection tasks and more cognitively demanding tasks such as reading (Palmer, 1994). Visual search is most often used to differentiate between spatially parallel processes (i.e., discriminating distractors at the preattentive stage) and spatially restricted serial processes.

One body of visual search research involves brief displays to mimic an individual eye fixation. These studies often use a simple yes/no response and low memory requirement to ensure that the manipulation of the set size affects perception and not memory or decision (Palmer et al., 1993). The phenomena of quickly and easily being able to distinguish between targets and distractors among a large set size, known as the “pop-out” effect (Treisman &

Gelade, 1980), is a sign of a parallel process that can take advantage of the dissimilarities between target and distractor stimuli. It occurs automatically and efficiently and, for simple form characteristics such as line length and orientation, has no capacity limitations (Palmer, 1994).

Spatial Attention

The construct of spatial attention represents elements from both the spatial processing perspective and the attention perspective and is especially relevant to those with spatial neglect. In healthy individuals, spatial attention has been described as operating like a spotlight (Posner et al., 1980) or a zoom lens (Eriksen & St James, 1986) in which selectivity for objects is heightened across a specific area of the visual field. It has been further suggested that selectivity within this localized area of the visual field decreases along a gradient as eccentricity from fixation increases (LaBerge & Brown, 1989).

Within this framework, patients with neglect may have an incomplete "spotlight" function (Posner et al., 1980) in which the contralesional portion of the spotlight is lacking, or a non-functioning "zoom lens" function in which contralesional objects receive less focal visual attention. The selectivity of stimuli that has been proposed to decrease along a gradient as eccentricity from fixation increases (LaBerge & Brown, 1989) may be impaired on the contralesional side.

Spatial cueing paradigms are widely used to study selective attention. In these paradigms, brief cues are presented at task-relevant spatial locations prior to the onset of a stimulus. In the partially-valid cueing paradigm, there are valid cues indicating the true spatial location of the target stimulus, in a majority of trials. A minority of trials use invalid cues indicating at a spatial location other than that of where the target stimulus is presented. Typically, a valid cue improves performance.

Posner et al. (1984) propose that an attentional shift happens in three stages: disengagement, orienting, and reengagement. Prior to an eye movement, the individual first must disengage from the currently attended object. The disengagement function has been suggested to be controlled by the temporofrontal and ventrolateral prefrontal areas (Giesbrecht & Mangun, 2005). After disengagement, the individual must orient their attention toward the new target. Covert orienting involves parafoveal and peripheral processing of the new target. This information is then used to inform overt orienting, which involves the eye movement toward the target. Covert and overt orienting share similar neural networks including the lateral intraparietal area, which encodes extrapersonal space, and the frontal eye field, which sends motor programs to the superior colliculi to direct eye movements (Mesulam et al., 2005). Finally, according to Posner et al.'s (1984) model, the individual must reengage on the target.

Cueing paradigms measure spatial attention by comparing the effects of different types of cues. Trials begin with subjects fixating on a central cross. The targets briefly appear at a peripheral location while subjects maintain their fixation on the central cross. A spatially relevant cue precedes target onset to manipulate a subject's knowledge about the possible spatial location of the target. Two main types of cues can precede the target presentation: endogenous cues, in which a centrally presented symbol (e.g., an arrow) provides informative target location information; or exogenous cues presented in relevant peripheral spatial locations that are not informative about the target location.

In a seminal study, Posner et al. (1980) performed five experiments that used a spatial cueing paradigm. Their overall objective was to demonstrate through effects on response times and accuracy that spatial allocation of attention enhances stimulus processing. Experiments generally compared response times of different types of valid endogenous cues to neutral and invalid cues. Subjects maintained central fixation throughout trials (i.e., no eye movement) and were to respond upon detection of a target stimulus eccentric to the central fixation cross. Manipulation of cues compared endogenous centrally presented cues (#1-4 indicating spatial position of the four boxes) and exogenous, location-based cues. Effects included significant costs to response times with invalid cues and benefits to response times with valid cues, suggesting that covertly orienting towards a spatial location facilitates detection of a stimulus (or is detrimental to detection in the case of an invalid cue). A final experiment in this study showed limitations in subjects' ability to attend to two different spatial locations at once. The authors concluded that all of these effects are supportive of a space-based explanation of selective attention: that the limitations in selective attention arise from spatial rather than object characteristics.

Duncan (1984) challenged the perspective that limitations observed in attentional capacity are attributable to the spatial nature of the stimuli. He instead supported an object-based perspective to explain the limitations of divided attention. He presented displays consisting of a box with a gap in its border and with an oblique dotted line superimposed upon it. The box and line were intended to be conceptualized as two discrete objects. This was confirmed by subjects' reports of their perceptions. Displays varied along four conditions: short versus tall box size, the presence of a leftward versus rightward box gap, clockwise versus counterclockwise tilt of the line, and tight or loose dotted texture of the line. Subjects were asked to name either one or two of these properties. Subjects were able to name two characteristics of the same object (e.g., short and rightward gap) with comparable accuracy as to when they named one. Their performance declined, however, when asked to report one characteristic of each of the two objects (e.g., short box, clockwise line). Since the objects were superimposed, a space-based account does not explain this effect. The results therefore suggest a limitation in processing characteristics of more than one object at a time.

Although space- and object-based theories represent opposing perspectives on selective and divided attention, it is widely acknowledged that they are not mutually exclusive but likely operate together with space-based mechanisms orienting to a spatial location and object-based mechanisms selecting one or more objects within that spatial location (Duncan, 1984; Egly et al., 1994). One notable study that followed a framework including both space- and object-based theories used a partially-valid cueing paradigm to compare spatially comparable within- and between- objects attentional shifts (Egly et al., 1994). They presented two identical skinny rectangles either above and below or on the left and right sides of a central fixation cross. The target was a shading in of a portion of either of the long ends of the rectangle. Valid and invalid cues preceded target onset. Invalid cues, occurring in 25% of trials, falsely indicated equidistant spatial locations either within or between the rectangle that the target eventually appeared. Response time was measured by a single button press when the target was detected. Results indicated main effects of valid versus invalid cueing and whether or not the target emerged within the same rectangle as the invalid cue. There was a cost to response time with invalid cues, supportive of a space-based explanation. However, there was an even greater cost to responding to invalidly cued targets presented in a different rectangle than those presented in the same rectangle, supportive of an object-based explanation.

Selective and Divided Attention in Spatial Neglect

Patients with neglect and extinction demonstrate limitations in processing and subsequent unawareness of certain environmental stimuli. Importantly, similar limitations were precisely what was exposed in neurotypical populations through many of the paradigms described above. Individuals with neglect show a failure to perceive objects in the left hemispace, the left of two competing objects, or the left side of individual objects. The paradigms described above allow one to address the role of selective attention.

In a response time detection task, Posner et al. (1984) tested the effects of spatial cueing on target detection in 13 patients with parietal lobe strokes and three control patients with frontal lesions. Their objective was to determine the effect of parietal injury on covert orienting. Targets were asterisks presented in two bilateral positions. Peripheral cues (at the target spatial location) and endogenous cues (a centrally presented arrow) were provided in both valid and invalid trials and the cue-target interval was modulated between trials. They found that the primary issue for these patients was disengagement following an invalid or neutral cue, a deficit of covert orienting to a competing contralesional stimulus.

Bartolomeo et al. (1999) used a cueing paradigm and varied the interval between cue and target onset. They attempted to tap into the phenomenon known as inhibition of return. This inhibitory mechanism, present in neurotypical individuals, occurs during visual search and is believed to facilitate efficiency. According to this phenomenon, cues within 200 milliseconds of target onset should facilitate response times while intervals longer than that and up until 3 seconds should inhibit the return to that spatial location. They found that right-sided cues facilitated right side target detection when they should have been inhibited. They suggest, based on these findings, that the inhibition of return phenomenon is absent in those with neglect and likely influences visual search. This apparent rightward disinhibition of return and the difficulty with disengagement from an ipsilesional stimulus as Posner et al. (1984) found both support the biased attention account for neglect behaviors under conditions of lateralized competing stimuli.

Line Bisection Paradigms

Several studies have manipulated aspects of the line bisection task, one of the paper-and-pencil tasks commonly used at bedside to determine presence of neglect, in order to pinpoint the effects of covert and overt attention on those with extinction. Those with neglect tend to bisect a line with an ipsilesional error. This error has been shown to increase with lines of longer length and with lines presented in the contralesional hemispace (Marshall & Halligan, 1990; Urbanski & Bartolomeo, 2008). Line bisection error has also been shown to have different effects in the peripersonal versus far extrapersonal space (Halligan & Marshall, 1991).

One hypothesis is that patients with neglect start their visual analysis of the line from the right endpoint and work their way leftward until the point where the two halves of the line appear to be equal (Ishiai et al., 2006). Eye movement analysis has also shown that they do not scan all the way to the left endpoint of the line. Using a biased competition lens, as one judges the midpoint of a line segment, the two endpoints of the line could be competitive and thus perceived with a salience gradient. Ipsilesional bisection errors may therefore be due to a perceptual asymmetry that causes the right portion to appear larger than it actually is (Urbanski & Bartolomeo, 2008). It can also be argued that as one computes the perceived midpoint, one imagines creating two distinct objects with the bisection. This imagined comparison of line length between the two newly created segments perhaps leads to competition between them and an ipsilesional error.

Riddoch and Humphreys (1983) examined the effects of egocentric positioning, line length, and cueing to the endpoint(s) of the line to be bisected. In Experiment 1, the authors presented patients with three pads of paper, one positioned at midline, one flanked left, and one flanked right. Each pad of paper contained 30 sheets of paper, each with a single line-to-be-bisected of a randomized line length. Each stimulus had one of four randomized cueing conditions: no cue, left-sided cue, right-sided cue, or bilateral cue. Cues were a single digit 1-5 and were positioned laterally to the endpoint(s) of the line. Findings revealed greater bisection error when lines were presented in the left hemispace and the least error when presented in the right hemispace (though not with statistical significance). Amount of error showed a significant linear increase with longer lines. Finally, unilateral left cues significantly decreased error compared to the no cue condition regardless of positioning. Conversely, unilateral right cues and bilateral cues increased the rightward error in all cases. The authors first point out that the lack of significant difference between egocentric spatial position refutes the possibility that a hemi-hypokinesia is responsible for the rightward error. The authors attributed the differences in cueing to patients' inability to orient to contralesional stimuli.

If the line bisection error is due to the competition between the two endpoints of the line segment, the presence of the right portion of the line should not influence length estimation of the left portion. Urbanski and Bartolomeo (2008) sought to determine if the presence or absence of the right portion of the line influenced line bisection error. Four experimental conditions compared bisection performance on physically present versus imagined lines. Performance was also compared between three task conditions: traditional line bisection with a single mark at the midpoint, marking the left endpoint, midpoint, then the right endpoint (L→R); and marking the right endpoint, midpoint, then left endpoint (R→L). The authors found the expected line bisection error in the traditional line bisection condition. However, with both physically present and imagined lines, the L→R condition abolished the deviation. In the R→L condition with the imagined line, bisection error also fell to within normal limits. These results support a biased competition account of line bisection error in those with neglect.

The Extinction Phenomenon

The extinction phenomenon is an example of lateralized spatial attentional deficits seen in some but not all patients with spatial neglect. Those with extinction successfully detect a solitary contralesional stimulus but fail to detect a stimulus in that same contralesional position when there is an ipsilesional stimulus presented simultaneously. Extinction may represent a deficit in selective attention or divided attention depending on the task.

The traditional extinction paradigm involves brief presentations of stimuli presented either to the left or right of fixation. Two conditions present a solitary unilateral stimulus and two conditions present two bilateral stimuli simultaneously. Participants that show the extinction effect should have some level of success for contralesional stimuli, but that performance plummets in the bilateral presentation condition.

Versions of the traditional paradigm that require participants to identify or detect only a single stimulus while disregarding distractors reveal a deficit of selective attention with a spatial component. In this case, participants with extinction are challenged to inhibit selection of ipsilesional distractors to select contralesional targets. For these participants, the competition that arises from the ipsilesional distractor is too difficult for their impaired attentional systems to resist selecting over the contralesional target. Other versions of the traditional paradigm require participants to identify or detect all stimuli displayed in both unilateral and bilateral conditions. This challenges divided attention as well as selective attention because more than one stimulus has to be processed at once. Under conditions of divided attention, individuals with extinction face capacity limitations biased toward the contralesional side on top of the limitations of selective attention.

There is evidence that some degree of processing of extinguished stimuli occurs, indicating a deficit at later stages of visual processing. It has been shown that some individuals with extinction are able to determine if two bilateral stimuli are the same or different but perform much worse when tasked with identifying the same stimuli (Berti et al., 1992; Volpe et al., 1979). Other studies have determined that contralesional priming affects performance for ipsilesionally presented targets (Berti & Rizzolatti, 1992; McGlinchey-Berroth et al., 1993).

Several innovative studies have used the well-known Kanisza subjective figures to explore preattentive grouping processes in patients with extinction (Mattingley et al., 1997; Vuilleumier & Landis, 1998). Kanisza figures are shaded circles with a quarter segment removed (resembling a “Pac-Man”). When arranged in a group with their open angles facing each other, the corners of the open angles create an illusory new shape. In a study with one patient with extinction, Mattingley et al. (1997) displayed four Kanisza figures in a rectangular arrangement around fixation. The researchers manipulated the rotation of each of the figures to eliminate or create an illusory square that emerges when all open segments of the figures face each other. Their subject demonstrated poor perception of left targets under bilateral presentation, as expected. However, her extinction of leftward targets was essentially abolished when the open segments were arranged to form the illusion. These results suggest that preattentive processing of left-sided stimuli is still intact when they help to form a singular perceptual group, in this case an illusory rectangle.

If some degree of preattentive processing occurs for extinguished stimuli, diminished perceived salience of contralesional stimuli as compared to ipsilesional could be a contributor to errors. Therefore, extinction might be reduced if the relative salience of the contralesional target is amplified as compared to the ipsilesional target. Shalev, Chajut, and Humphreys (2005) introduced an extinction paradigm to manipulate the salience of contralesional stimuli and test the effects of cueing to spatial locations. Manipulations elicited effects supportive of a deficit in selecting among competing stimuli. A single participant, “YE”, who had right frontoparietal and occipital lesions from a multiple shell injury 30 years prior, was the sole subject in the study. He was diagnosed early on with dense homonymous hemianopia based on perimetry testing but had never been tested for neglect.

The experiments used the traditional extinction paradigm for simple detection of lateralized targets. The authors manipulated the size of the stimuli to modify their perceived salience. In the first experiment, they gradually increased the size of both left- and right-sided targets simultaneously. At all sizes, detection of ipsilesional targets was perfect. They found that YE’s accuracy for unilateral contralesional targets improved steadily as text size was increased. This improvement was not observed in bilateral conditions, however. In the second experiment, the authors stabilized the size of ipsilesional targets while increasing the size of contralesional targets. They found that YE’s performance in contralesional and ipsilesional bilateral conditions was equalized by this manipulation. In short, YE’s performance for unilateral contralesional targets in the first experiment improved because of enhanced sensory input. Performance for contralesional targets under bilateral conditions improved only when the relative salience of the contralesional target was increased. These findings suggest first that that the attentional deficit in extinction may be a result of diminished perceived salience of contralesional stimuli under competition; and, second, that effects of extinction can be reduced through modifications of relative salience.

Representational Deficits in Neglect

Some individuals with neglect show different effects at later stages of visual processing or when recalling a visual scene from memory. Such deficits can be thought of as representational in nature. But there is evidence that neglect can be demonstrated at a higher level of visual processing or in visual memory. They are framed together here as representational deficits.

Marr (1982) proposes three distinct stages of visual processing that allow us to form a complex three-dimensional map of the world around us. First, in primal sketch, the visual system processes the low-level information about a visual stimulus including color, edges, and size. Then, in 2.5D sketch, the visual system fills in some of the texture and detail of the primal sketch. Finally, in 3D model, the visual scene is interpreted as complete or an object is perceived as having its own left and right and top and bottom. Both primal sketch and 2.5D sketch can be thought of as viewer-centered representations while the 3D model stage is an object-centered representation.

