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Computers in Human Behavior 22 (2006) 971–980

Computers in Human Behavior

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Development of a world-wide web based contour integration test

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Abstract

Possibilities for dynamic psychophysical experimentation on the World-Wide Web are just beginning to be explored. We sought to develop a Web-based version of a contour integration test that is suitable for clinical studies, and to determine whether the previously described contour integration deficit in schizophrenia could be replicated using the new test. Fields of Gabor patches against a gray background were used as stimuli, and a closed contour had to be located within a noisy background. A two-alternative forced-choice paradigm was developed in which the subject had to identify which direction an egg-shaped contour was pointing. The signal-to-noise ratio of the images, and the spacing between contour elements were kept constant, but the orientation of the contour elements was varied as the critical manipulation. The program to administer the task and record data was implemented within Java. Past results of a contour integration deficit in schizophrenia were replicated. Potential future uses of this test for clinical and research purposes are discussed.

Keywords: Perception; Vision; Contour integration; Schizophrenia; World-wide web

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doi:10.1016/j.chb.2004.03.017

1. Introduction

The World-Wide Web has increasingly become a useful tool for the behavioral sciences. At present, however, its potential for use in vision research is just beginning to be explored (Hecht, Oesker, Kaiser, Civelekm, & Stecker, 1999). There are a number of advantages to developing precise psychophysical testing paradigms for delivery via the Web. These include: (1) the facilitation of standardization of stimulus parameters across multiple testing sites, including clinical situations; (2) elimination of the need for special hardware on local computers; and (3) the possibility of much larger scale data collection on new paradigms, for both norming and test purposes. In this paper, we describe the development of a Web-based contour integration test for use in normal and clinical samples.

In order to arrive at a unified percept of any visually perceived object, the activity of local analyzers responding to the same object has to be integrated. We have been using a contour integration task to study the integration of orientation information across the visual field (e.g., Kovács, 1996; Kovács, Fehér, & Julesz, 1998, 1999; Silverstein, Kovacs, Corry, & Valone, 2000). The task involves the detection of spatially extended patterns with continuous paths of Gabor signals and orientational noise (see Fig. 1). Gabor signals roughly model the receptive field properties of orientation selective simple cells in the

