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Normal discrimination of spatial frequency and contrast across visual hemifields in left-onset Parkinson's disease: Evidence against perceptual hemifield biases

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ABSTRACT

Individuals with Parkinson's disease (PD) with symptom onset on the left side of the body (LPD) show a mild type of left-sided visuospatial neglect, whereas those with right-onset (RPD) generally do not. The functional mechanisms underlying these observations are unknown. Two hypotheses are that the representation of left-space in LPD is either compressed or reduced in salience. We tested these hypotheses psychophysically. Participants were 31 non-demented adults with PD (15 LPD, 16 RPD) and 17 normal control adults (NC). The spatial compression hypothesis was tested by showing two sinusoidal gratings, side by side. One grating's spatial frequency (SF) was varied across trials, following a staircase procedure, whereas the comparison grating was held at a constant SF. While fixating on a central target, participants estimated the point at which they perceived the two gratings to be equal in SF. The reduced salience hypothesis was tested in a similar way, but by manipulating the contrast of the test grating rather than its SF. There were no significant differences between groups in the degree of bias across hemifields for SF discrimination or for contrast discrimination. Results did not support either the spatial compression hypothesis or the reduced salience hypothesis. Instead, they suggest that at this perceptual level, LPD do not have a systematically biased way of representing space in the left hemifield that differs from healthy individuals, nor do they perceive stimuli on the left as less salient than stimuli on the right. Neglect-like syndrome in LPD instead presumably arises from dysfunction of higher-order attention.

1. Introduction

Recently an emphasis has been placed on exploring the non-motor aspects of Parkinson's disease (PD) such as cognitive and perceptual disturbances, which substantially impact quality of life beyond the disease's classical motor symptoms (Cronin-Golomb, 2013). PD is usually asymmetrical in its onset, and individuals whose motor symptoms start on the left side of their body (LPD) have shown particular perceptual abnormalities that are suggestive of a mild form of visuospatial neglect. First, those with LPD have been shown to bisect lines in a way that is milder but similar to that shown by individuals with neglect syndrome, perceiving the middle of the line to be shifted rightward from its physical location (Lee, Harris, Atkinson, & Fowler, 2001). Second, they more frequently begin exploring a stimulus by first gazing to its right side than its left side, which is opposite to the pattern seen in healthy control adults and in PD with right side onset (RPD) (Ebersbach et al., 1996). Third, LPD view objects on the left as smaller than they really are, as compared to objects on the right side of space (Harris, Atkinson, Lee, Nithi, & Fowler, 2003). These perceptual disturbances may have negative effects on daily life: LPD more frequently report bumping into the left side of doorways (Davidsdottir, Cronin-Golomb, & Lee, 2005), and it takes little imagination to generate additional sequelae in walking, navigation, and especially in regard to driving.

Despite the clinical importance of this phenomenon in LPD, the functional mechanisms underlying this neglect-like pattern of performance remain unknown. At a neurophysiological level, the differential dysfunction of the right hemisphere, which accounts for the fact that motor symptoms begin on the left side of the body, also presumably accounts for perceptual disturbance in LPD (Cronin-Golomb, 2010). At a functional level, the mechanisms underlying LPD's neglect-like performance are less certain. One explanation that has been offered is that in LPD, the representation of the left side of space may be compressed (Davidsdottir, Wagenaar, Young, & Cronin-Golomb, 2008; Harris et al., 2003). If

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this were the case, it might explain why some LPD bisect lines rightward of their true center, because the left portion of the line would be compressed and therefore appear smaller—leading to a shift of perceived center.

Another possibility is that visual signals (such as salience or contrast) in the left hemifield are generally weakened in LPD. Several studies have found reduced contrast sensitivity in PD (e.g., Amick, Cronin-Golomb, & Gilmore, 2003; Kupersmith, Shakin, Siegel, & Lieberman, 1982; Pieri, Diederich, Raman, & Goetz, 2000), with some suggesting a generalized loss of contrast sensitivity across spatial frequencies (Price, Feldman, Adelberg, & Kayne, 1992), and others indicating a shift in the contrast sensitivity function resulting from changes at specific spatial frequencies (Bodis-Wollner et al., 1987). With respect to LPD-specific biases, Davidsdottir et al. (2008) found no evidence for such. Whether LPD may view objects in the left hemifield to be lower in contrast than those in the right hemifield, using some sort of contrast-matching procedure (Georgeson & Sullivan, 1975) is as yet unknown. If visual signals were weakened in the left hemifield relative to in the right hemifield in LPD, it might affect perception of stimulus length, which would subsequently affect line bisection performance. Such a disparity in signal strength would also seem to be a potential explanation for patterns of exploratory eye movements seen in LPD, who tend to begin exploring the right side of a stimulus rather than the left on a visual search task (Ebersbach et al., 1996), since the salience of a physical stimulus (largely determined by visual signals such as contrast or motion) is an important factor in determining where eye movements will be directed (Hart, Schmidt, Klein-Harmeyer, & Einhauser, 2013).