Similar to Marr's perspective, Hillis & Caramazza (1995) propose three distinct levels of object-based visual processing of words. They report on a patient with right-sided neglect dyslexia, the reading impairment associated with spatial neglect, who tended to make errors on the ends of words. This is the expected error pattern, known as a unilateral paralexia. However, the patient consistently tended to commit errors on the end of the word whether it was presented normally, vertically, or mirror-reversed, indicating a deficit at a higher level of abstraction. Their three levels included a viewer-centered representation, a stimulus-centered representation, and a word-centered representation. Egocentric and allocentric frames of reference, discussed above, represent the elementary stages: viewer-centered and object-centered representations. But these frames of reference only pertain to the stimuli that hit the retina; they do not capture the representations of words and objects held in the mind's eye.

One of the most well-known accounts of neglect involves deficits to imagined space (Bisiach & Luzzatti, 1978). Two Italian patients with neglect were asked to describe from memory, details about the famous Piazza del Duomo in Milan. When told to imagine themselves standing at one end of the Piazza, they omitted features on the contralesional side from that vantage point. When they were asked to then imagine standing at the opposite end of the Piazza, turned 180°, they then described the features that were now positioned on their ipsilesional side. This account and other similar accounts since (e.g., Beschin et al., 1997; Cristinzio et al., 2009) indicate a deficit that exists not to visual memory of topographical space, but rather to spatial attention of that space within the mind's eye.

Anosognosia in Neglect

One common non-spatial aspect of the neglect syndrome is that a patient typically has a poor awareness of their own deficits, a condition known as anosognosia. Anosognosia is occurs alongside other neurological conditions such as Wernicke's aphasia or hemiparesis and is not always present in neglect. Years ago, it was considered to be in the family of neglect (Heilman, 1979), but lately it has been generally accepted as a separate condition (Appelros et al., 2007). It is included here because it shares overlap with the patient population and has a negative impact on rehabilitation outcomes. Anosognosia responds to several of the same treatments as neglect (Beschin et al., 2012; Cappa et al., 1987), is also moderated by both top-down and bottom-up processes (Prigatano, 2013), and can perhaps be thought of as a neglect of one's self and situation, or as a "neglect of the neglect."

Like neglect, anosognosia is heterogeneous and multimodal. For example, someone can have anosognosia to their hemiparesis but have intact awareness of their hemianopia or vice versa. They can also have awareness of certain neglect subtypes but not others. Also similar to neglect, anosognosia is induced by diverse lesion sites and is associated with large strokes (Appelros et al., 2007; Mort et al., 2003). It occurs more commonly in older persons, those with premorbid dementia, and those with right than left hemisphere damage. Theories of anosognosia have included psychological denial, confusion and emotion, impaired sensory feedback, and confabulation (Heilman et al., 1998).

Two notable theories of anosognosia are Geschwind's (1965) disconnection theory and Heilman's (Heilman, 1991) feedforward theory. In the disconnection theory, it was proposed that right hemisphere lesions disconnect sensory monitors from the language dominant left hemisphere. Lacking that information from the right, the left hemisphere fabricates responses to questions about its lesioned counterpart (Geschwind, 1965; Heilman et al., 1998). Heilman's (1991) feedforward theory is of particular interest because it proposes that anosognosia is tied to motor-intentional deficits as are certain subtypes of neglect. The theory states that recognition of failure is dependent on expectations; impairment is detected when there is a mismatch between expected and perceived movement. In the case of motor-intentional neglect such as hemihypokinesia, expectations for movement are impaired and thus the expected/perceived comparison never occurs (Heilman, 1991; Heilman et al., 1998).

The affective impairments in neglect, however, go beyond a lack of awareness. There is an apathy, a lack of logical concern, even a disdain for all things left. In the Bisiach and Luzzatti (1978) case study of the imagined descriptions of the Piazza del Duomo, they noted, "...something may be added about patient N.V.'s exposition of the parts of remembered scenes:

while central and right-sided items were enumerated in rather lively manner and sometimes dwelt upon, the few left-sided items were mentioned in a kind of absent-minded, almost annoyed tone" (p. 132). Kinsbourne (1987) described this phenomenon similarly: "The patient evaluates favorably whatever is rightward but denigrates the same stimulus when it is located on the left... They not only disdain to use left limbs, appearing not to regard them as useful, but refer to them with contempt or disgust, directly or in metaphor" (p. 74-5).

As anosognosia resolves, it is often replaced by anosodiaphoria, an indifference to disability with a distinct lack of emotional response. Over time, after repeated instances of those around them drawing awareness to their deficits, individuals may acknowledge that they indeed have an impairment but lack a personal buy-in on an emotional level. As symptoms of their neglect present in daily life and are commented on individuals will confabulate excuses. Many times, I have asked patients with neglect if they tend to ignore the left side of the world. They often respond with something to the effect of, "that's what they tell me." The acknowledgement is there, but the person's willingness or ability to make behavioral change is not. This phenomenon might be explained by an affective deficit or by an attentional or intentional deficit since many compensatory strategies inherently demand a high degree of endogenous control and overt orienting. As in most of the alternate perspectives presented throughout this paper, it is likely that both of these contribute to variable degrees in each individual.

Conclusions

Spatial neglect is a complex syndrome with effects that have a major impact on one's independence and quality of life. The variety of neglect behaviors and the multitude of double dissociations suggests that neglect is not a unified condition but rather is an umbrella term under which fall distinct deficits of spatial processing, selective attention, and/or divided attention.

Patients with neglect commonly have poor rehabilitation outcomes. Undoubtedly, features of the condition itself cause poor outcomes. However, they are likely also in part due to the challenges rehabilitation clinicians face associated with assessment and treatment planning at the level of specificity needed to affect function. Through a greater understanding of the specific subtypes of spatial neglect clinicians should be able to better tailor their treatment plan to include interventions that target the true underlying deficit that causes dysfunction.

Neglect of self or body		
	Hemiasomatagnosia, aka “body neglect”	Decreased spontaneous awareness of one’s contralesional body
	Somatosensory neglect	Decreased response to contralesional tactile and proprioceptive input
Neglect of peripersonal and extrapersonal space		
	Visual neglect, aka “pseudo-hemianopia”	Decreased response to contralesional visual stimuli
	Auditory neglect	Decreased response to contralesional auditory stimuli
	Representational neglect	Impaired memory/imagination of contralesional space
	Oculomotor-directional hypokinesia	Decreased visual exploration of contralesional space, and/or diminished contralesional eye movements
	Motor-directional hypokinesia	Decreased movement into or toward contralesional space, or decreased interaction with objects positioned in contralesional space
Neglect of objects and their spatial relationships		
	Allocentric neglect	Impaired processing of/attention to the contralesional side of individual objects regardless of their spatial position relative to the viewer
	Extinction	The phenomenon of the “extinguished” perception of a contralesional stimulus with the addition of an ipsilesional competitive stimulus
Other		
	Neglect dyslexia	Omissions of entire words nearest the contralesional margin of text; unilateral paralexic error pattern for individual words
	Anosognosia	Lack of insight into and decreased awareness of one’s deficits; can pertain to neglect but also seen with other neurologic impairments

Table 1.1. Subtypes of spatial neglect. The subtypes of spatial neglect as proposed in Chapter 1.

Chapter 2

Spatial and Attentional Contributions to Word Reading Errors in Patients with Neglect Dyslexia

Statement of Co-Authorship

As co-author of the manuscript entitled: “Spatial and attentional contributions to word reading errors in patients with neglect dyslexia” that had been prepared for submission to Cortex,

I confirm that Timothy Rich was the primary contributor to the study in each of the following areas:

- Design of the study
- Data collection
- Data analysis and interpretation of the findings
- Writing of the manuscript and critical appraisal of the content

Co-Author's Name	Co-Author's Signature	Date
John Palmer		8/12/2020

Patients with spatial neglect, a common and debilitating syndrome associated with stroke or brain injury, characteristically fail to respond to things positioned towards the contralesional side of space or the contralesional of two competing stimuli (Kerkhoff, 2001; Vallar, 1998). Neglect dyslexia is the reading impairment that results from spatial neglect, in which entire words nearest to the contralesional margin are omitted. At the individual word level, the typical error pattern, known as the unilateral paralexic error pattern, is characterized by omissions, substitutions, or additions on the contralesional letters within the word. In this study of patients with neglect dyslexia, we investigated the relative contributions of spatial processing and selective attention to errors in word reading.

The neuroanatomical epicenter of spatial neglect has been shown to be in the parietal lobe, along the angular gyrus near the temporoparietal junction, though it also occurs after infarcts to frontal or temporal lobes, thalamus, or the basal ganglia or the subcortical white matter tracts connecting these regions (Chechlacz et al., 2010, 2012; Corbetta & Shulman, 2011; Gillebert et al., 2011; Hillis et al., 2005; Mort et al., 2003; Ringman et al., 2004). The diversity of cortical and subcortical lesion sites suggests that neglect might be more accurately understood as a disconnection syndrome, in which critical cortical areas are unable to effectively coordinate to affect behavior (Bartolomeo et al., 2007). Left-sided spatial neglect after right hemisphere stroke is more common, more severe, and more persistent than right-sided spatial neglect after left hemisphere stroke (Kerkhoff, 2001). For this reason, in this study we consider only left-sided spatial neglect following right hemisphere stroke.

The errors in spatial neglect must be understood in both egocentric and allocentric spatial frames of reference. The egocentric frame of reference is relative to the viewer, anchored at the midline of the viewer. The allocentric frame of reference is relative to the midline of an object or groups of objects. With an egocentric frame of reference, patients with spatial neglect are expected to commit errors for stimuli positioned on their subjective left side. With an allocentric frame of reference, patients are expected to commit errors on the left side of an object or group of objects. This is expected even if that group is positioned on the patient's egocentric right side. Egocentric neglect has been shown to be more consistent with lesions to the dorsal stream of visual processing while allocentric neglect has been shown to be more consistent with lesions to the ventral stream (Hillis et al., 2005; Medina et al., 2008).

In addition to spatial neglect, patients with right hemisphere stroke are known to commonly have non-spatial attentional impairments (Adair & Barrett, 2008; Robertson, 2001; Van Vleet & DeGutis, 2013). These include deficits to selective, sustained, and divided attention. They are stereotypically distractible and have difficulty under dual task conditions – when dividing their attention between any two tasks. A generally low level of arousal and slowed information processing is also typical with this population. It is likely that these various impairments contribute to the errors seen in patients with spatial neglect and neglect dyslexia, but it is not known to what degree.

Here we consider two general perspectives on the deficits that underlie spatial neglect in general and reading errors in neglect dyslexia in particular. The first perspective is that a failure in spatial processing is the primary deficit. This perspective highlights the deficit for words positioned on the left. Accuracy improves along a gradient, with words positioned furthest to the right being read with the greatest accuracy. This plays out differently within egocentric and allocentric frames. Within an egocentric frame, spatial processing deficits may cause greater errors for target words positioned on the left side of the page or display, and within an allocentric frame they may cause greater errors on the left side of individual columns even if positioned on their egocentric right side. In the case of unilateral paralexic errors, this perspective points to the left-to-right gradient in accuracy within a single word that is characteristic of this error pattern as supportive evidence for a deficit of allocentric spatial processing.

The other perspective is that a failure in selective attention is the primary deficit. This perspective highlights that errors are due to the competition brought on by nearby additional words. This also can occur differently within egocentric and allocentric coordinates. Given an egocentric frame, errors are due to the competitive distractors positioned in their subjective left hemispace. Given an allocentric frame, errors are due to the competitive distractor word positioned to the right of the left-sided word.

One way to study the attentional contribution is the extinction phenomenon. Extinction is a phenomenon seen in many but not all patients with spatial neglect. The traditional psychophysical paradigm for extinction involves four conditions. Two conditions use a solitary stimulus, presented on either the left or the right side. The other two conditions are responses to the left or right stimuli when presented with an additional contralateral stimulus. Typically, a patient with extinction is able to accurately read the left- and right-sided solitary stimuli, but their reading of the left-sided stimulus is "extinguished" with the introduction of a right-sided distractor stimulus (Driver & Vuilleumier, 2001). One can imagine how extinction might play a role in the functional deficits observed in patients with spatial neglect, as the visual world around us is filled with many stimuli competing for our attention.

Previous Research on Extinction and Neglect Dyslexia

Several studies have examined if extinction plays a role in the word reading deficits observed in patients with neglect dyslexia. Siéroff and Michel (1987) showed that, for about one third of their sample of patients with stroke, accuracy for contralateral word reading was poorer in bilateral conditions than when presented solitarily on the contralesional side. This was one of the first demonstrations of extinction for words. Interestingly, several other patients demonstrated an ipsilesional extinction – the reverse effect – calling into question the laterality of this selective attention deficit.

Behrmann and colleagues (1990) showed that extinction for words is dependent on their physical separation. They compared reading accuracy for compound words with two distinct morphemes (e.g., “PEANUT” or “COWBOY”) when they were displayed with a space between the two morphemes (e.g., “PEA NUT”) to when they were displayed as one contiguous word (“PEANUT”) or with the two morphemes joined by an asterisk (“PEA*NUT”). Patients did much worse when there was a physical separation between the two morphemes than when they were displayed contiguously, suggesting that there is an effect of competition between two or more words displayed simultaneously. In this study, both words were displayed to the right of the central fixation cross, showing that extinction occurs even for competing words in the fully intact ipsilesional hemifield.

In both of these studies, subjects were required to read both of the displayed words. Siéroff and Urbanski (2002) set out to determine if extinction was caused by the mere presence of a competitive right-sided word or if identification of the right-sided word was a necessary factor in inducing extinction. The performance of patients with spatial neglect was compared to that of age- and cultural level-matched neurotypical controls. Patients all had full visual fields and were between one- and nine-months post-stroke.

In all conditions, subjects read aloud four-letter words presented on a computer monitor. After a subject fixated on a central cross, one or two words were briefly presented followed by a pattern mask. The duration of the presentation was adapted to each subject through a staircase method to equalize errors. Three blocked conditions were used: unilateral, a bilateral-x, and a bilateral-word condition. In the unilateral condition, a solitary word was presented either to left or right of fixation. In the bilateral-x condition, a target word was presented on the left or right with a contralateral string of four “x”. Subjects were to report only the word in the bilateral-x condition, not the string of “x”. In the bilateral- word condition, two words were presented simultaneously, one in each hemifield, and subjects read aloud both presented words.

The control group performed with near equal performance between left and right target conditions and a relatively small drop in accuracy in the bilateral conditions. The patients showed poorer accuracy for left target conditions than right and showed a larger drop in performance in bilateral conditions, especially for left-sided targets. The authors argued that the extinction phenomenon was observed because patients with neglect dyslexia have a “magnetic” attraction to ipsilesional stimuli. They stated that the presence of an ipsilesional distractor string of “x” was sufficient to cause extinction, suggesting a breakdown of selective attention.

In summary, Siéroff and Urbanski (2002) suggest that extinction plays a role in reading errors in neglect dyslexia due to the competition that arises between selection of two words. They showed that stimulus identification was not necessary to elicit extinction during lateralized presentation, but their paradigm demanded a covert shift of attention to the contralesional side. Behrmann et al. (1990) did not require this contralesional shift of attention but did require both words to be reported.

Our Question and Alternate Hypotheses

What remains unclear is if an extinction effect is observed in those with neglect dyslexia when words are presented foveally with context words to be ignored, as occurs during typical reading of a string of words within a block of text. During naturalistic reading, perhaps a greater number of errors are committed on the leftward margins of a block of text, in part, because of the competition that arises between each sequentially foveated word and the subsequent words on that line.

We consider four hypotheses to account for the errors observed in extinction experiments. The four hypotheses represent a 2x2 combination of the spatial processing and selective attention perspectives described above. These hypotheses are not mutually exclusive. First, consider the spatial processing perspective. This asserts that performance depends on space, with accuracy improving monotonically from left to right. Other words on the page may contribute to the frame of reference that is called upon, but the other words do not compete directly with the relevant word to cause errors.