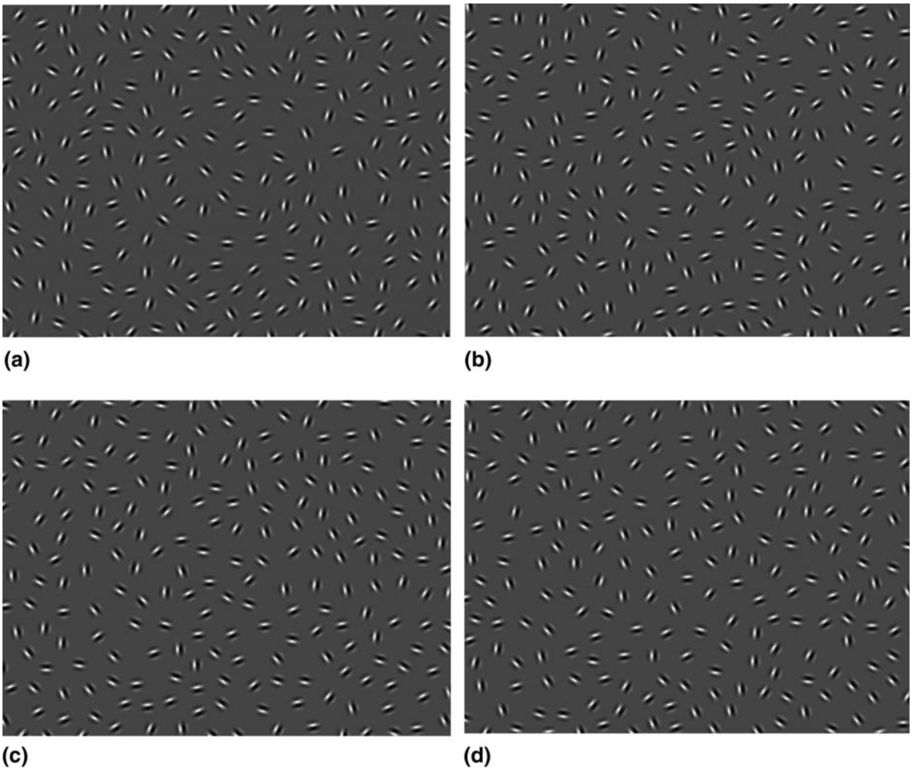

Fig. 1. Samples of images. (a) 0° jitter, (b) 7–8° jitter, (c) 15–16° jitter, (d) 27–28° jitter.

primary visual cortex (V1). They are therefore appropriate stimuli for the examination of these small spatial filters and their interactions. Linking of local Gabor elements in this task requires both local orientation analysis and lateral interactions among the local analyzers. The embedded contour cannot be detected by purely local filters, or by neurons with large receptive fields corresponding to the size of the contour (see also Dakin & Hess, 1998; Hess & Field, 1999). The long-range orientation correlations along the path of the contour can only be detected by the integration of local orientation measurements. The noise forces the observer to carry out these local measurements at the scale of the individual Gabor signals, and to rely solely on long-range interactions between local filters while connecting the signals perceptually. Thus, with these stimuli, long-range interactions subserving spatial integration and perceptual organization can be studied in isolation.

The study of contour integration is of interest for several reasons. One is that it is considered to be a paradigmatic example of feature binding, and is therefore closely linked to several influential theories of coordinated activity. For example, recent theories posit that contour integration results from the context-mediated interaction of feature detectors in the visual cortex, which is thought to involve synchronization of neural firing within the gamma band, and to involve NMDA receptor functioning (Phillips & Silverstein, 2003; Raizada & Grossberg, 2001). Moreover, it has been proposed that the type of coordinated activity involved in contour integration represents a low-level example of a cortical computation algorithm that is common to all areas of the cerebral cortex, and that therefore also underlies aspects of coordination of higher cognitive functions, including psychomotor functioning, memory and language. Computational studies support this view (Phillips & Singer, 1997), as does psychophysical and electrophysiological data from clinical populations demonstrating relationships between impaired perceptual organization (using the contour integration paradigm and other tasks) and disorganization in thinking (Knight & Silverstein, 1998; Silverstein, Bakshi, Chapman, & Nowlis, 1998, 2000; Spencer et al., 2003).

Psychophysical data on contour integration in nonclinical samples are consistent in indicating the thresholds at which contours can be perceived (Field, Hayes, & Hess, 1993; Kovács, Kozma, Fehér, & Benedek, 1999, 2000; Silverstein et al., 2000). The manipulations that are used to determine sensitivity are typically of two types: (1) the individual Gabor patches that make up the contour are jittered at increasing degrees from the circumference of the imaginary contour, making the contour more difficult to detect; or (2) the relative density of the array as a whole, including both contour and noise elements, is varied. With the latter paradigm, at higher density levels, as noise elements enter both the perimeter and the interior of the contoured shape, the contour becomes more difficult to detect.

Impairments in contour integration have been demonstrated in certain clinical disorders. These include schizophrenia (Silverstein et al., 2000), Williams Syndrome (Kovács, Lukács, Fehér, Racsmány, & Pléh, 2001; Lukács, Kovács, Fehér, Racsmány, & Pléh, 2001), and amblyopia (Kovács, Polat, Pennefather, Chandna, & Norcia, 2000; Pennefather, Chandna, Kovács, Polat, & Norcia, 1999). In all of these cases, the contour integration deficit is thought to involve a reduced long-range interactivity between the spatial filters signaling the individual contour elements. In amblyopia, this impairment is considered to be limited to visual processing. In contrast, in schizophrenia, coordination of cognitive activity is thought to be impaired globally (Phillips & Silverstein, 2003;

Silverstein & Schenkel, 1997; Silverstein et al., 2000), and so contour integration can be seen as a "window" from which the integrity of this process can be easily assessed.