In the present study, we tested both of these hypotheses using psychophysical methods. To avoid the potential confound of biased eye movements, we employed a brief presentation time in both tasks (<100 ms) and used eye tracking to ensure fixation in the center of the screen. The spatial compression hypothesis was assessed using a task in which the spatial frequency of an object on the left was compared with the spatial frequency of an object on the right. Healthy adults show mild spatial compression of the left hemifield on spatial frequency discrimination tasks (Edgar & Smith, 1990). For the hypothesis to be supported, LPD (relative to the control group) would have to overestimate the spatial frequency of objects in the left hemifield as compared to those in the right hemifield. The reduced salience hypothesis was tested in a similar way, but using contrast as the physical metric of comparison rather than spatial frequency. For the reduced salience hypothesis to be supported, LPD would have to underestimate the contrast of stimuli in the left hemifield as compared to those in the right.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Thirty-one non-demented individuals with Parkinson's disease (15 LPD and 16 RPD) and 16 normal control adults (NC) participated in the study. Demographic and other participant information is shown in Table 1. The groups were matched on age, education, male:female ratio, and premorbid intelligence as measured by the vocabulary section of the Wide Range Achievement Test (Wilkinson, 1993). Potential participants were excluded from the study on the basis of having neurological conditions other than PD, coexisting serious chronic medical illnesses including psychiatric illness, use of psychoactive medication besides antidepressants and anxiolytics in the PD group, history of intracranial surgery (e.g., deep brain stimulation or other invasive PD treatments), traumatic brain injury, current alcohol dependence or substance abuse. All participants except two RPD, one LPD, and two NC received a detailed neuro-ophthalmological examination to rule out visual disorders including significant glaucoma, cataracts, or macular degeneration. All participants were screened for dementia using the Columbia Modified Mini-Mental State Examination (MMSE) (Stern, Sano, Paulson, & Mayeux, 1987). The minimum score for inclusion in the study was 27. The LPD and RPD groups each had a median Hoehn and Yahr score of 2, with most being at a mild to moderate motor stage. The range of scores for LPDs was between 1 and 4 (single individual for the latter) and the range of scores for RPDs was between 1 and 3. LPD and RPD did not differ significantly on their Hoehn and Yahr scores (Kolmogorov–Smirnov, $Z = .97$, $p = .31$) nor on motor severity as measured by the Unified Parkinson's Disease Rating Scale (UPDRS) (Movement Disorders Society Task Force on Rating Scales for Parkinson's Disease, 2003). The Beck Depression Inventory II and Beck Anxiety Inventory were administered to ensure that the groups were matched on mood (Beck & Steer, 1993; Beck, Steer, & Brown, 1996).

2.1.2. Stimulus and procedures

Data were obtained in compliance with regulations of the Institutional Review Board of Boston University, in accordance with the Declaration of Helsinki. All participants provided informed consent.

The stimulus was a pair of static Gabor patches, presented side by side as shown in Fig. 1a. One was designated as the "test", meaning its spatial frequency (SF) varied from trial to trial, and the other was designated as the comparison, meaning it was held constant throughout the testing block. In each trial, the task was to determine which grating, the test or the comparison, had the higher SF (i.e., thinner bands of light and dark), while fixating on the center cross. Eye tracking was used to ensure fixation, as detailed below. The test grating's SF was adjusted over 20 trials in response to the participant's responses, according to a QUEST procedure (quantile method) (Watson & Pelli, 1983). The test grating's SF was adjusted broadly at the start of the procedure, and became more fine-tuned as it progressed (Fig. 1b), approaching the participant's point of subjective equality (PSE) regarding the two gratings' SF. The PSE was quantified as the average of test SF at each of the points at which the staircase changed direction (e.g., from increasing to decreasing SF), excluding the first 5 trials, in which SF varied quite widely.

A PSE was derived for each test condition (when it was on the left versus the right), and converted to a percent of spatial compression. The contrast of the comparison grating was set at 31% Michelson contrast. The contrast of the test was randomly jittered by up to 1.2 log unit in either direction (above or below the comparison's contrast), but was centered on 0.3 Michelson contrast also. This was done in order to remove the potential confound that the perceived contrast of a visual object is affected by its spatial frequency (Robson & Campbell, 1997), and presumably vice versa. Jittering the contrast of the test ensured that participants could not use the perceived contrast of the Gabor patches (linked to SF) as a cue to help them do the task. Stimulus duration was 50 ms. Stimuli were programmed using Psychophysics Toolbox and MatLab (Brainard, 1997) and were presented on a 21″ CRT monitor (Hewlitt Packard FP2141SB) running at 120 Hz.

The procedure was done separately with the test in the left hemifield and in the right hemifield, and a separate PSE was attained for each. This meta-procedure was then repeated at four baseline SFs: 0.5, 1.0, 2.0 and 4.0 cpd. For example, with the Gabor patch on the left (the comparison) set to the baseline SF of 1 cpd, the Gabor patch on the right (the test) might be initially chosen to have a higher SF than that of the test (e.g., 1.8 cpd). The participant would report that the SF of the grating on the right was higher than that of the grating on the left; this response would