Behavior Research Methods
2008, 40 (2), 383-390
doi: 10.3758/BRM.40.2.383

Visualized representation of visual search patterns for a visuospatial attention test

HO-CHUAN HUANG
National Kaohsiung University of Applied Sciences, Taiwan

AND

TSUI-YING WANG
National Cheng Kung University, Taiwan

Cancellation tests have been widely used in clinical practice and in research to evaluate visuospatial attention, visual scanning patterns, and neglect problems. The aim of the present work is to present a visualized interface for the visuospatial attentional assessment system that can be employed to monitor and analyze attention performance and the search strategies used during visuospatial processing of target cancellation. We introduce a pattern identification mechanism for visual search patterns and report our findings from examining the visual search performance and patterns. We also present a comparison of results across various cancellation tests and age groups. The present study demonstrates that our system can obtain more processing data about spatiotemporal features of visual search than can conventional tests.

Visual search is a common scanning procedure that people use to locate objects in real life. During a typical experiment with the visual search task, a participant is required to search for a specific target in a visual scene; the number of targets and nontargets (distractors) or feature dimensions (e.g., colors) may be manipulated to evaluate reaction times and performance on the visual search task. Visual search is often affected by neurological deficits and, therefore, requires clinical attention for problem identification and further management of symptoms. However, most lab instruments for visual search studies may be inappropriate for clinical evaluation. Therefore, we modified a popular assessment instrument, the cancellation task, from a paper-and-pencil test to a computer-based test (Wang, Huang, & Huang, 2006) for education and clinical administration. To better express the spatiotemporal process during the assessment, we introduced a pattern identification mechanism for visualized representation of visual search patterns.

Previous studies have indicated that the features shared by the target and the distractors, as well as the number of search items, will affect reaction times and the performance of visual search (Hogeboom & van Leeuwen, 1997; Müller & Found, 1996; Scharroo, Stalmeier, & Boselie, 1994; Treisman, 1991; Wolfe, 2001). Treisman and Gelade (1980) proposed the feature integration theory, in which two types of visual search tasks are distinguished: feature search and conjunction search. Feature search, in which a single feature, such as size, color, orientation, motion, curvature, or depth, solely defines the target, can be executed easily. Feature search is performed in parallel in the preattentive stage, and reaction time will not be affected by the number of distractors. In contrast, conjunction search is a more complex task requiring the examination of targets and nontargets that share the same features. As the number of distractors increases, participants require more time to complete the conjunction search task.

Visual search tasks have been used to study the deployment of visual attention in a visual scene (Bundesen, 1990; Bundesen, Habekost, & Kyllingsbaek, 2005; Johnson & Proctor, 2004). An individual's intention controls the allocation of attention and guides the attentional focus and the processing of selected information consecutively. Posner and Rafal (1987) reported that visual-scanning deficits can disrupt visual attention. Shifts in visual attention (i.e., the orienting process) are usually accompanied by motor behavior (overt movements of the head and eyes to align the fovea with the spatial locus of the target) and can be observed by means of reaction time for motor output. Therefore, visual attention can be observed through people's motor behavior when they perform a visuospatial task.

In the studies of visuospatial attention, an individual has to search for a specific target in a search scene, which involves the spatial processing with the temporal component of the task (Robinson & Kertzman, 1990; Snowden, Willey, & Muir, 2001). When an individual searches for a target scattered in a visual scene but fails to point out the target and its location, it is likely that the person has deficits in visuospatial attention. The cancellation test is one of the most popular tools for assessing visuospatial

T.-Y. Wang, michwang@mail.ncku.edu.tw

attention (Byrd, Touradji, Tang, & Manly, 2004; Lowery, Ragland, Gur, Gur, & Moberg, 2004). Traditional paper-and-pencil cancellation tests are used for clinical settings and research to evaluate visuospatial attention, visual-scanning patterns, and neglect problems (Halligan, Burn, Marshall, & Wade, 1992; Weintraub & Mesulam, 1985). The formats of cancellation tests vary widely in terms of complexity, with respect to stimulus shapes, set sizes, and array layouts (Friedman, 1992; Halligan et al., 1992; Wilson, Cockburn, & Halligan, 1987).

Despite the extensive application of cancellation tasks in research, there are relatively few reports on the spatial aspects of cancellation performance in healthy populations. Some studies have examined error distributions for the left and right halves of cancellation forms, finding no significant difference for small samples of healthy adults (Gauthier, Dehaut, & Joanette, 1989; Weintraub & Mesulam, 1987, 1988). Geldmacher and colleagues studied verbal and nonverbal cancellation performance in a large sample of healthy adults and reported conflicting findings for visuospatial attention bias. They suggested that the reading habit may be an interacting factor to be considered for the directional bias (Geldmacher & Alhaj, 1999; Geldmacher, Doty, & Heilman, 1994).