Given that contour integration is a robust phenomenon, that there are hypothesized relationships between contour integration and specific neurobiological processes, and that it is impaired in specific disorders, future studies of this process seem warranted. In particular, a standardized version of the contour integration task that can be used across sites, including in clinical settings, would assist in generating both normative data and data on clinical populations. Web-based neuropsychological test batteries for large-scale, multi-site research efforts have recently been developed (Gordon, 2003a, 2003b), but, as yet, visual processing research has not made use of the potential inherent in web-based research. The purposes of this study, therefore, were to: (1) develop a contour integration paradigm that would be easy to administer to clinical and nonclinical populations at multiple sites; and (2) determine whether the previously demonstrated contour integration deficit in schizophrenia can be replicated using this test. The task we developed is similar to that of Field et al. (1993) and Hess and Demanins (1998) who measured contour detection by keeping the noise density stable while varying the angle of the path between adjacent elements. Unlike in those studies, however, we used closed contours as target stimuli rather than open paths. In addition, while prior studies required subjects to indicate whether they could detect a contour or not (and then to indicate its precise location if one was detected), we developed a task which used a two-alternative forced choice format. This was because many clinical populations (especially in psychiatry) may have motivational deficits, which would lead them to give up easily on more difficult stimuli. By using a forced-choice procedure, which requires subjects to respond on every trial, we hoped to maximize the number of trials where subjects would generate significant effort in trying to produce the correct response.

2. Methods

2.1. Subjects

We tested a group of schizophrenia patients ($n = 12$; 4 females, 8 males) and a control group of 11 normal adults (6 females, 5 males). The two groups were age-matched. The mean age was 33.00 years in the schizophrenia and 33.09 years in the normal group. The diagnosis of schizophrenia was established according to DSM-IV (American Psychiatric Association, 1994) criteria. All schizophrenia patients were hospitalized at the time they were tested. The visual acuity of the subjects was assessed by Snellen eye chart at the start of the study. Only subjects with normal or corrected to normal visual acuity were included. None of the subjects had a history of amblyopia and/or strabismus, or suffered from closed head injury, mental retardation and other neurological syndromes, or alcohol and/or drug abuse.

2.2. Contour integration task

Stimuli were initially generated on a Silicon Graphics Iris Indigo R 4000 computer by using a Monte Carlo technique (Braun, 1999), where the contour and the background were controlled independently. The carrier spatial frequency of the Gabor patches was 5 c/deg and their contrast was 95%. The images consisted of a closed chain of Gabor patches forming an egg-like shape within a background of randomly oriented Gabor stimuli (Gabor elements not part of the contour were found both outside and inside the contour). The spacing between the contour elements was kept constant (8λ; where λ is the wavelength of the Gabor stimulus) as was the average spacing between the background elements. The Δ value (average background spacing/contour spacing) of each image was 0.9. It is known from previous results that when $\Delta < 1$, the contour can only be detected on the basis of long-range horizontal interactions between the adjacent elements and that first-order density cues do not play a role in contour detection. By keeping the signal-to-noise ratio at a constant level below 1.0 ($\Delta = 0.9$), subjects' performance was a function of the adequacy of long-range interactions between spatial filters. Only the orientation of the contour elements was varied, between 7° and 27° across six difficulty levels (7–8°, 11–12°, 15–16°, 19–20°, 23–24°, 27–28°). A set of 40 images was presented in 4 blocks of 10 trials at each of the six difficulty levels. A new shape and background were generated for each card, but all of the contours had the same general size and egg-like shape.

The blocks of images were presented in increasing order of orientation jitter. The egg was placed horizontally with its narrower part pointing either to the right or to the left. The number of the images where the egg pointed to the right or to the left was equal within a set of 40 images, although the order of presentation of left and right stimuli was randomized within the different blocks. The contour was always positioned centrally around the fixation point that appeared in the center of a solid gray display during the one second interstimulus interval (ISI). The duration of the presentation was set to 2 s. The subjects had to make a decision within that time frame. We used a two-alternative forced-choice (2AFC) method. The subject's task was to indicate by the mouse buttons which side of the screen the narrower part of the egg was pointing to. The subjects were tested binocularly. They were seated about 0.4 m away from a 17 in. Dell monitor in a normally lit testing room. Monitor resolution was set to 1280×1024. The images subtended 19.93° of visual angle vertically and 26.57° of visual angle horizontally from the testing distance. The mean luminance of the monitor was 21.5 cd/m^2.