The *egocentric space hypothesis* is the first of our four hypotheses. Under this hypothesis, the further a target word is positioned in the patient's left hemispace, the worse the accuracy. Similarly, the further a target is positioned in the patient's right hemispace, the better the accuracy. There is no effect of other words present on the page or display. If the page itself is moved into the patient's left hemispace, performance declines.

The *allocentric space hypothesis* shares the idea that there is a deficit in spatial processing that occurs along a left-to-right gradient. But this allocentric hypothesis is distinct from the egocentric in that space is defined relative to a group of words irrespective of the subjective midline of the patient. Errors occur because the words are positioned on the left side of an allocentrically framed group of words. From this view, patients commit errors because of the spatial position of the target word within an allocentric frame, whether that be a column, title, caption, or figure.

Next, consider the two hypotheses derived from the selective attention perspective, which are also subdivided between egocentric and allocentric frames of reference. The *egocentric competition hypothesis* asserts that there is a failure of selective attention that occurs more in the left side of egocentric space than in the right side. In other words, the left hemispace is more vulnerable to the effects of competition than the right hemispace. Under conditions of competition, words that are positioned on the left side of the subject's midline should have poorer accuracy than those positioned on the right.

Finally, by the *allocentric competition hypothesis*, patients commit left-sided errors because of a failure of selective attention that occurs for words in the left side of allocentrically defined space. These failures are due to an allocentric frame in which the competitive distractor word and the target word form a perceptual group. From this view, accuracy does not simply follow a left-to-right gradient, but rather occurs in a relative fashion, in which right-sided words are selected at the expense of left-sided words.

In this study, we examined the relative influence of space and attention on the word reading errors in patients with neglect dyslexia. In Experiment 1, we replicated the findings of the extinction studies described above to ensure that we had comparable methods and a comparable sample of patients.

In Experiment 2 we tease apart the effects of space and attention by displaying the target word at the fovea either solitarily or flanked by a single distractor word on its left or right. If patients show a decrement in word reading accuracy in conditions with a distractor word present, it is consistent with the competition hypotheses. Alternatively, if the position of the context word affects performance it is consistent with the allocentric space hypothesis. Finally, if there was no effect of distractor words, it is consistent with the egocentric space hypothesis.

The study also allows for analysis of letter position accuracy within words, to measure unilateral paralexic errors. The typical pattern of errors on the leftmost letters is consistent with the allocentric space hypothesis. In addition, the egocentric space hypothesis predicts a greater degree of unilateral paralexic errors for words that are positioned further into the left periphery. Though unilateral paralexic errors themselves suggest an allocentric frame of reference, there might still be a contribution of competition on unilateral paralexic errors. If that is the case, patients should show more unilateral paralexic errors in conditions with a distractor than in solitary conditions regardless of the spatial position of the words.

General Methods

Subjects

Twelve patients with right hemisphere stroke and spatial neglect were recruited from the inpatient and outpatient rehabilitation facilities of Harborview Medical Center in Seattle, Washington. Patients were considered for inclusion if they were identified as having left-sided spatial neglect by the rehabilitation physicians and therapists. Additionally, they were required to have intact visual fields and had corrected or uncorrected intermediate visual acuity of 20/50 or better. Potential recruits were excluded if they had a history of prior neurologic incident or left hemisphere infarct, aphasia or alexia, history of diagnosed or self-reported reading disability, intraocular disease or retinopathy, or diplopia. One patient's testing was aborted, and data were not included in analysis because his neglect had all but resolved in the few days between screening and testing. Another patient's data were not included in analysis because he required stimulus durations longer than 200 milliseconds to obtain an adequate level of accuracy.

Patient demographic data are presented in Table 2.1. Patients included five men and five women with an average age of 57±3 years old. Educational backgrounds ranged from 9th grade to

ID	Sex	Age (years)	Education	Type of stroke	Location of stroke	Weeks post-stroke
P-01	M	48	GED; Some trade school	R MCA aneurysm rupture	Frontal/ temporal	5
P-04	F	69	BA	R MCA occlusion	Insular/ parietal/ peri-ventricular	85
P-05	F	52	Some college	SAH and R temporal IPH following R MCA aneurysm rupture	Frontal/ temporal	11, 12
P-06	M	44	High school	R MCA occlusion	Frontal/ temporal/ parietal	4
P-07	M	72	High school	R IPH	Subcortical/ basal ganglia	2
P-08	F	46	Some college	R M1 and ACA occlusion	Basal ganglia	2, 3
P-09	M	55	9th grade	R IPH	Thalamic	2
P-10	F	67	MS	R IPH	Frontal/ basal ganglia/ uncal	150
P-11	M	75	MS	R IPH	Frontal/ parietal	3
P-12	F	47	High school	R MCA occlusion with small hemorrhagic conversion	Frontal/ temporal/ parietal	4

Table 2.1. Patient demographics. R=right; MCA=middle cerebral artery; SAH=subarachnoid hemorrhage; IPH=intraparenchymal hemorrhage; ACA=anterior cerebral artery.

an MS degree. Patients had a wide range of lesion sites, all affecting the right hemisphere. Most patients were seen within a few weeks of their stroke but two patients with chronic neglect (P-04 and P-10) completed testing 85 weeks and 150 weeks post-stroke.

At the time of enrollment, patients completed the Menu Reading and Article Reading subtests from the Behavioural Inattention Test (BIT; Wilson et al., 1987) and/or the Indented Paragraph Test (Caplan, 1987) to ensure they demonstrated neglect dyslexia. Patients' scores on these assessments are detailed in Table 2.2. Of note, our first patient subject (P-01) did not complete these tests as we modified the baseline assessment procedure after he had enrolled. That subject did demonstrate neglect dyslexia in clinical observation, however. The assessment scores of subject P-04 do not reflect a lateralized deficit; however, unilateral paralexic errors were observed during testing which are not captured by the scoring method of the Indented Paragraph Test. We decided to include these two patients based on our clinical judgment that they indeed had neglect dyslexia.

Control subjects were a convenience sample of students and faculty from the University of Washington. There were two groups of controls. One group, comprised of five subjects, completed testing in a laboratory setting prior to patient recruitment. One of these subject's data were excluded due to requiring longer than 200 milliseconds to obtain an adequate level of accuracy. This was probably because she was a non-native English speaker/reader. We therefore decided to subsequently include only native English speakers/readers in our samples. The second group of controls, comprised of three subjects, completed testing on the same equipment as our patient group and in comparable environmental conditions.

ID	BIT- menu	BIT- article	Indented Paragraph Test
P-01	9/9 (no errors)	9/9 (no errors)	n/a
P-04	9/9 (no errors)	9/9 (no errors)	12 errors L: 4% R: 3.5%
P-05	7/9 (mild)	7/9 (mild)	19 errors L: 9.6% R: 3.5%
P-06	9/9 (no errors)	7/9 (mild)	12 errors L: 2.4% R: 4.5%
P-07	9/9 (no errors)	1/9 (severe)	29 errors L: 12.8% R: 6.5%
P-08	1/9 (severe)	0/9 (severe)	42 errors L: 21.6% R: 7.5%
P-09	7/9 (mild)	5/9 (moderate)	174 errors L: 64% R: 47%
P-10	7/9 (mild)	5/9 (moderate)	47 errors L: 17.6% R: 12.5%
P-11	9/9 (no errors)	9/9 (no errors)	5 errors L: 3.2% R: 0.5%
P-12	0/9 (severe)	5/9 (moderate)	56 errors L: 36.8% R: 5%

Table 2.2. Patient baseline test scores. BIT=Behavioral Inattention Test (Wilson, Cockburn, & Halligan, 1987); Indented Paragraph Test (Caplan, 1987)

Stimuli and Apparatus

Target and distractor stimuli were drawn randomly from a list of 539 common English words, each four letters in length. All of the stimulus words were chosen because of their morphologic structure. That is, each word has one or more "orthographic neighbor" words, formed by the substitution or omission of the first letter of the word (e.g., CARE, DARE, and FARE were included since they all share -ARE). The use of such words was intended to increase the sensitivity to unilateral paralexic errors. All words were drawn randomly and were orthographically and semantically unrelated unless by chance.

Stimuli were briefly presented using custom MATLAB software (MathWorks, Natick, MA, USA) and the Psychophysics Toolbox (Brainard, 1997). Target and distractor words were presented at the horizontal meridian of the screen in all capital, white 24-point Courier font with variable luminance against a dark background. The first group of control subjects (n=4) completed testing in a psychology laboratory on the University of Washington campus. Stimuli were presented on a calibrated ViewSonic PF790 monitor with a maximum luminance of 104 cd/m^2. Room lighting was kept dim with an approximate black level of 1.0 cd/m^2. Subjects maintained a 60 cm distance from the monitor with the use of a chinrest to stabilize their head.

The second group of controls and patients completed testing in a secluded room at the hospital, a classroom at the University of Washington campus, or in their home. Stimuli were presented on a calibrated HP EliteDisplay E190i monitor with a maximum luminance of 216 cd/m^2. Low ambient lighting was kept consistent with the laboratory, with an approximate black level of 0.55 cd/m^2. Subjects maintained a 60 cm distance from the monitor by using a string tied to the base of the monitor to measure a distance to the tip of their nose. If the subject's position changed significantly, the experimenter remeasured with the string and either moved the monitor or asked the subject to move to a position to maintain the 60 cm distance.

Procedure

Figure 2.1 presents the sequence of stimulus presentation, consistent throughout both experiments. First, the subject fixated on a central cross. Control subjects used a keypress to advance the stimulus display while most patients used a verbal signal (e.g., “okay” or “ready”) because they often faced difficulty properly performing the keypress. After the keypress or verbal signal, the central cross disappeared, and an underline was presented as a pre-cue in the spatial position of the target stimulus for 0.016 seconds. Next, the target word appeared with or without a distractor word for a duration individualized for each subject; and, finally, an underline was again briefly presented in the target’s spatial position for 0.5 seconds as a post-cue. Pre- and post-cues were valid in 100% of trials. The subject responded verbally by saying aloud the underlined target word with no time constraint. The experimenter then confirmed or clarified the subject’s response by repeating the word back or confirming its spelling, especially in the case of potential homonyms. Finally, the experimenter typed their confirmed response into the computer.

Prior to each testing session, subjects were informed that all stimulus words were common English words, and all were four letters long. During testing, the control subjects were able to self-monitor to ensure their responses were four letters long and needed no reminders during testing. Patients, however, did make responses with shorter or longer words, albeit infrequently. We later modified their answers to reflect their omission or addition with an error symbol “X” in the letter position in which the error occurred, so that the analysis program could directly measure the accuracy of each of the four letter positions. Addition and omission errors were treated the same by the analysis program. Modifications always maximized the correct

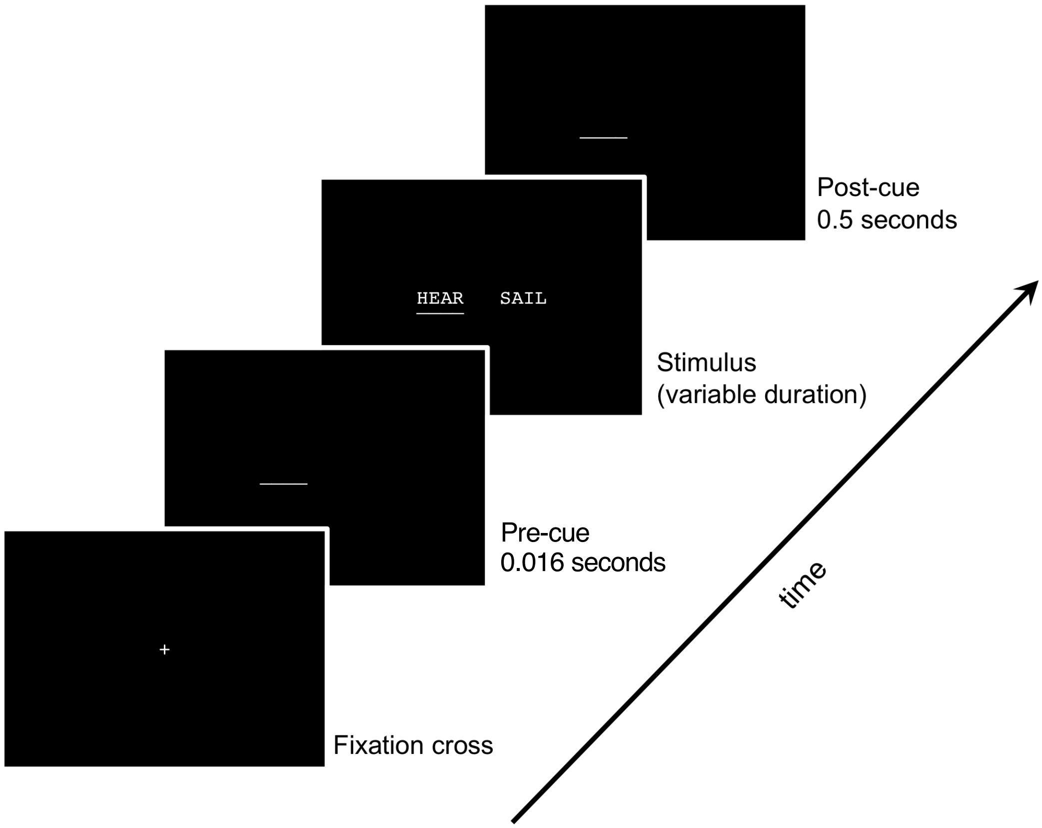

Figure 2.1. Stimulus sequence. This sequence was used in both experiments. First, subjects fixated on a central cross. After fixation, an underline was presented as a pre-cue for 0.5 seconds in the spatial position of the target word. The stimulus was then presented for a duration individualized for each subject with the underline remaining under the target word. Finally, the underline remained as a post-cue for 0.5 seconds.

letters in the correct letter positions when applicable. For example, in the case of an addition error such as the response “CHART” for the target “CART”, the modification entry would be “XART”; in the case of an omission error such as the response “SEE” for the target “SEEM”, the modification entry would be “SEEX”; in order to most accurately reflect letter position accuracy within an incorrect overall response.

Relative luminance and display durations were customized for each subject individually through the use of an informal staircase procedure. We used blocks of ten trials of solitary stimulus presentation and incrementally adjusted the relative luminance and display duration so that subjects’ performance was between 50 and 80% correct for whole-word accuracy. Display duration was kept below 0.2 seconds to prevent eye movements from occurring during the stimulus presentation.

Experiment 1

The purpose of Experiment 1 was to ensure that with our patient sample, our methods induced a similar extinction effect to that observed in prior studies. That is, we expected to see a decrement in accuracy for target words positioned on the left in all cases, but particularly when they were presented at the same time as a right-sided distractor word. Additionally, we sought to determine if the unilateral paralexic error pattern was seen even for right-sided target words, and if there was an effect of spatial position and/or competition on the occurrence of this error pattern.