In other experiments, cancellation tests have been used as a tool for understanding visual exploratory performance during the target-searching process. It has been assumed that the extent of the disorganization of cancellations may relate to visual inattention. Healthy participants usually cancel targets in organized patterns, generally horizontal (e.g., left to right) or vertical (e.g., top down) (Donnelly et al., 1999; Gauthier et al., 1989; Weintraub & Mesulam, 1988). However, Mark, Woods, Ball, Roth, and Mennemeier (2004) reported no significant correlations between omissions and search organization variables for cancellation performance. They used a small camera to record the test performances of 18 stroke patients and conducted a frame-by-frame analysis on the searching path, with marked stimuli identified by Cartesian (x, y) coordinates. Difficulties arise when one attempts to replicate the study with a large sample through such an all-by-hand method. We suggest that further examination of the topography of target searching is necessary to rule out visual attention problems and that an automated procedure is required.

Computerized technologies have been widely used in different assessment tools. Both Donnelly et al. (1999) and Potter et al. (2000) used computers to record and analyze spatiotemporal performance, such as premovement time (initial movement), movement time (time between two successively marked stimuli), drawing time (completing a cancellation), and pause time (the preparatory process). These computer-assisted assessment tools more sensitively measured visuospatial attention performance than did traditional assessment tools. Wang et al. (2006) constructed the computer-assisted cancellation test system (CACTS) to investigate the performance of visuospatial attention in a population of schoolchildren. We used CACTS to analyze visual attention performance in terms of visual search pattern, moving time, pause time, and performance, which allowed us to observe not only the correct/error responses, but also the cancellation process. However, the system did not support a visualized interface for analyzing the visual search path and attentional center, which could increase our understanding of attentional deployment.

In the present article, we present a new visuospatial attentional assessment system for assessing and obtaining more detailed information of attentional processes and performance. We use the cancellation test to assess attention performance, the efficiency of attentional shifts, and the strategies of visuospatial search in a visual scene. A visualized tool is introduced that presents the geographical location of the attentional center for visuospatial attentional processes. In addition, a pattern identification algorithm is proposed for automatically identifying the type of visual search pattern. With the assistance of computerized tools, we can understand individual discrepancies in the process and strategy of visuospatial search better.

Visual Search Pattern and Attentional Center

During a visual search task with more than one target, all the stimuli marked by the participant can be linked sequentially to form a visual scanpath. A scanpath is the serial deployment or shifts of the attentional spotlight across displayed visual information mapped in iconic memory (Posner & Peterson, 1990). We define a scanpath as "the total of the cancellation sequences (i.e., links of marked stimuli) based on the temporal order of stimuli marked during the visual search process." In other words, a scanpath shows the attentional shifts for stimuli marked from one location to the next across the visual scene. With the assistance of the CACTS scanpath analysis, we were able to monitor the attentional shifts of participants in order to understand their deployment of visuospatial attention.

A visual scanpath can be as simple as a straight line or as complex as a visual search graph. We classified a visual search graph into three search pattern types: a horizontal, a vertical, and a mixed search pattern. To avoid trivial processes in identifying search patterns by human-made detection, we established a pattern identification algorithm with an evaluation measure, the search pattern index, for automatically identifying the visual search pattern (Figure 1). Two expressions relevant to the search pattern index are

$$\text{line}_{(i-j)} = \sqrt{\left(X_j - X_i\right)^2 + \left(Y_j - Y_i\right)^2} \tag{1}$$

and

$$\text{slope}_{(i-j)} = |S_y/S_x|, \tag{2}$$

where $S_x = (X_j - X_i)$ and $S_y = (Y_j - Y_i)$; (X_i, Y_i) and (X_j, Y_j) are the coordinates of the stimuli i and j, respectively; $\text{line}_{(i-j)}$ is the distance between two marked stimuli i and j; $\text{slope}_{(i-j)}$ is the slope of the straight line (i.e., $\text{line}_{(i-j)}$) and is used to identify the type of the straight line (horizontal or vertical). Two variables, H-sum and V-sum, are used to calculate the total length of paths for horizontal and vertical lines, respectively. If the value of $\text{slope}_{(i-j)}$ is less than 1 or the value of S_y is zero, the line will be horizontal, and the length of line segment $\text{line}_{(i-j)}$ will be accumulated into the H-sum variable. On the other hand, if the value of $\text{slope}_{(i-j)}$ is larger than 1 or the value of S_x

```
Algorithm: SP-index(G, P) Pattern Identification.
Input: G, a visual search graph (a set of visual search paths)
Output: P, a type of search pattern for the input G.
Method:
  Scan G for a set of sequential lines, ℓ.
  H-sum = 0, V-sum = 0; // the total value for vertical and horizontal lines
  Repeat
  {
   for each line ℓ ∈ G          // identifying individual lines
     S_x = (X_j – X_i); S_y = (Y_j – Y_i);   // i ∈ (X_i, Y_i), j ∈ (X_j, Y_j)
     Line_(i–j) = square-root((S_x)^2 + (S_y)^2); //calculating line's length
     Slope_(i–j) = |S_y/S_x|;          //calculating the slope of the line
     If Slope_(i–j) < 1 or S_y = 0 then H-sum = H-sum + Line_(i–j);
        else if Slope_(i–j) > 1 or S_x = 0 then V-sum = V-sum + Line_(i–j);
  } until the line is empty;
  SP-index = (H-sum / V-sum) – 1;
  Procedure (SP-index);

Procedure (SP-index)
  {
   If |SP-index|≤ θ then P = "mixed"; //a mixed pattern
    else if SP-index > θ then P = "horizontal"; //a horizontal pattern
    else P = "vertical";   //a vertical pattern
    Output P;              //output the type of search pattern
  }
```