Percentage correct answers as well as the number of omissions were recorded. The subjects were first given a block of 10-practice trials with the easiest condition until their performance reached at least 80% correct criterion. Data collection began after that point. When the number of omissions exceeded 20%, subjects were excluded or were run on extra trials. Omissions were more frequent in the schizophrenia group. The omissions were calculated into the final performance of the subjects by adding half of its value to the subjects‘ result. We plotted psychometric functions for each subject using mean scores for each of the six levels of jitter, and calculated threshold performance on the task by fitting a logistic function on the data points. Threshold was defined as the orientation jitter when the performance was 75% correct. Out of the six points, usually two were above criterion performance, two points were around chance (50% correct) and the remaining two points were near threshold.

The program to administer the task and record data was implemented in Java. Instructions for accessing and completing the task, and for scoring results, can be located at the following web site, through the Laboratory of Vision Research at Rutgers University: http://zeus.rutgers.edu/~ikovacs/S&P_contour_manual.html. The data entry form can also be accessed separately at: http://zeus.rutgers.edu/~ikovacs/S&P_contour_dataentry.

html. The test can be accessed separately at http://zeus.rutgers.edu/~ikovacs/H_S&P_contour.html.

2.3. Procedure

Subjects were tested once to determine their threshold on the contour integration test. Testing was done in a quiet room during late morning or early afternoon hours. Every subject was tested binocularly using the same procedures described above. All patients were tested at the Westchester Division of the New York Presbyterian Hospital-Weill Medical College of Cornell University and the normal subjects were tested at the Laboratory of Vision Research at Rutgers University.

3. Results

There were clear effects of jitter condition on the performance of the sample as a whole ($F = 103.61$; df = 3,54; $p < 0.05$) (see Figs. 2–4), indicating that the jitter manipulations were effective in altering detectability of the contours. A significant difference between groups was observed: $t = 2.36$; df = 21; $p < 0.05$ (see Figs. 2–4). The mean threshold values were 18.21° for the nonpatient and 15.56° for the schizophrenia group. These data indicate that the schizophrenia group stopped being able to detect the contours at a lower level of jitter than the controls, suggesting reduced responsivity to grouping cues.

A discriminant function analysis was conducted to determine how well the web-based contour integration test identified people as being in the schizophrenia or the control group. Using the 75% threshold criterion, test scores were able to discriminate groups to a significant degree: Wilk's Lambda = 0.79, $F(1,21) = 5.57$, $p < 0.05$. Ten of 12 schizophrenia patients (83.33%) were classified correctly, along with 7/11 (64%) controls.