Methods

The four conditions used in Experiment 1 are represented in Figure 2.2. In two conditions, represented in the top two panels of Figure 2.2, the target word was presented solitarily either to the left or right (solitary left target condition and solitary right target

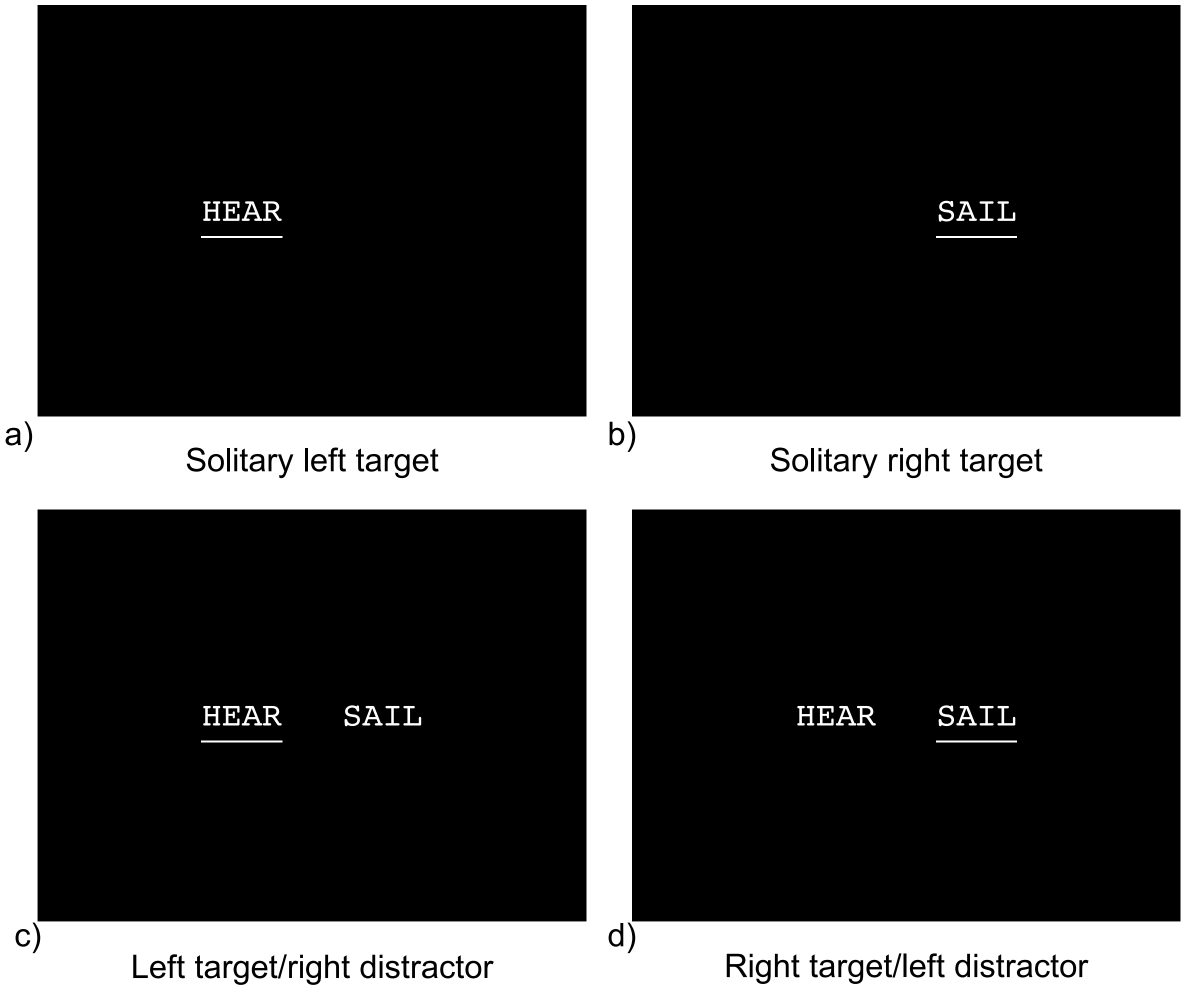

Figure 2.2. Experiment 1 conditions. The four conditions of Experiment 1 included: a) a solitary left target condition; b) a solitary right target condition; c) a left target/right distractor condition; and, d) a right target/left distractor condition.

condition). In the other two conditions, represented in the bottom two panels, a distractor word was presented simultaneously on the opposite side (left target/right distractor condition and right target/left distractor condition). For all of our patients and two of our controls, targets and distractors were positioned with their midpoint 1.5° to the left or the right of the central fixation cross. Four of the early controls were tested on a different apparatus with 3° spacing and our first control tested on the primary apparatus with 2° spacing as we made minor adjustments to the details of the experiment. Conditions were randomized in blocks of 72 trials, with patients completing 3-5 blocks for a total average of 268 trials and controls completing 1-2 blocks for a total average of 134 trials. For patients, a mean 0.1% of trials were discarded due to the occurrence of an eye movement, subjects reporting they were not ready or were not paying attention, or operator error.

Results

Data from seven control subjects and six patients were included in these analyses. Controls required a mean 34% relative luminance and a mean duration of 0.11 seconds while patients required a mean 87% relative luminance and a mean duration of 0.18 seconds to achieve 50-80% accuracy in the solitary word conditions. In the right solitary condition, easiest for both groups, controls had a mean 76.2±4% correct while patients had 65.4±8.7% correct. Thus, performance was roughly matched for the right solitary word condition. In summary, to match performance patients needed substantially higher relative luminance and longer display durations to achieve comparable accuracy to controls.

In Figure 2.3, mean whole word reading accuracy is plotted for controls in the left panel and for patients in the right panel. Within each panel, left target conditions are plotted on the left and right target conditions on the right. The solitary conditions are shown by filled symbols and

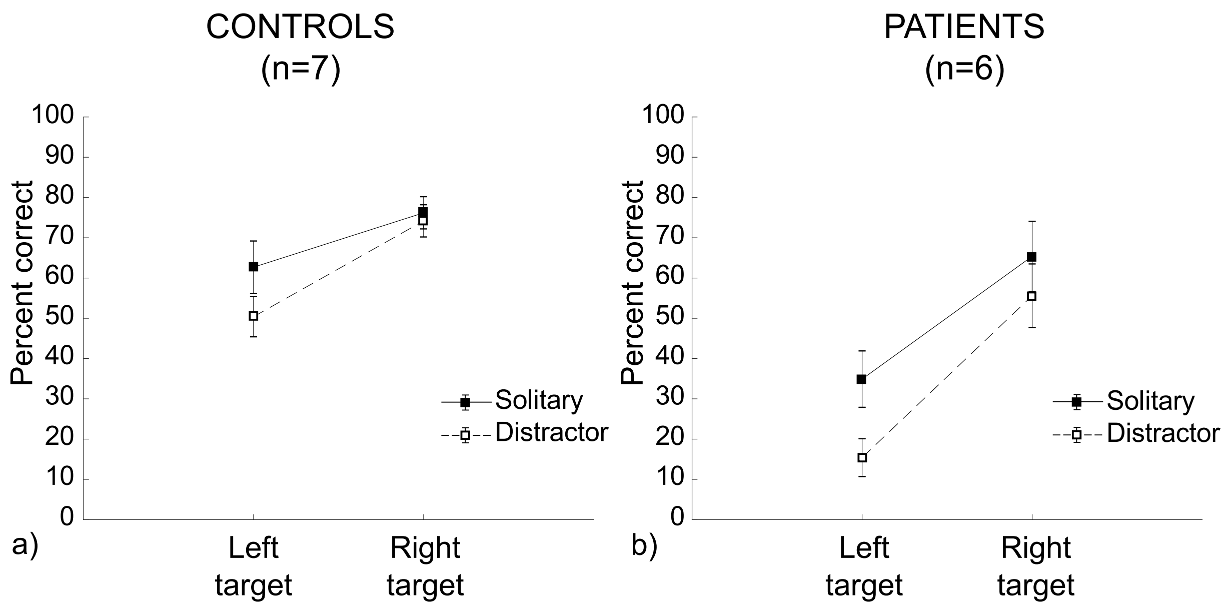

Figure 2.3. Experiment 1, whole word accuracy results. Whole word accuracy in percent correct is plotted as a function of target location. The filled symbols joined by a solid line are the two solitary conditions and the open symbols joined by a dashed line are the distractor conditions. a) Controls showed poorer performance for left-sided target words than right and had a decrement in performance with the addition of a distractor. b) Patients showed a larger difference between left and right-sided targets and a more severe decrement in accuracy with the addition of a distractor.

joined by a solid line and the distractor conditions are shown by open symbols and joined by a dashed line. In the solitary conditions, controls had a mean 62.7±6.5% and 76.2±4% correct for left- and right-sided targets, respectively, an unreliable difference of 13.5±9.3% ($t(6)=1.5$, $p=0.1$). In the distractor conditions their accuracy dropped to a mean 50.4±5% correct in the left target/right distractor condition and 74.2±4% correct in the right target/left distractor condition, a reliable difference of 23.8±8% ($t(6)=3$, $p=0.007$). The effect of adding a distractor was 12.3±2.5% lower accuracy for left-sided targets ($t(6)=5$, $p=0.007$) and 2±0.1% lower accuracy for right-sided targets ($t(6)=1$, $p=0.012$). The difference of these differences was a mean of 10.3±3.5% ($t(6)=2.9$, $p=0.013$).

In the solitary conditions, patients had a mean 34.9±7% and 65.4±8.7% correct for left- and right-sided targets, respectively, a reliable difference of 30.5±6.1% ($t(5)=5$, $p=0.002$). In the distractor conditions, patients had a mean 15.4±4.7% and 55.6±7.9% correct for left- and right-sided targets, respectively, a reliable difference of 40.2±5.7% ($t(5)=7.1$, $p<0.001$). The effect of adding a distractor was 19.5±3.6% lower accuracy for left-sided targets ($t(5)=5.5$, $p<0.001$) and 9.8±1.5% lower accuracy for right-sided targets ($t(5)=6.4$, $p<0.001$). The difference of these differences was a mean of 9.7±3.9% ($t(5)=2.5$, $p=0.027$).

In summary, controls showed poorer performance for left-sided target words than right and had a decrement in performance with the addition of a distractor. Patients showed a larger difference between left and right-sided targets and a more severe decrement in accuracy with the addition of a distractor. These results are generally consistent with those of Siéroff and Urbanski (2002).

Next, consider the within-word error patterns shown by each group. In Figure 2.4, individual letter accuracy is plotted as a function of its position within the word when all

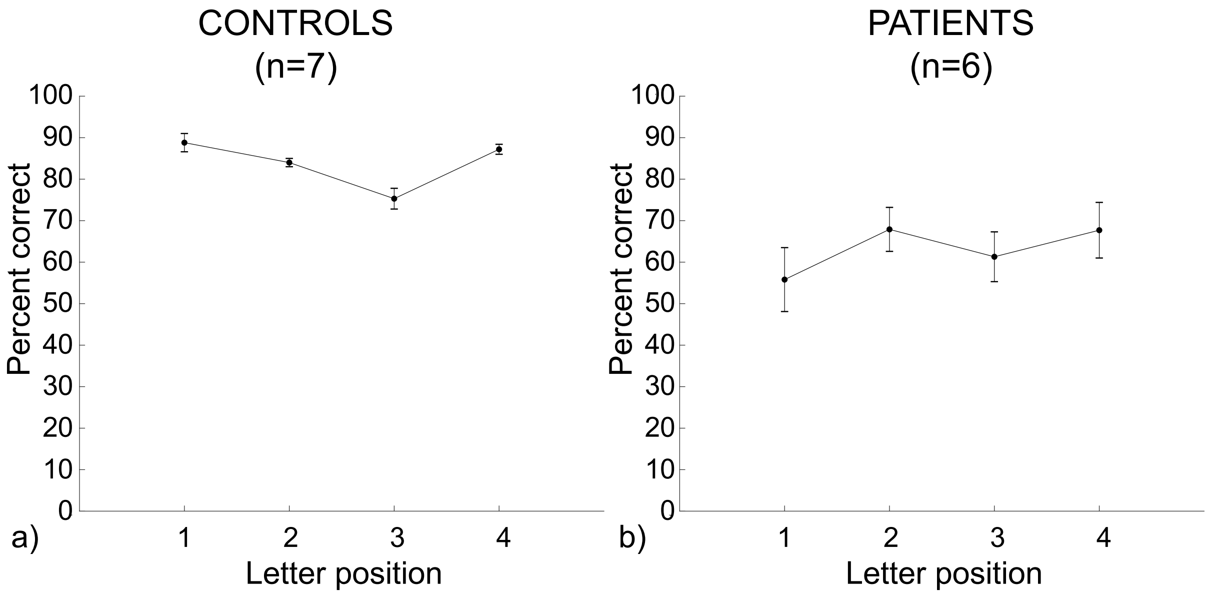

Figure 2.4. Experiment 1, letter position accuracy results, combined conditions. Accuracy in percent correct is plotted as a function of each of the four letter positions within the word. These data are collapsed from all four conditions. a) Controls showed the typical U-shape error pattern, with greatest accuracy for the first and last letters of words. b) Patients showed the unilateral paralexic error pattern, with poorest accuracy for the first letter position and greatest accuracy for the fourth letter position.

conditions are combined. Controls showed a U-shaped error pattern, with greatest accuracy on the first and fourth letter positions. Patients showed the unilateral paralexic error pattern with poorest accuracy on the first letter and greatest on the fourth. To measure unilateral paralexic errors we calculated the mean difference between the accuracy on the fourth letter position and the first. Controls showed no reliable difference (-1.6±2.3%; $t(6)=-0.7$, $p=0.26$) while patients performed with 11.9±4% greater accuracy on the fourth letter position than the first ($t(5)=3$, $p=0.015$).

Figure 2.5 shows that both groups had a consistent within-word error pattern regardless of target position. In this figure, letter accuracy is plotted as a function of both its position within the word and the four main conditions. Left target conditions are shown on the left side of each panel and right target conditions are shown on the right. The solitary conditions are shown by filled symbols connected by a solid line and distractor conditions are shown by open symbols connected by a dashed line. Controls showed the U-shaped error pattern and patients showed the unilateral paralexic error pattern regardless of the side of the target word and the presence of a distractor. One-way analyses of variance show no significant difference for controls ($F(3,24) = 0.52$, $p=0.67$) and patients ($F(3,20)=0.89$, $p=0.46$) in the relative accuracy of the fourth and first letter positions between the four conditions.

Discussion

For whole word accuracy, we found similar results to previous studies, suggesting that our methodology was sound, and our patient sample was representative of the population of interest. Patients and controls both did worse for left-sided than right-sided words, but patients showed a larger effect of space and distractors.

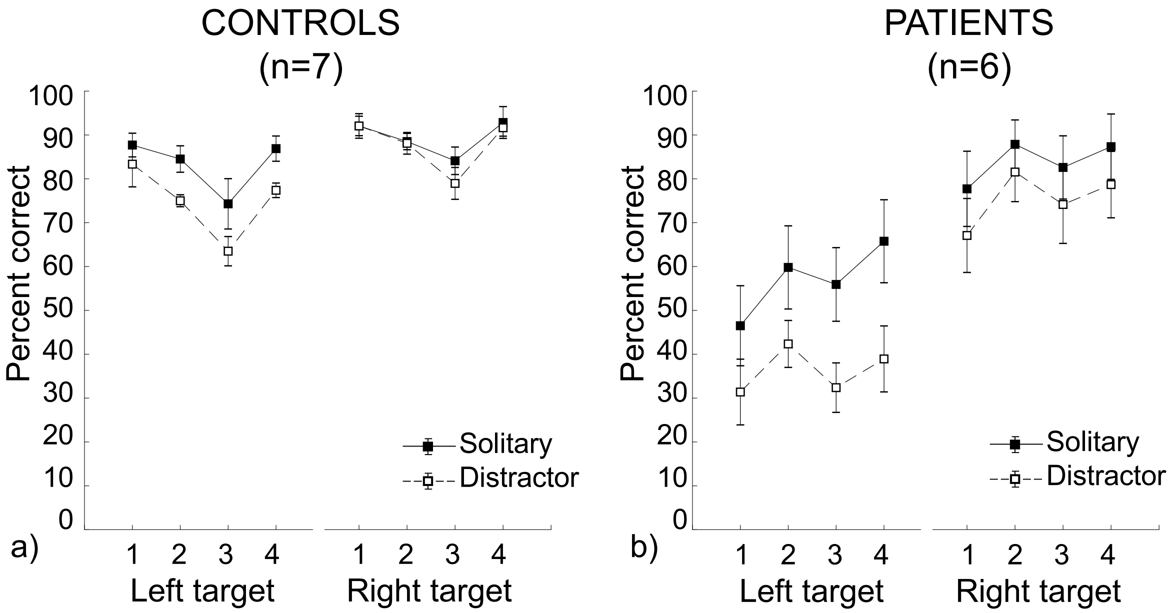

Figure 2.5. Experiment 1, letter position accuracy results, by condition. Accuracy in percent correct is plotted as a function of each of the four letter positions within the word. Left target conditions are shown on the left half of each panel, right target conditions on the right half. Solitary conditions are shown by filled symbols and joined with a solid line and distractor conditions are shown by open symbols and joined with a dashed line. a) Controls showed the U-shaped error pattern in all four conditions. b) Patients showed the unilateral paralexic error pattern in each of the four conditions.

Proponents of the competition hypotheses point to the effect of distractors as evidence of extinction for word reading. However, there are two issues with this paradigm that leave that interpretation unclear. First, both spatial position and competition are at play at the same time in all conditions. In particular, the distractor word might have changed the relative position of the target word due to an allocentric frame of reference. Thus, this experiment does not rule out a purely spatial account. Second, naturalistic reading does not occur parafoveally. We move our eyes to each word or group of words in sequence. These two limitations of the traditional paradigm were motivation to modify the extinction paradigm to have a foveal target word.

Experiment 2

Experiment 1 showed that there is a large contribution of space for our patients with neglect dyslexia: they did much worse for left-sided targets as compared to right-sided. It also showed that there was an effect of presenting two words: they did worse in the distractor conditions, especially for left-sided targets. However, the paradigm used in Experiment 1 cannot tease apart effects of space versus effects of competition because both of those elements are at play.

The main tenet of the spatial processing perspective is that patients with neglect dyslexia do worse on left-sided words and that is unsurprisingly what happened in Experiment 1. But Experiment 1 was unable to distinguish whether this left-right effect occurs within the egocentric or allocentric frames of reference. This is because with peripheral words in the distractor conditions, the egocentric and allocentric frames make the same predictions. The absolute spatial position of the target word changes within the egocentric frame, but the relative spatial position of the target word also changes with the addition of a distractor word within the allocentric frame.

The main tenet of the selective attention perspective is that competition from the other words causes errors. This is also consistent with Experiment 1: patients did worse in the distractor conditions. But what remains unclear is if the poorer performance observed in the left target/right distractor condition is because selective attention deficits are worse with the presence of distractors or because the distractor word changed the allocentric frame of reference. In Experiment 2, we modified the task by always presenting the target word centrally in an effort to distinguish between our hypotheses.

Methods

Figure 2.6 shows the three conditions used in Experiment 2: a solitary central condition, in which the target word was presented at fixation; and two distractor conditions, in which a left-sided or right-sided distractor word was presented alongside the central target word. Distractor words were positioned with their midpoint 2.5° away from the midpoint of the central target word for all patients and two controls. Distractor words for three early controls were positioned with their midpoint 3° from the midpoint of the central target word prior to the researchers making minor adjustments to the details of the experiment with a different apparatus. Trials were randomized in blocks of 72 trials, with controls completing 1-2 blocks for an average of 134 trials and patients completing 3-8 blocks for an average of 318 trials. For patients, a mean 0.4% of trials were discarded due to the occurrence of an eye movement, subjects reporting they were not ready or were not paying attention, or operator error.

As in Experiment 1, relative luminance and display durations were customized for each subject. We used blocks of ten trials of solitary central stimulus presentation, adjusting the relative luminance and display duration until performance was between 50 and 80% correct. These relative luminances and display durations were used for central targets throughout

Figure 2.6. Experiment 2 conditions. The three conditions of Experiment 2 included: a) a solitary central target condition; b) a central target/right distractor condition; and, c) a central target/left distractor condition. Note that the central target word has a reduced relative luminance as compared to the distractor words.

Experiment 2. The distractors were presented at a relative luminance of 3x that of central targets to equalize their visibility, based on a pilot experiment completed with our first group of control subjects (see Appendix).

Predictions

Figure 2.7 represents the predictions of the four hypotheses for whole word accuracy when applied to the conditions of Experiment 2. Whole word accuracy is plotted against the relative location of the target word. The solitary central target condition is plotted in the middle position, the central target/right distractor condition is plotted on the left side because the target word is in the relative left position, and the central target/left distractor condition is plotted on the right side.

First, consider the perspective that the primary deficit in neglect dyslexia is one of spatial processing. By the egocentric space hypothesis, errors are due to their leftward spatial position within the egocentric frame of reference and there is no effect of competition from distractor words. The central spatial position of the target word in all conditions of Experiment 2 means that spatial orienting within the egocentric frame of reference is not required for the task. Therefore, as shown in the top left panel of Figure 2.7, whole-word accuracy across conditions should be equivalent.

By the allocentric space hypothesis, word reading errors are due to their leftward spatial position within an allocentric frame of reference and there is no effect of competition from distractor words. In Experiment 2 the allocentric frame changes in each condition. The target is central in the solitary condition; it is in the relative left position in the central target/right distractor condition; and it is in the relative right position in the central target/left distractor condition. In Figure 2.7, the allocentric space hypothesis is represented in the top right panel.

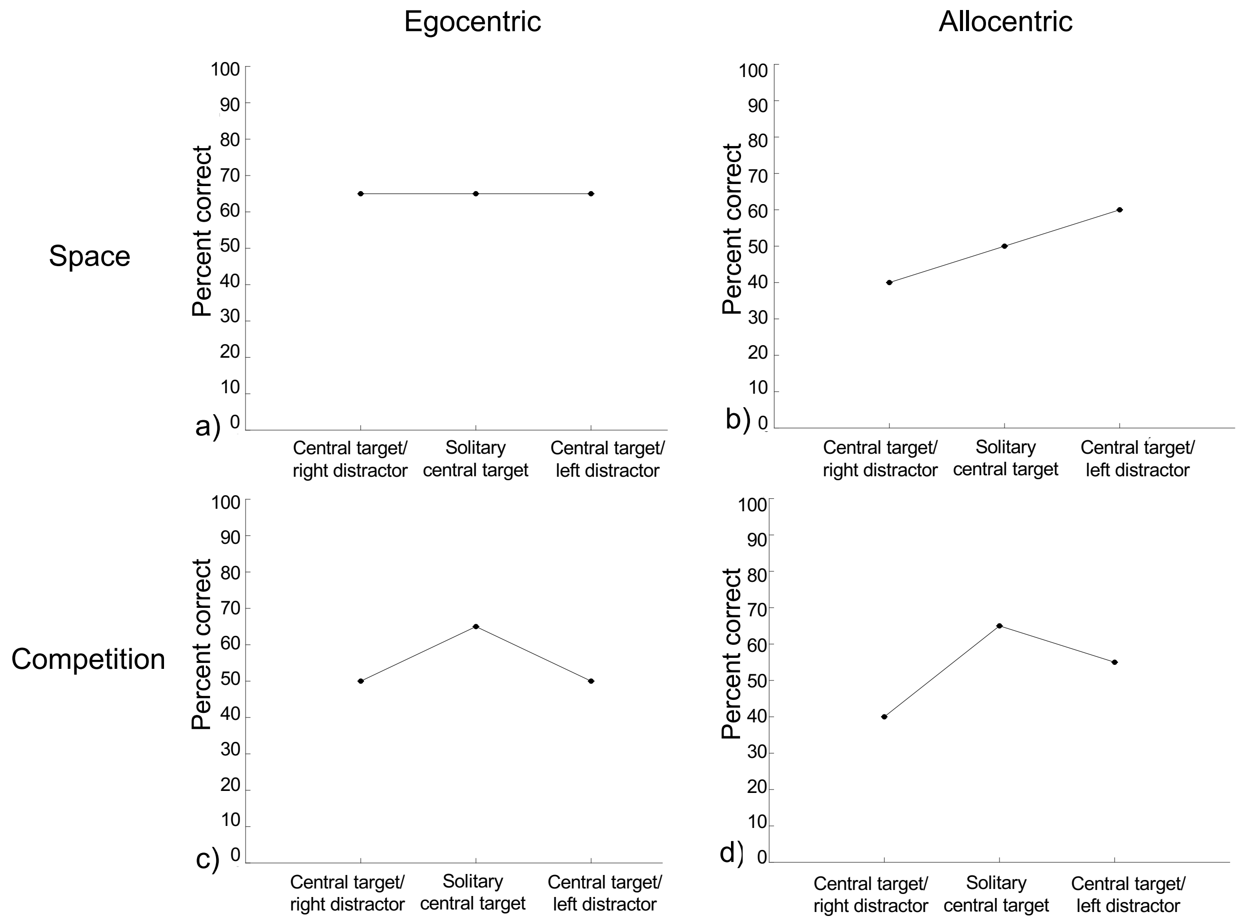

Figure 2.7. Predictions for Experiment 2. Whole word accuracy is plotted against the relative spatial position of the target word. a) The egocentric space hypothesis predicts equivalent performance between conditions; b) the allocentric space hypothesis predicts worst performance in the central target/right distractor condition, intermediate performance in the solitary central target condition, and best performance for the central target/left distractor condition; c) The egocentric competition hypothesis predicts best performance for the solitary central condition and equivalent effects of right- and left-sided distractors; and, d) The allocentric competition hypothesis predicts an advantage for the solitary central target and an advantage to the left distractor condition. The relative size of these advantages is not predicted.

Performance follows a left-to-right gradient within the allocentric frame, with worst accuracy when the target word is positioned on the left side relative to the right-sided distractor and best accuracy when the target word is positioned on the right side relative to the left distractor.

Next, consider the perspective that the primary deficit is one of selective attention. The egocentric competition hypothesis asserts that the left hemispace is more susceptible to errors due to a selective attention deficit. Distractors to the left and right sides of the target cause equivalent interference because the allocentric frame is not relevant. The prediction of the egocentric competition hypothesis is represented in the bottom left panel of Figure 2.7. Whole word accuracy suffers under conditions of competition, regardless of the side of the distractor. There is no effect of space in this experiment because the target word remained in the same central egocentric position in all conditions.

Finally, in the allocentric competition hypothesis, patients commit left-sided errors due to a failure of selective attention between multiple words. Parafoveal distractors positioned to the right of the target put the target in the relative left position within an allocentric frame. Similarly, distractors to the left put the target in the relative right position. The bottom right panel of Figure 2.7 shows the predictions of this hypothesis. The extinction effect is predicted for whole word accuracy in the central target/right distractor condition. There are two parts to this prediction. The distractor conditions on average should have more errors than the solitary condition. In addition, the left distractor condition should have more errors than the right distractor condition. The general hypothesis does not say which of these effects is larger.

Results

As in Experiment 1, we matched difficulty for the controls and patients in the solitary central target condition through manipulation of display durations and relative luminance.

Accuracy in the solitary central condition was 61.9±6% for controls and 60.5±3.3% for patients. To obtain this matched level of difficulty, we used for the controls a mean 2% relative luminance and mean display duration of 0.03 seconds; for the patients we used a mean 32% relative luminance and a mean display duration of 0.08 seconds. In short, patients needed substantially higher relative luminance and longer display durations to achieve comparable accuracy as controls.

In Figure 2.8, the mean accuracy is plotted for the three conditions of central target/right distractor, solitary central target, and central target/left distractor in the same manner as our predictions in Figure 2.7. Controls are presented in the left panel and patients are in the right panel. There are no reliable effects for the controls but there is one effect for the patients.

Consider first the effect of distractor regardless of side. Control subjects showed little or no effect of distractors, with a mean 61.9±6% for solitary and 66.1±4.6% for distractor conditions, a difference of -4.0±2.9%. This difference was not reliable ($t(6)=-1.45$, $p=0.1$). In contrast, patients showed a decrement in accuracy in distractor conditions as compared to the solitary central condition. They had a mean of 60.5±3.3% for the solitary central condition and combined mean of 53.3±4.1% for the distractor conditions, a reliable difference of 7.3±2.7% ($t(9)=2.7$, $p=0.012$).

Next, consider the effect of left versus right distractor. Neither controls nor patients showed a reliable difference in accuracy for the left versus the right distractor condition. Controls had a mean accuracy of 66.4±4.3% in the central target/right distractor condition and 65.8±5.1% in the central target/left distractor condition, a difference of -0.6±2.1% ($t(6)=-0.3$, $p=0.396$). Patients had a mean accuracy of 54.1±4.9% in the central target/right distractor

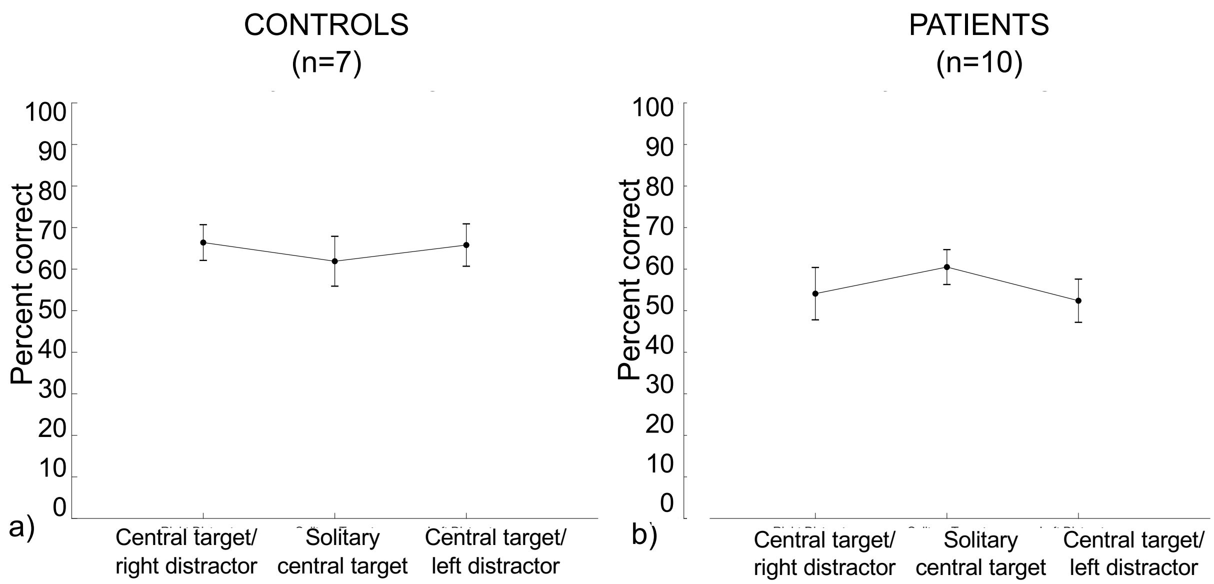

Figure 2.8. Experiment 2, whole word accuracy results. Whole word accuracy is plotted against relative target location. a) Controls showed equivalent performance between conditions; b) patients showed a small but reliable decrement in performance for both right and left distractor conditions as compared to solitary.

condition and 52.4±4.1% in the central target/left distractor condition, a difference of -1.6±3.6% (*t*(9)=-0.46, *p*=0.328).

Finally, consider where in the word the errors occurred. In Figure 2.9, accuracy is plotted as a function of letter position of an error. These data are collapsed from all three conditions. The controls repeat the U-shaped pattern, with equivalent accuracy for the first and last letter positions (90.4±2.7% and 90.4±3.1%, respectively). In contrast, patients repeat the same unilateral paralexic error pattern as found for them in Experiment 1. They had a mean of 66.7±3.9% for the first letter position as compared to 83.4±4.2% for the fourth letter position, a reliable difference of 16.8±4.6% (*t*(9)=3.6, *p*=0.003).

In Figure 2.10, there is a consistent within-word error pattern for central target word reading across the three conditions. Letter position accuracy is plotted based on the relative position of the target word with the right distractor condition on the left side of each panel, the solitary condition in the middle, and the left distractor condition on the right. Both control and patient groups again showed the U-shaped and unilateral paralexic error pattern, respectively, regardless of the presence of a distractor. One-way analyses of variance show no significant difference for controls ($F(2,18) = 0.4$, p=0.67) and patients ($F(2,27)$=0.61, p=0.55) in the relative accuracy of the fourth and first letter positions between the three conditions.

Discussion

There are four main results of Experiment 2. First, patients show a deficit in foveal reading relative to controls similar to what was observed in Experiment 1 with parafoveal reading. Patients needed substantially greater relative luminance and display duration than controls to achieve comparable level of accuracy.