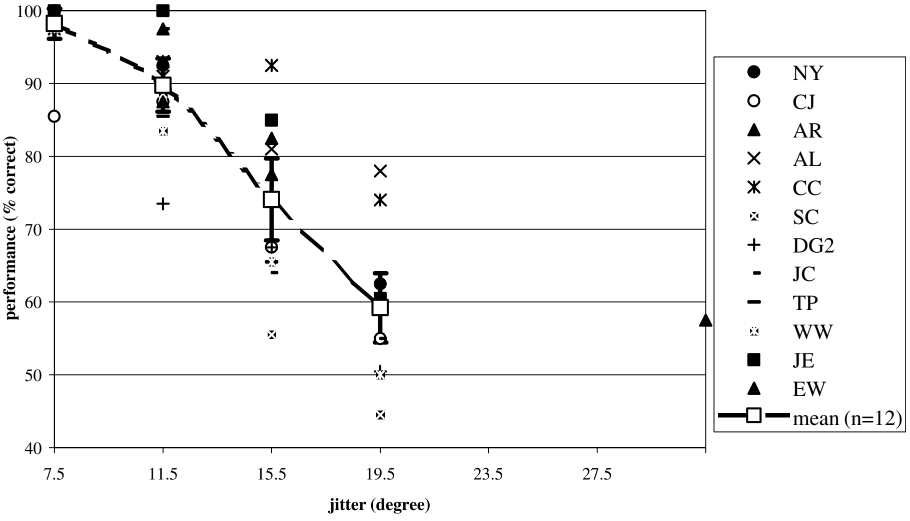

Fig. 2. Summary function of the schizophrenia group with individual results. The performance of each subject is shown as a function of orientation jitter within the contour elements.

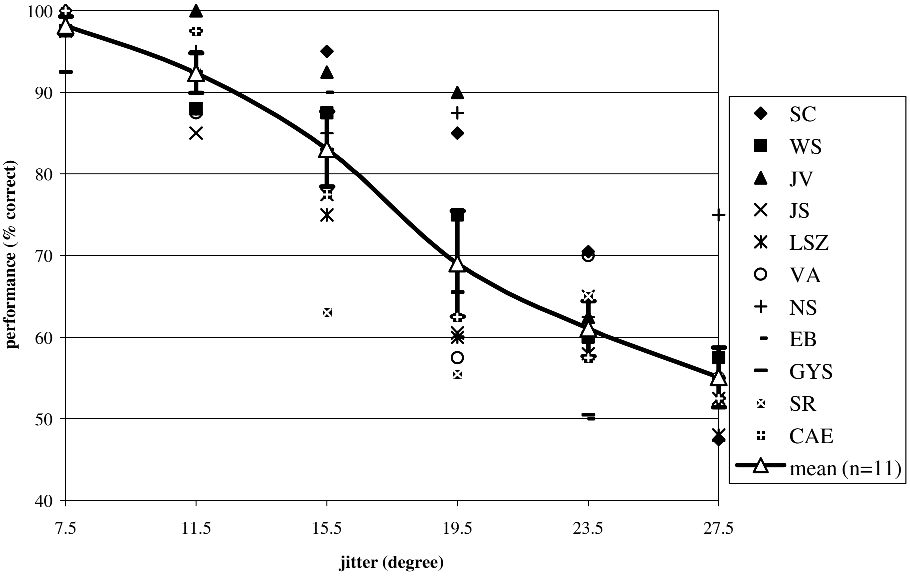

Fig. 3. Summary function of the normal group with individual results.

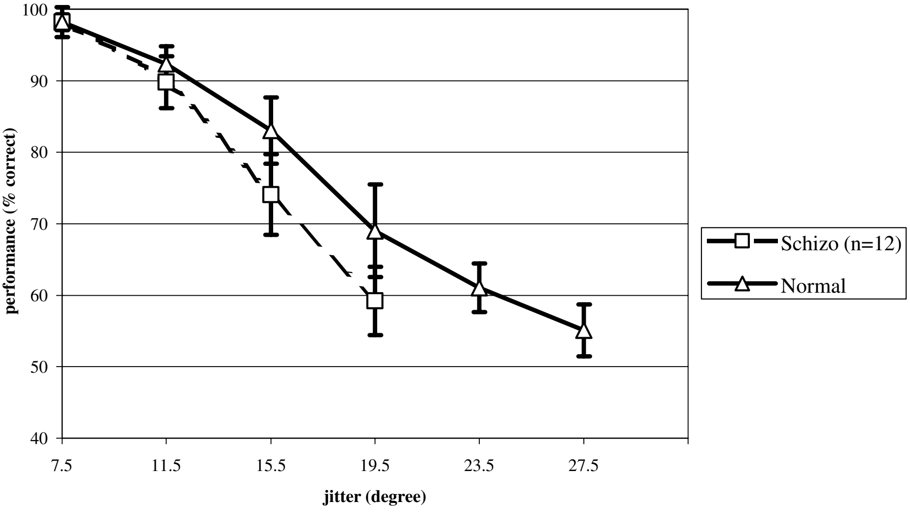

Fig. 4. Comparison graph of the normal and schizophrenia groups.