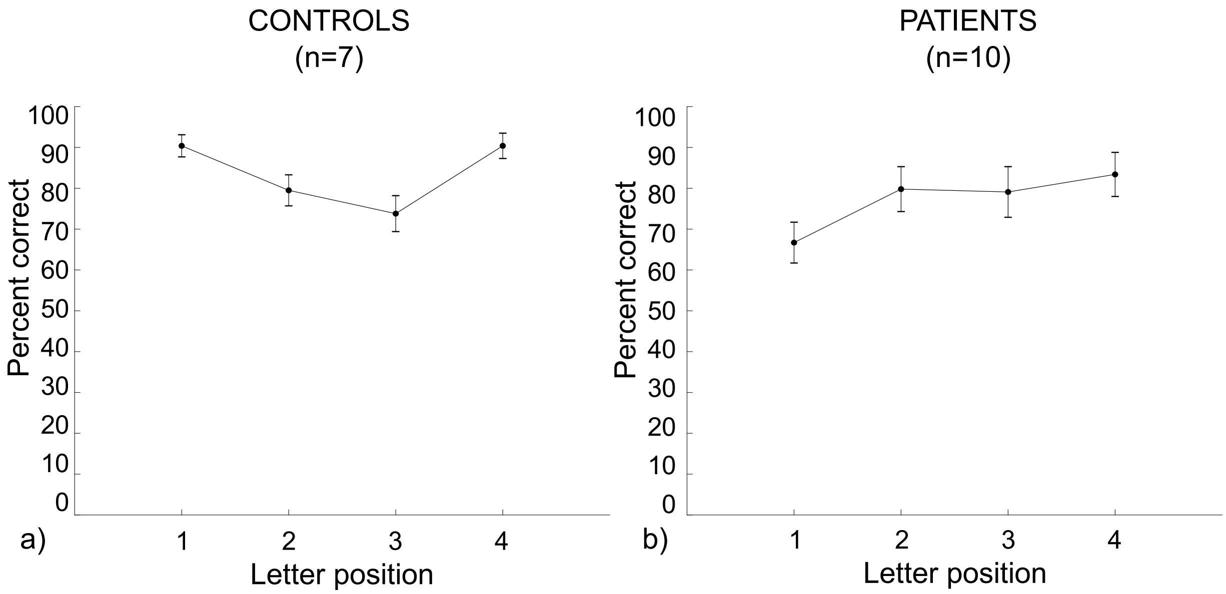

Figure 2.9. Experiment 2, letter position accuracy results, combined conditions. Accuracy in percent correct is plotted as a function of each of the four letter positions within the word. These data are collapsed from all three conditions. a) Controls showed the typical U-shape error pattern, with greatest accuracy for the first and last letters of words. b) Patients showed the unilateral paralexic error pattern, with poorest accuracy for the first letter position and greatest accuracy for the fourth letter position.

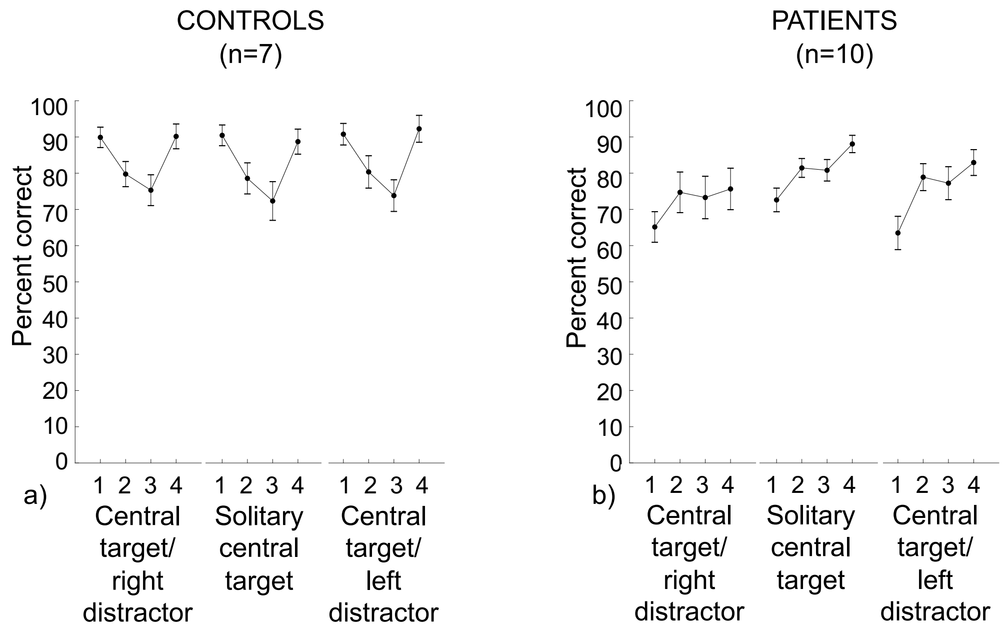

Figure 2.10. Experiment 2, letter position accuracy results, by condition. Accuracy in percent correct is plotted as a function of each of the four letter positions within the word. The central target/right distractor condition is on the left side of each panel, the solitary central condition is in the middle, and the central target/left distractor condition is on the right. a) Controls had the U-shaped pattern consistently in all conditions. b) Patients had the unilateral paralexic error pattern in all conditions.

Second, patients show an effect of distractors that was not found for controls. This result is consistent with the predictions of the egocentric competition hypotheses. It is not consistent with either of the two spatial hypotheses.

Third, neither controls nor patients showed an effect of the distractors being to the left or right of the foveal targets. This is quite unlike the large effect found for parafoveal targets in Experiment 1. It is not consistent with either of the allocentric hypotheses.

Fourth, errors by letter position within a word followed different patterns for controls and patients. Patients showed a clear deficit for the left side of words while controls consistently showed the U-shaped pattern with greatest accuracy for the first and last letters. This is consistent with the allocentric space hypothesis as it was seen irrespective of its position in egocentric space and irrespective of the presence of distractors.

General Discussion

In this study, we investigated the relative influences of space and attention on word reading errors in patients with neglect dyslexia. We completed two experiments. Experiment 1 was a replication of studies that used the traditional extinction paradigm for words with lateralized targets and distractors, to ensure our patient sample and methodology were consistent with prior studies. Experiment 2 used a modified paradigm in which the target word was always positioned centrally, with and without a flanking distractor word. Always presenting the target word at the fovea controlled the effects of spatial processing while measuring the effects of attention. It also allowed us to distinguish the predictions of the egocentric and allocentric frames of reference. Finally, the central position of the target word provided an experience more representative of naturalistic reading.

We considered four hypotheses to guide this research. The egocentric space hypothesis asserts that errors are due to the spatial position of the target word relative to the subject. The allocentric space hypothesis asserts that errors are due to the spatial position of the target word within an allocentric frame surrounding the word(s). The egocentric competition hypothesis asserts that the left side of egocentric space is more susceptible to the effects of competition. And, finally, the allocentric competition hypothesis asserts that errors are due to competition when the target word is positioned to the relative left side of a pair of words.

Our findings can be summarized as follows. In Experiment 1, our results were consistent with the literature. Patients had worse performance for left-sided targets than right-sided. In addition, performance was worse in the presence of a distractor word. This second effect has been described as the extinction phenomenon and has been suggested to be evidence of a competition effect. However, in the left target/right distractor condition, both spatial position and competition are at play at the same time. In Experiment 2, patients showed significantly poorer accuracy in both left distractor and right distractor conditions compared to a solitary central target.

For whole word reading accuracy, our findings are consistent with the egocentric competition hypothesis because errors were greatest with distractors in both experiments and were more pronounced on the left than right in Experiment 1. By this interpretation, reading errors in neglect dyslexia are due to a primary deficit of selective attention that is more severe for words positioned in left egocentric space than right. Words positioned closest to the left margin are under the heaviest influence of competition, followed by centrally positioned words, and words positioned closest to the right margin are under the least influence of competition.

However, there is an alternative interpretation that includes an additional allocentric contribution. As mentioned above, our task in Experiment 1 was different than that used by Siéroff and Urbanski (2002) and others because we required subjects to read only one word while previous authors had their subjects read both words. As a result, it is possible that in Experiment 2 the distractor word did not effectively contribute to creating an allocentric frame because it was never relevant. In other words, the visual system might have been able to more effectively disregard the distractor words because their spatial positions were not relevant to the task at hand. If this is the case, it leaves open the possibility that our results would also be consistent with a modified allocentric hypothesis, in which the allocentric frame is defined by the attended words and not the unattended words. But this idea does not eliminate the fact that irrelevant words do affect performance.

Another alternative interpretation is that patients with neglect dyslexia experience two distinct deficits – one of spatial processing and another of selective attention – that occur independently of each other and contribute separately to whole word reading errors. We observed left-right differences in performance that clearly indicate a spatial processing deficit. We also observed an effect of competition that was not limited to right-sided distractors, indicative of a selective attention deficit. Rather than a single process of spatially biased selective attention, these effects might be due to two separate processes: a failure of selective attention that is not spatially biased and an independent spatial deficit for the left side.

Our findings for within-word letter accuracy are supportive of an allocentric contribution. Controls and patients both showed a consistent error pattern that was not dependent on egocentric spatial position. Controls showed the U-shaped pattern while patients showed the unilateral paralexic error pattern regardless of whether the target was positioned on the left, at center, or on the right; and whether or not distractors were present. This suggests that the target word was processed as an allocentrically framed perceptual unit. The rate of errors was higher for left-sided target conditions and distractor conditions but the shape and magnitude of the unilateral paralexic error pattern remained unchanged. The egocentric hypotheses do not account for this consistency between conditions.

In summary, we found that multiple deficits contribute to the reading errors made by patients with neglect dyslexia. They performed most consistently with the egocentric competition hypothesis, which asserts that left-sided egocentric space is more susceptible to the effects of distractors. However, the consistency between conditions with which patients showed the unilateral paralexic error pattern points to an additional allocentric contribution.

Approaches in Rehabilitation

A difficult but critical task for rehabilitation clinicians who work with patients with stroke and other neurologic conditions is to determine the underlying neuromotor and/or neurocognitive deficits that cause an impairment in participation in the various activities of one's daily life. Though quite common, spatial neglect is well-known to clinicians as being a poorly understood condition. This is in part because it is also an umbrella term under which falls a wide variety of behaviors that share only a deficit to the left. In this study we used a version of the extinction paradigm that more accurately reflects naturalistic reading in an effort to inform potential interventions that might be useful to clinicians. Currently, there are some interventions for spatial neglect and/or neglect dyslexia that address spatial processing deficits and other interventions that address selective attention deficits. But to our knowledge there is not yet an intervention that combines these two factors, which our findings suggest may be necessary.

Some interventions address a possible spatial deficit. For example, optokinetic stimulation is an intervention studied widely in patients with spatial neglect. It typically uses an array of dots or other visual stimuli that constantly moves across the display either from left to right or right to left. It is intended to elicit optokinetic nystagmus, the after-effects of which create an illusory shift of egocentric space. In the case of left-sided spatial neglect, stimuli that move from right to left will produce the desired after-effect of moving the left hemispace further toward the right.

Another intervention that shifts the perception of egocentric space is prism adaptation treatment. Patients complete a series of short sessions in which they wear goggles with unidirectional prismatic lenses while completing visuomotor tasks. The lenses cause a shift of the entire visual scene in one direction, and, over time, the visual system adapts to this shift and creates a new subjective midline. When the goggles are removed, the adaptation causes an after-effect that shifts the visual scene in the opposite direction. The results of studies using this intervention in the general spatial neglect population are mixed. Unfortunately, these kinds of spatial interventions cannot address all of the deficits found in this study.

As applied to our results, these spatial approaches might improve performance on left-sided words by shifting the perceived egocentric frame of reference further into the right hemispace. However, these types of interventions do not address our findings related to non-lateralized effects of competition as well as the allocentric within-word error pattern that was present regardless of egocentric spatial position.

Other studies have described allocentric approaches involving manipulations of the text. In one study, investigators place a hash mark to the immediate left of each word and saw positive effects (Riddoch et al., 1990). Ellis et al. (1987; 1993) performed an extensive variety of investigations on a single patient with neglect dyslexia. In one instance they placed a red digit immediately to the left of the target word and had the patient report the digit prior to reading the word. Their intent was to ensure that the entire word fell within the right visual field, however, based on the framework used here, they also extended the allocentric frame of the word, thus putting the target word further toward the right side within that frame. Their patient still made errors on 12% of the words, the majority of which were unilateral paralexic errors, even after correctly reporting the digit. They also manipulated the salience of the left or right side of each five-letter word by printing in bold either the first two or last three letters. Their patient did show better accuracy on left-bolded words than right-bolded in all four sessions, suggesting that manipulation of salience within the word itself may be an effective method to ameliorate the effects of unilateral paralexic errors.

Though results from these studies are mixed at best, efforts to increase the relative salience of the left side of an individual word represents a promising line of intervention for allocentric errors. Increasing the font size, changing the color, or bolding the first character position seems like the most logical way to improve processing of the left side of the allocentric frame. To further increase the relative salience of the left side, one can reduce the font size or contrast of the letters on the right side of the word. These interventions do not, however, address the selective attention deficit we observed with the addition of distractors.

Therefore, an intervention that addresses egocentric, allocentric, and selective attention deficits in combination should be the most effective. Rapid serial visual presentation (RSVP) is an alternative reading presentation format which minimizes the effects of space and competition at the same time. In RSVP, each word is serially presented at fixation for a fraction of a second. In our patient population, RSVP might limit the effects of space by always presenting the word at the fovea and limit the competition of other words by presenting only one word at a time. Further, using intra-word saliency manipulation of the first few letters along with RSVP might be an effective combination of interventions.

Conclusions

In this study, we investigated the relative contributions of spatial processing deficits and selective attention deficits to word reading errors in patients with neglect dyslexia. Both of these possible deficits contribute differently within egocentric and allocentric frames of reference. We first replicated the literature with the traditional extinction paradigm that has lateralized targets. Then we modified the paradigm to eliminate the effects of egocentric spatial position by always presenting the target word at fixation, either solitarily or with a right- or left-sided distractor word. The results were an effect of distractor words but no effect of the left-right position of the distractor words. When considering the results of both experiments, our patients demonstrated performance most consistent with the egocentric competition hypothesis, which asserts that errors in neglect dyslexia are due to poorer selective attention in left-sided egocentric space. However, patients also showed allocentric deficits within words that occurred irrespective of egocentric spatial location. Thus, there are clearly multiple deficits contributing to neglect dyslexia. Our findings support a multi-faceted approach to interventions to address neglect dyslexia in clinical rehabilitation.

Appendix

Prior to Experiment 2, control subjects completed testing to determine an appropriate luminance ratio between foveal and parafoveal targets. Our intention was to compensate for the decrement in the visibility of parafoveal targets due to eccentricity effects by providing a higher luminance for parafoveal distractors in Experiment 2. In Experiment 2, luminance of foveal words was driven down to a point necessary for errors to be made. If parafoveal distractor words were set at that same luminance, it is possible that their effect might be limited by the low luminance. Since we wanted the parafoveal distractor words to have a chance at extinguishing foveal targets, we attempted to equalize the visibility of the foveal and parafoveal words.

Four conditions were used: two solitary conditions (solitary central target, solitary right target) and two distractor conditions (central target/right distractor, right target/central distractor). Stimulus words were positioned either centrally or with their midpoint 3° to the right of fixation. Luminance was adjusted incrementally and separately between central and parafoveal targets. Left side targets were not included since we predicted right-sided distractors to have more of an effect than left-sided distractors.

We tested four control subjects. When the right-sided target was set at 2x the luminance, the right-sided target had 22% poorer accuracy than the central target. When set at 4x the luminance, the right-sided target had 22.5% better accuracy than the central target. When set between 2x and 4x higher, performance on the right-sided target was roughly equal to that of the central target. Thus, for Experiment 2 we used 3x luminance for parafoveal distractors for all subjects.