4. Discussion

Validity of the web-based contour integration test was demonstrated in the regular pattern of performance deterioration with increasing jitter (replicating prior results by Field et al., 1993), and in the group differences between schizophrenia patients and normal controls. The performance deficit observed in schizophrenia is consistent with prior data using an older version of the contour integration task, which did not involve a two-alternative forced-choice format (Silverstein et al., 2000). Moreover, the data are in agreement with a number of prior studies indicating a perceptual organization deficit in schizophrenia patients (Izawa & Yamamoto, 2002; Knight, 1984; Knight & Silverstein, 1998; Place & Gilmore, 1980; Rabinowicz, Opler, Owen, & Knight, 1996; Silverstein et al., 1996, 1998, 2000; Wells & Leventhal, 1984).

The contour integration test described in this report is an advance over past versions of the paradigm in several respects. First, it uses a two-alternative forced choice method, which requires the subjects to generate a response on each trial. In past versions the subjects had to indicate only whether or not they saw a contour and then identify the location. For clinical situations however, in which patients may be poorly motivated and may repeatedly say they do not see a contour, this forced choice format can be expected to produce more accurate results because requiring a response may keep patients more engaged in the task. Second, the better control of the timing of stimulus presentation is a methodological improvement over the earlier card set versions, and can allow for easier comparison of data across sites. Third, by using a web-based format, the identical paradigm could be used at multiple sites (Weill Medical College of Cornell University and at Rutgers). Using a Web-based test, data can be generated much more rapidly, and assessment of generalizability (e.g., across nonpatients at multiple sites, clinical populations, cultures, etc.) can be facilitated. A further benefit of the web-based paradigm over older methods is that each study site needs only an internet connection to administer the test and does not require additional hardware to control the timing and presentation of the stimuli. To begin to compare newly collected data to those reported in this paper, it is only necessary that the visual angle of the stimuli be consistent with what we report (which is simplified if a 17 in. monitor is used), that resolution is set to 1280 × 1024, and that luminance be set to 21.5 cd/M^2.

In the new contour integration test, the parameters of grouping as well as the timing of stimulus presentation are precisely specified and controlled. The task is closely tied to biological models of visual perception. The individual Gabor elements activate relatively small numbers of spatial filters, and successful task performance requires intact, coordinated, long-range activity between these filters. This is thought to involve synchronization of neural activity within the gamma band, and to occur early in the visual processing stream (Kovács, 1996; Kovács & Julesz, 1993, 1994; Kovács et al., 1998, 1999; Phillips & Silverstein, 2003; Raizada & Grossberg, 2001). Therefore, the contour integration test is potentially useful not only as a psychophysical tool, but also as a method to examine the underlying neurophysiology of perceptual organization and cognitive coordination. This, in turn, may provide important information on the biological bases of both normal and disordered perception and cognition.

Due to the stimulus and task design advantages afforded by this new contour integration task it is an ideal paradigm for studying the time course (using event-related potentials) and neurophysiological substrates (using functional imaging techniques) of cognitive coordination involved in visual perception. For example, a critical question regarding the neurophysiology of visual perception organization is the degree to which attentional and contextual influences occur within V1 when subjects are interpreting the visual environment (Gilbert, Ito, Kapadia, & Westeimer, 2000). While it has been proposed that activity within V1 is sufficient to achieve contour integration (Giersch, Humphreys, Boucart, & Kovács, 2000), stimulus and condition presentation effects in contour integration performance

(Silverstein et al., 2003), and expectancy and top-down effects in basic visual processes such as lateral interaction and temporal integration (Freeman, Driver, Sagi, & Zhaoping, 2003; Visser & Enns, 2001) raise the possibility of dynamic interactions between horizontal connections within V1 and feedback connections from higher cortical areas. The two-alternative forced choice design along with the precise psychophysical nature of the stimuli makes this task well suited for clarifying these types of issues regarding the neurobiology of visual perception.

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