Chapter 3

Rehabilitation of Spatial Neglect: Assessment and Intervention

Every new patient seen by rehabilitation clinicians is first evaluated with a variety of assessment tools and observation of performance of activities of daily living. This fundamental first step sets the new baseline for that patient from which goals are set and an intervention plan is created. After some time participating in rehabilitation, clinicians will often reassess with the same assessment tools to measure progress and make adjustments to the intervention plan. It is therefore critical that the assessments chosen fully capture deficits with sensitivity and specificity.

Clinicians must choose from a wide variety of assessments to measure spatial neglect, including behavioral observation, paper-and-pencil tasks, and tests of functional mobility. Each measures a slightly different aspect of the diverse syndrome. It is therefore important that clinicians use a battery of tests that covers the spectrum of deficits seen in patients with spatial neglect. Further, clinicians must understand the underlying deficits that affect performance on each of the assessments they use.

A lack of effective interventions for patients with neglect is another challenge. No intervention specific to neglect has yet been put through a large multi-site, randomized controlled trial. Most studies of intervention methods described in the literature consist of small samples or case reports. A recent Cochrane review concluded that no current interventions are adequately supported by the research (Bowen et al., 2013).

This chapter describes two comprehensive assessments and four interventions commonly used with patients with spatial neglect, as well as how each fits within the discussions in earlier chapters regarding spatial processing, selective/divided attention, egocentric and allocentric frames of reference, and delineations of space.

Assessment of Spatial Neglect

There are numerous assessments that have been used clinically to quantify neglect behaviors. This chapter will focus on two comprehensive neglect assessments representing two different approaches. The Behavioural Inattention Test (Wilson et al., 1987) uses a battery of mostly paper-and-pencil tasks and the Kessler Foundation – Neglect Assessment Process (Chen et al., 2012) uses a behavioral observation approach to measure neglect.

The Behavioural Inattention Test

The Behavioural Inattention Test (BIT; Wilson et al., 1987) was the first comprehensive test battery for spatial neglect. It is comprised of a variety of tasks that are each intended to pick up on a different aspect of neglect. The first grouping of subtests in the BIT, called conventional subtests, are versions of traditional paper-and-pencil tasks used by clinicians for many years. The second grouping, called behavioral subtests, involve more functional tasks that one might encounter in everyday life.

The BIT has been shown to have excellent test-retest reliability (r=0.89 for conventional subtests and r=0.97 for the behavioral subtests) and interrater reliability (r=0.99; Halligan et al., 1991; Wilson et al., 1987) and convergent validity with several established clinical measures (Cassidy et al., 1999; Halligan et al., 1991; Hartman-Maeir & Katz, 1995). It has also been shown to be an excellent predictor for poor functional outcomes (Jehkonen et al., 2000).

Conventional Subtests: Cancellation

Line crossing, based on Albert's Test (Albert, 1973), is the first subtest of the BIT. It is a type of cancellation task, meaning the patient is to place a hash mark on target items. It is comprised of a sheet of paper with 40 one-inch line segments in random orientations arranged in six columns from left to right. The patient is instructed to cross out all the line segments on the page.

Letter cancellation and *star cancellation* are similar to line crossing, but patients need to find target items embedded in field of distractors. In letter cancellation, five lines of 34 random letters are presented on a sheet of paper. Patients are instructed to cross out all E's and R's on the page. In star cancellation, patients are to cross out all 56 small stars embedded in a field of 52 large stars, 13 letters, and 10 short words.

Scoring for the cancellation tasks involves a tally of all cancelled items. The line crossing and star cancellation subtests embedded targets evenly across six columns on the page and the targets in the letter cancellation were distributed evenly across four columns. Although there is a separate tally for each column, the total score is simply a total tally of all marked items. This leaves open the possibility of a low score even if errors are evenly distributed across the page. Therefore, interpretation of test results should consider the distribution of errors in addition to the score.

Cancellation tasks can be thought of as examining neglect within egocentric peripersonal space because the stimulus sheet is positioned at midline of the patient. The tasks demand action and intention from the patient in addition to perception. Therefore, cancellation would be sensitive to neglect subtypes including visual neglect, oculomotor-directional hypokinesia, and motor-directional hypokinesia. As there are multiple stimuli on the page at once, there is a possibility that extinction could also play a role. Interestingly, several studies have found that the point on the stimulus sheet at which the participant starts their search is a strong indicator of presence of neglect (Azouvi et al., 2002).

The erasure task is a variation of cancellation that, when compared to the performance on standard cancellation, helps to show the effects of competition on performance. Instead of crossing out the stimuli as in a standard cancellation task, the patient is to erase targets instead. After each target is obtained the number of distractors decreases. Better performance on the erasure task than standard cancellation might therefore indicate a larger role of selective/divided attention deficits.

Conventional Subtests: Allocentric Tasks

Ota et al. (2001) designed a cancellation task that includes a demand for object-based processing. In their task, complete shapes (triangles or circles) are embedded in a field of the same shape with a small incomplete segment on either the left or right side. Patients are tasked with circling all complete shapes and crossing out all incomplete shapes. Patients that do not cross out or circle stimuli on one side of the sheet demonstrate an egocentric deficit, and those that cross out incomplete shapes with an ipsilesional open segment but fail to cross out incomplete shapes with a contralesional segment demonstrate an object-based, or allocentric deficit.

In the *figure and shape copying* subtest of the BIT, patients copy line drawings of a star, a cube, and a daisy. The stimulus items are positioned on the left side of the page and the patient is to draw their version on the right side of the page. A patient with allocentric deficits will fail to include details on the contralesional side of the drawing. This subtest demands egocentric processing as well. For example, inadequate oculomotor exploration of the contralesional side of the page would cause errors. The subtest calls upon both perception and action and, therefore, in addition to allocentric neglect, would be sensitive to visual neglect, oculomotor-directional hypokinesia, and motor-directional hypokinesia subtypes.

Scoring on the figure and shape copying subtest involves a rating of the completeness of the drawing. For each of the three items, patients earn 1 point for a complete drawing and 0 points for an incomplete drawing. As mentioned above regarding scoring of the cancellation tasks, low scores on this subtest do not necessarily reflect a lateralized deficit. The test administrator must therefore take note of the lateralization and severity of errors.

Line bisection is the other allocentric task in the conventional subtests. The task is perhaps one of the most commonly used tasks to diagnose spatial neglect. In the BIT version, three 8-inch horizontal line segments are presented in a staircase fashion, descending from right to left. Variations on the task outside of the BIT include line segments of different lengths and/or in different orientations. The patient is instructed to place a hash mark at the precise midpoint of the line segment. A patient with allocentric deficits will show a tendency to bias their hash mark toward the ipsilesional side of the line segment. Those with egocentric deficits with show a more pronounced bias in their contralesional hemispace. In addition to allocentric deficits, line bisection is also sensitive to egocentric subtypes including visual neglect, oculomotor-directional hypokinesia, and motor-directional hypokinesia.

Interestingly, the line bisection task is one way to differentiate between homonymous hemianopia and spatial neglect. In the acute phase after stroke individuals with homonymous hemianopia will often show an ipsilesional deviation of their perceived midline on this task that is similar to those with neglect. Over time, however, this error tends to drift contralesionally, presumably due to compensation for their sensory loss (Machner et al., 2009). The hemianopic line bisection error is well-documented in the literature (Barton & Black, 1998; Kerkhoff & Bucher, 2008; Lanyon & Barton, 2013).

An oculographic study of the line bisection task showed that patients with neglect tend to initially fixate on the ipsilesional endpoint of the line and have difficulty scanning to the contralesional endpoint (Kim et al., 1997). Neurotypical participants tended to initially fixate on the left end point of the line, then to scan all the way to the right end point, and finally to return their gaze to the middle (1997). Another oculographic study of line bisection revealed that there was an increased rightward fixation bias as line segments grew longer, demonstrating that rightward bias and response time is significant for longer segments, but not shorter ones (Balconi et al., 2013).

Conventional Subtests: Representational Drawing

The final conventional subtest is *representational drawing*. In this task, the patient is instructed to draw three things from memory: a clock, a man or woman, and a butterfly. The typical error for those with neglect is a lack of detail on the contralesional side of the drawing. Errors on this subtest indicate allocentric representational or imaginal deficits. Scoring for this subtest is similar to that of the figure and shape copying subtest in that complete drawings receive a score of 1 and incomplete drawings receive a score of 0.

Behavioral Subtests: Perceptual Tasks

The behavioral subtests as a whole place a higher set of demands on the patient, as they rely on both perception and action, occur in multiple frames of reference and delineations of space, and demand both spatial processing and selective/divided attention for success. Therefore, a patient who performs within normal limits on conventional subtests might show neglect with higher processing demands.

Picture scanning is the only primarily perceptual subtest of the BIT. Patients are presented with three photographs of an everyday scene with objects equally distributed on the left and right sides of the midline of the picture. Patients are instructed to name and point to each object they notice. Scoring is based on the number of omissions of objects. Low scores on this subtest indicate visual neglect, oculomotor-directional hypokinesia, or motor-directional hypokinesia.

Behavioral Subtests: Reading and Writing Tasks

Subtests including *menu reading*, *article reading*, and *address and sentence copying* are intended to show the presence of passage-level neglect dyslexia. In menu reading, 24 food items (12 on the left and 12 on the right) are listed on a large sheet of paper, presented at the patient's midline. In article reading, a short newspaper article is presented in three columns across a large sheet of paper. The patient is instructed to simply read all of the items on the menu and in the article, respectively. Scoring is based on the number of omissions of words.

In address and sentence copying, the patient is presented with an individual's address including name, street, city, and province. The patient is tasked with copying the address onto a separate sheet of paper. Both the stimulus sheet and the response sheet are to be positioned at the patient's midline. Scoring is based on the number of letters omitted from the address. In addition to the neglect dyslexia subtype, these subtests also show visual neglect and oculomotor-directional hypokinesia.

Behavioral Subtests: "Functional" Tasks

Finally, several subtests of the BIT involve what clinicians would consider to be more "functional" tasks, as they simulate actions that occur in real life. These subtests include *telephone dialing*, *telling and setting the time*, *coin sorting*, *card sorting*, and *map navigation*. In telephone dialing, the patient is to dial telephone numbers that are presented on cards. In telling and setting the time, the patient reads the time from photographs of both digital and analog clocks and is instructed to set an analog clock to times that the administrator instructs. In coin and card sorting, an array of coins or playing cards is presented in columns and rows in front of the patient. They are asked to point to the coin or card called out by the administrator. Finally, in map navigation, a sheet of paper with letters of the alphabet connected by a "road system". The patient is asked to trace with their finger the route to connect two letters called out by the administrator. In all subtests considered functional tasks, scoring is based on number of omissions or errors committed.

Limitations of the Behavioural Inattention Test

As already mentioned, some patients may perform much better on conventional subtests than behavioral subtests. This could be because they have started implementing compensatory strategies or their deficits have improved to a point that they have success with highly structured and relatively simple tasks. Their performance suffers, however, with more complex real-life tasks. A strength of the BIT is that it uses tasks that are objectively measurable. However, in order to achieve measurability, the tasks sacrifice much application to real-life scenarios.

Furthermore, few clinicians actually use lengthy assessment batteries such as the BIT. In one study, although neglect was a widely recognized problem by occupational therapists, only about one quarter report using standardized assessment tools to measure it (Menon-Nair et al., 2007). Furthermore, none of the therapists in the study reported conducting assessments in all delineations of space.

Kessler Foundation – Neglect Assessment Process

The Kessler Foundation – Neglect Assessment Process (KF-NAP; Chen et al., 2012) takes a much more functional approach to assessment than the BIT. The KF-NAP expanded on the Catherine Bergego Scale (CBS; Azouvi, 1996), a ten-item assessment of commonly observed neglect behaviors that span regions of space and frames of reference and demands both spatial processing and selective/divided attention. It has been shown to be more sensitive to neglect than any other single assessment tool (Azouvi et al., 2002). Examples of items include “forgets to groom or shave the left part of his/her face” and “collides with people or objects on the left side, such as doors or furniture”. The administrator scores each item on a four-point scale from “no neglect” to “severe neglect”.

The KF-NAP was developed to address limitations of the Catherine Bergego Scale, including its lack of specification as to the environmental context and timeframe within which the tasks are to occur (Chen et al., 2012). The KF-NAP provides more thorough descriptions of context, administration procedures, and scoring criteria. It is designed to be conducted during a typical occupational therapy session focused on basic activities of daily living, taking between 20 and 40 minutes in total (2012).

As the KF-NAP is relatively new, only one psychometric analysis has been reported in the literature. That study (Chen et al., 2015) found excellent internal consistency (α=0.96) with two commonly used and well-validated assessment tools, the Functional Independence Measure (FIM: Keith et al., 1987) and the Barthel Index (BI; Mahoney & Barthel, 1965). They also found that the KF-NAP was unique to those tools, capturing 11.6% additional variance that the FIM and BI did not capture (Chen et al., 2015). Additionally, they found that the KF-NAP predicted FIM scores at discharge (2015).

The first category, *gaze orientation*, indicates deficits in the visual neglect and oculomotor-directional hypokinesia subtypes. It is based on overall spontaneous gaze orientation over the course of the entire session. Patients with a score of severe on this category do not attempt to gaze toward their contralesional side. Patients with milder scores have asymmetries in gaze orientation but are able to direct their gaze contralesionally to some degree.

Limb awareness, the second category, captures the hemiasomatagnosia, somatosensory neglect, and hemihypokinesia subtypes. Recall that those with hemiasomatagnosia have a decreased awareness of their contralesional body, those with somatosensory neglect have a decreased response to contralesional tactile and proprioceptive input, and those with hemihypokinesia show a decreased use of their contralesional extremity. A score of severe in this category would be given if the patient completely disregards their contralesional limb. They do not attempt to protect it or move it.

The *auditory attention* category obviously measures the auditory neglect subtype. Scoring is based on a comparison of the patient's reaction to a sudden, loud noise made on their contralesional side to one made on their ipsilesional side. A patient with a score of severe shows an immediate reaction to ipsilesional sounds but does not react to contralesional sounds. Patients with milder scores react more slowly to contralesional sounds but do regard them.

In *personal belongings*, the patient is tasked with identifying the location of six personal items – three on their left and three on their right – kept in a consistent location in their room. This category identifies deficits in extrapersonal space, including representational neglect in remembering where the object is located, and oculomotor-directional hypokinesia in visually exploring contralesional space to locate the items. Patients with a severe score locates and points to all ipsilesional items but none of the contralesional items.

Four categories assess performance on basic activities of daily living: *dressing*, *grooming*, *meals*, and *cleaning after meals*. Patients with severe scores show a clear asymmetry in care for their ipsilesional body as compared to their contralesional body. In dressing, for example, a patient with neglect might not don the contralesional sleeve of their shirt. For meals, the patient might not eat any of the food on the left side of their plate or tray. Dressing, grooming, and cleaning after meals generally capture deficits within personal space, namely hemiasatomagnosia, somatosensory neglect, and hemihypokinesia. The meals category occurs within peripersonal space and could detect visual or allocentric neglect. However, these tasks demand processing resources from multiple systems in peripersonal and extrapersonal space as well, so a deficit in any of the subtypes could influence performance.

Finally, *navigation* and *collisions* are two categories that would detect deficits in extrapersonal space. In navigation, the patient is instructed to ambulate or self-propel their wheelchair to a familiar place. Patients with severe deficits fail to make contralesional turns along the way. This could be representative of representational neglect in the recall of contralesional places and directions, or of motor-directional hypokinesia in the movement of one's body into contralesional space.

Assessment of Spatial Neglect: Summary

The BIT and the KF-NAP represent two different approaches to the assessment of spatial neglect. The BIT consists of a battery of primarily paper-and-pencil tasks, many of which have been used in some iteration for decades prior to the inception of the BIT. As all of the tasks occur in peripersonal space, a segment of the neglect population might be missed by this tool.

Another weakness of the BIT is its feasibility for clinical use. Assessment is critical for treatment planning, but if therapists feel that they cannot realistically administer a lengthy battery or feel that their limited time is best used for assessment and treatment focused solely on activities of daily living.

The KF-NAP provides a more practical and functional assessment of the global functioning of a patient with neglect. It is intended to be completed within a 40-minute therapy session within which many of the category items would normally take place. Categories span personal, peripersonal, and extrapersonal delineations of space; they require both perception and action; they use multiple frames of reference; and, they demand both spatial processing and selective/divided attention.

Rehabilitation of Spatial Neglect

Interventions for patients with spatial neglect are lacking. The few options available are complicated and time consuming. Even if improvements are seen on assessment tools, effects do not seem to generalize to daily living tasks. Furthermore, patients have a difficult time implementing compensatory strategies due to a poor awareness of their state as well as the numerous comorbid conditions that create their own barriers to independence. A recent Cochrane review concluded that no current intervention is sufficiently supported by the literature (Bowen et al., 2013).

Intervention approaches for neglect have been framed as either following a top-down or bottom-up approach. It is important to note that the definitions of these terms as used in the psychology literature is different than in the occupational therapy literature. In occupational therapy, top-down assessment and intervention refers to an approach focused on task performance and role competency; bottom-up assessment and intervention refers to an approach focused on the sensorimotor, cognitive/perceptual, or psychological performance skills that underlie occupational performance (Weinstock-Zlotnick & Hinojosa, 2004). In the top-down approach, the occupational therapist assesses the tasks that the patient needs to do that contribute to their roles and routines and establishes a treatment plan focused on task performance. In the bottom-up approach, the occupational therapist assesses the underlying skills (e.g., strength, balance, visual and oculomotor skills) and establishes a treatment plan that addresses the deficits in performance skills.

In the psychology literature on neglect, a top-down approach is focused on teaching patients strategies to compensate for their deficits; a bottom-up approach modifies the features of the environment or task to affect behavior (Bowen et al., 2013; Adair & Barrett, 2008). A top-down approach requires the agency of the patient to affect change while a bottom-up approach requires no change in core skills or active compensation from the patient. In this section, interventions are organized according to whether they follow a top-down or bottom-up approach as defined in the psychology literature on neglect.

Top-down Approaches

Visual scanning training, first described by Diller and Weinberg (1977), is intended to retrain patients to visually explore contralesional space by cueing attention toward and completing tasks of graded complexity on that side. This type of retraining happens frequently and spontaneously within therapy sessions. Examples include placing a bold vertical line along the left margin of the page while reading and providing cues as needed to improve performance, asking about details on the contralesional side of the hallway while ambulating, or providing spatial cues during a visual search task. Many variations of visual scanning treatment exist, but they all share the philosophy that therapeutic activities that retrain spatial attention will result in an improvement in spontaneous spatial attention.

Unfortunately, this has not been consistently shown to be the case. Visual scanning training has been shown to be effective for some, but not all, patients with neglect (Kerkhoff & Schenk, 2012). Improvements have been reported on peripersonal tasks such as cancellation and line bisection tests (Bowen et al., 2013), but improvements may not translate to personal neglect (Zoccolotti et al., 1992). Reported improvements on assessments could be due to the virtue of visual scanning training being very similar to assessment materials. For example, a clinician might provide graded feedback during a paper-and-pencil visual search task, which closely resembles a cancellation task as seen in the BIT. Naturally, performance on these arbitrary paper-and-pencil tasks improves with practice. The key takeaway, therefore, is that visual scanning training does not appear to make much of an impact on daily function for patients with spatial neglect.

Limb activation treatment is an intervention approach that involves the facilitation of small or large active movements by the contralesional upper extremity (Robertson & North, 1992). This approach has been argued to improve neglect by enhancing both personal and peripersonal spatial representations in the lesioned hemisphere (Pierce & Buxbaum, 2002). Studies on limb activation have had small sample sizes and mixed results, which may be attributable to the heterogeneity inherent to the neglect syndrome (2002). Unfortunately, limb activation treatment has limited application to this population because patients most often have some form of hemiplegia in their contralesional upper extremity (Kortte & Hillis, 2011).

Mental imagery, a top-down approach that addresses representational neglect, involves visual imagery of contralesional space and/or motor imagery involving movement into contralesional space or moving the contralesional limbs (Smania et al., 1997). An example of a commonly used mental imagery technique is known as “the lighthouse strategy.” Patients are instructed to imagine their gaze as a beam of light from a lighthouse, sweeping fully back and forth across the ocean. In a study of 31 patients who received the treatment for a mean 25 days, the lighthouse strategy was found to improve sustained attention and line bisection (Niemeier, 1998).

Mental imagery involving rehearsing motor actions has been shown to activate neural networks that closely resemble those seen with actual movements (Sirigu et al., 1996). One study with two patients with neglect showed significant improvement in neglect after 40 sessions of 50 minutes each that persisted at least six months following intervention (Smania et al., 1997).

After weeks of various forms of top-down interventions in and outside of therapy, family members of patients with neglect are often baffled and frustrated by their loved one's persistent trouble with paying attention to their contralesional side despite their near-constant cueing. They sometimes misinterpret the patient's apperception of the syndrome as a lack of motivation or that they are in denial. The lack of "stickiness" of visual scanning training and other top-down approaches due to this apperception is part and parcel of the neglect syndrome.

Bottom-up Approaches

Bottom-up approaches include those that shift the perception of egocentric space and those that modify the relative salience of contra- and ipsilesional stimuli. They require no active change in behavior on the part of the person with neglect, and, therefore, might be more beneficial than top-down approaches since many have anosognosia to varying degrees. Bottom-up approaches are aimed at either shifting the perception of space or increasing the relative salience of contralesional space or stimuli as compared to ipsilesional space or stimuli.

Interventions that Shift the Perception of Space

Several interventions use sensory stimulation to cause a desirable skewed perception of space. These include optokinetic stimulation, prism adaptation, caloric vestibular stimulation, and neck muscle vibration. Only the former two are discussed here since their underlying mechanisms are similar.

In optokinetic stimulation, stimuli such as an array of dots or vertical lines constantly move across the visual field. This gives the patient the feeling that their body is moving in the opposite direction of the movement. As the stimuli move, the eyes jump rhythmically in an alternating pursuit-saccade pattern known as optokinetic nystagmus, a reflex believed to produce an attentional bias toward the direction of the pursuit phase (Pizzamiglio et al., 1990). The stimulation continues for some time while the patient either simply looks straight ahead or completes a perceptual or motor task. After stimulation is over, the patient will experience an aftereffect of perceived egocentric space shifted toward their contralesional side.

Optokinetic stimulation has been shown to show a reduction in ipsilesional orientation bias, though effects are most often transient (Kerkhoff et al., 2006; Pizzamiglio et al., 1990). Long-lasting effects have been noted, however, after repetitive intervention over five 45-minute sessions (Kerkhoff, 2002).

Prism adaptation treatment, another intervention that shifts the perception of space, has been shown to have more substantial and long-lasting effects (Rossetti et al., 1998). A patient completing prism adaptation treatment wears goggles with binocular unidirectional prismatic lenses. The prisms cause an intended contralesional shift of their perceived midline. When reaching for objects while wearing the goggles, the patient will undershoot in the direction of the perceptual shift. Over time, their visual system adapts to this shift to facilitate successful reaching. Finally, when the goggles are removed, the patient experiences a visual aftereffect of a shift in the opposite direction, thereby improving their processing of veridical contralesional space. As in optokinetic stimulation, prism adaptation treatment spanning several sessions is more beneficial than those that consist only of one or a few sessions (Frassinetti et al., 2002; Nys et al., 2008; Serino et al., 2009).

Interventions aimed at shifting the perception of space were once promising but now seem to have several limitations. First, improvements in perception are fleeting. The desired aftereffect of an ipsilesional shift of perceived midline occurs due to visual adaptation. It is therefore logical that the visual system would gradually adapt again back to the baseline of an ipsilesional orientation bias.

Second, any long-lasting effects have been attributed to repetitive treatment that spans many sessions. The time-consuming nature of these interventions limits their feasibility in rehabilitation. Clinicians are hesitant to embark on a lengthy and complicated treatment regimen that might or might not make a difference for their patients. Furthermore, these interventions do not resemble any kind of functional task that patients encounter in real life. Rehabilitation clinicians are focused on improving their patients' participation in the activities that help to form their roles and identities. Time spent on complex treatments such as these takes away time that could be spent on more functional tasks.

Finally, eliciting a shift in perception of space addresses the egocentric spatial bias inherent to neglect. It does not, however, address either the allocentric spatial deficit or the attentional deficits. Failures of selective and divided attention that occur for contralesional stimuli occur regardless of their position in egocentric space. Therefore, this group of bottom-up interventions is insufficient to address difficulties that result from biased competition between stimuli.

Interventions that Modify Relative Salience

Working under the framework that the orientation in neglect is due to a disinhibited contralesional hemisphere that causes a hyperattention to the ipsilesional side (Kinsbourne, 1970), several interventions have been developed that facilitate ipsilesional inhibition. This is accomplished by dampening ipsilesional salience while contralesional salience remains stable, boosting contralesional salience while ipsilesional salience remains stable, or a combination of both. This approach is supported by the Sprague effect, which was an observation that in rats, an ipsilesional spatial bias following a lesion to one of the superior colliculi is ameliorated by a second lesion to the contralateral superior colliculus (Weddell, 2004).

In hemifield patching, the patient wears goggles with the ipsilesional half of each lens occluded with opaque or translucent tape. This method of taping is more effective than patching the entire ipsilesional eye (Beis et al., 1999), likely because each hemisphere processes the image projected on the ipsilateral side of each eye's retina. Hemifield patching has been shown to have variable effects and improvements in standardized test scores may not generalize to functional skills (Beis et al., 1999; Butter & Kirsch, 1992; Tsang et al., 2009).

As discussed in Chapter 2, manipulations of text have been studied in patients with neglect dyslexia. Examples of text manipulations include placing a hash mark on the contralesional left side of each word (Riddoch et al., 1990), placing a red digit on the left side of each word and having the patient report the digit prior to reading the word (Ellis et al., 1987), and bolding the letters on the left side of the word (Ellis et al., 1993). These few examples of text manipulations were completed with single subjects and had mixed effects. There is not yet any kind of formalized intervention methodology using text manipulations currently used in rehabilitation.

A bottom-up approach may be more promising than a top-down approach for patients with neglect because of poor awareness of their impairments and a poor ability to spontaneously compensate for their deficits. Interventions such as optokinetic stimulation, prism adaptation, and others that shift the perception of space address the spatial processing bias inherent to neglect but fail to address attention deficits. Interventions that boost the salience of contralesional stimuli relative to ipsilesional stimuli such as hemifield taping and text modifications are promising but are sparsely investigated.

Rehabilitation of Spatial Neglect: Future Directions

Clearly much more needs to be done for the assessment and treatment of patients with spatial neglect. The lack of a gold standard in assessment methods creates the potential for heterogeneity of patients included in research studies. Few clinicians spend the time or energy completing lengthy and complicated assessment tools. The lack of a gold standard in treatment is due to mixed methodologies, mixed results, and a lack of generalization of benefit to activities of daily living. Additionally, most interventions address only spatial processing deficits but fail to address attentional deficits. Therefore, looking toward the future, assessment methods need to be comprehensive yet quick and interventions need to be precise yet functional.

Technological advances in recent years present many opportunities for new methods of assessment and intervention. Specifically, these include virtual reality, augmented reality, and eye tracking devices. A few studies report on the early use of virtual reality for assessment of neglect (e.g., Baheux et al., 2005; Buxbaum et al., 2008; Kim et al., 2004; Myers & Bierig, 2000) and many on virtual reality interventions (e.g., Castiello et al., 2004; Kim et al., 2011). However, interventions mostly involved versions of extant intervention techniques such as visual scanning training involving arbitrary and non-functional visual search tasks. We already know that these techniques have limited carryover to function.

Eye tracking has been used in studying the oculomotor patterns of patients with neglect (for example, see Behrmann et al., 2002; Butler et al., 2009; Llorens & Noé, 2016) and, in one study, for an assessment method similar to line bisection (Chiba et al., 2008). However, it has not been examined as a potential comprehensive clinical standardized assessment method nor as a potentially viable intervention technique.

Recent improvements in the sophistication of these technologies as well as declining costs makes them a more attractive prospect for rehabilitation in the future. The research presented in Chapter 2 of this dissertation provides evidence that attentional impairments may play a large role in neglect behaviors in addition to the spatial processing deficit. Virtual and augmented reality create the possibility of addressing both spatial and attentional deficits simultaneously, using both top-down and bottom-up approaches.

First, consider the following example intervention focused on improving spatial processing. A virtual reality system presents a real-life visual scene to the patient with a lateralized “fish-eye” effect so that contralesional space occupies more of the perceived space than ipsilesional space. Within this distorted view, the patient completes a visual scanning activity simulating a real-life scenario.

With the addition of an eye tracking device mounted within the virtual reality headset, real-time cueing could be provided based on eye position. If the eye tracker detects that the patient did not fixate on a task-relevant target, it notifies the system to provide a visual or auditory cue to the patient. Once the patient fixates on the target, a positive feedback cue is provided.

Next, consider the following example intervention focused on improving selective or divided attention. A virtual reality system presents a real-life visual scene involving real objects that the patient must identify. The system modifies the relative salience of the two or more stimuli presented to a level that equates ipsi- and contralesional performance. This might be accomplished by highlighting or enlarging the contralesional stimulus or dampening or shrinking the ipsilesional stimulus. Over time, as the patient's performance improves, the system gradually reduces the salience manipulations.

Next, consider the possibilities that these technologies create for potential interventions for neglect dyslexia. For errors attributable to spatial processing deficits involving the omission of entire words along the contralesional margin of text, an eye tracking device could monitor eye movements and could direct the system to provide a visual or auditory cue if sections of text are being omitted. For errors attributable to attentional deficits, the system could modify the text in various ways to equalize the competition between the words on the page.

Finally, the use of augmented reality is perhaps the most exciting prospective intervention modality for patients with neglect in the future. The virtual reality examples above of modifying perceived space with a "fish-eye" effect or increasing the relative salience of contralesional stimuli in simulated scenarios could be enacted in real-life scenarios with augmented reality.

Imagine, for example, a patient using augmented reality while ambulating. The system uses computer vision artificial intelligence via a front facing camera to identify potential obstacles and monitor the ambulatory trajectory of the patient. The eye tracker supplements these data through monitoring visual attention to these obstacles via eye position. The system makes a judgment to provide a visual or auditory cue to the patient if it determines that a collision is likely to occur.

Augmented reality can also provide a graded modification of the relative salience between stimuli in the visual field. During a functional visual search task, such as looking for a food item nested within a crowded refrigerator, the system could, in real time, dampen the salience of ipsilesionally-located food items and heighten the salience of contralaterally-located items. With an eye tracker, this intervention could be enhanced to follow retinocentric coordinates by changing the salience modifications with every refixation.

Conclusions

There are a variety of assessment methods and intervention approaches used in the rehabilitation of patients with spatial neglect. However, there is a lack of a clinical gold standard in both of these areas. The BIT is a comprehensive yet time-consuming assessment that is rarely used in its entirety clinically and has questionable application to daily living. The KF-NAP is relatively new and represents a more functional approach to assessment but has not yet been widely adopted.

Interventions for neglect can be divided into those that use a top-down approach and those that use a bottom-up approach. Patients with neglect face barriers to success with a top-down approach because of an apperception of their condition that makes difficult the spontaneous deployment compensatory strategies. Bottom-up approaches, therefore, show more promise for this clinical population but are not conclusively supported by the literature.

The recent proliferation of virtual and augmented reality and eye tracking opens the door for new interventions in the future. These technologies allow for the combination of top-down and bottom-up approaches as well as the combination of techniques addressing spatial processing and those addressing attentional deficits. Further, the use of real-life scenarios in virtual and augmented reality likely has a greater chance of making a positive impact on activities of daily living for patients with neglect.

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