Figure 1. Pattern identification algorithm. SP, search pattern.

is zero, the line segment $\text{line}_{(i-j)}$ will be vertical, and the length of the line segment will be accumulated into the *V*-sum variable.

In addition, the system automatically identifies the type of search pattern according to the threshold value, θ. If the ratio of *H*-sum to *V*-sum is within the threshold value, the type of search pattern will be identified as mixed. If the ratio of *H*-sum to *V*-sum is larger than the threshold value, the pattern will be identified as horizontal. On the contrary, if the ratio is less than the threshold value, the pattern will be identified as vertical. The higher the threshold value, the more likely it is that a mixed search pattern will be identified. The task administrators of the CACTS can adjust the threshold value for different research purposes. In the present study, we set up the initial value of the threshold on the basis of our training data obtained from a previous experiment (Huang & Wang, 2005). The search patterns of the 50 participants in the structured array were identified by human visual examination, as well as automatically by the system. To obtain the optimal threshold for the pattern classification, we chose six different threshold values (i.e., 0, 0.1, 0.2, 0.3, 0.4, and 0.5) for the analysis of visual search patterns. The frequencies of vertical versus horizontal patterns were (14, 34), (12, 32), (8, 30), (6, 29), (5, 27), and (4, 25), and the frequency for the man-made judgment was (13, 32). The interrater reliability between human visual examination and system-automated identification was examined using the intraclass correlation coefficient. The Cronbach's alpha values were .874 ($\theta = 0$), .989 ($\theta = 0.1$), .891 ($\theta = 0.2$), .857 ($\theta = 0.3$), .805 ($\theta = 0.4$), and .783 ($\theta = 0.5$), respectively. Therefore, the reasonable range of the threshold was from 0 to 0.2, and we chose the optimal value ($\theta = 0.1$) for the present study. The details of the pattern identification algorithm are provided in Figure 1.

We adopted another performance measure, *Q score*, to assess the visuospatial performance of the participants as follows (Hills & Geldmacher, 1998):

$$Q \text{ score} = \frac{\text{correct responses}}{\text{total target}} \times \frac{\text{correct responses}}{\text{completion time}}. \quad (3)$$

Correct responses are the total number of correct targets marked by a participant, and *total targets* are the total number of targets in a test ($n = 60$ in this test). *Completion time* is how long it took the participant to finish the test. The higher the *Q* score, the better the visuospatial attention performance. In addition, the search screen was invisibly divided into four quadrants, using Cartesian coordinates, when the system recorded the spatiotemporal data of the visual search. To specify the location of any stimulus on a 2-D coordinate system, every stimulus was coded using its *x*- and *y*-axes coordinates. The center point (also called the *origin point*) was at the center of the page with the coordinates (0, 0).

Mark and Monson (1997) proposed the concept of attentional/neglect centers to identify visual attention problems. We adopted their idea and included it as part of the analytical mechanism of our system. The attentional center is the geographical center of all the marked stimuli on the test screen and is quantified by averaging the Cartesian coordinates of all the marked stimuli. The system automatically calculates and identifies the attentional center for each participant when the participant completes the test. Because all the target stimuli are symmetrically scattered across the screen from the center point, the mean coordinates of all the symmetrical stimuli are the center point. If a participant does not mark all of the targets (i.e., missed one or more target stimuli) or marks one or more nontargets in a test, the attentional center falls away from the center point. An attentional center in CACTS is visualized as a coordinate point (x, y) connected to the center point (0, 0) by a line segment. The standardized length unit of the attentional center is centimeters, to allow for evaluating the discrepancies between different layouts of cancellation tests.

To support the analysis of attentional processes, the test screen is divided into nine identical regions, one circular central region surrounded by eight equal regions (45º in radius for each region) labeled center, far, far-right, right, near-right, near, near-left, left, or far-left (see Figure 2). In addition, the system also provides task administrators with the coordinate information of the attentional center for individual demands of visuospatial attentional analysis, such as *near or far regions*, *left-side and right-side regions*, and so forth. In the present study, we separated the screen into four quadrants: The first quadrant represented the far-right region (+, +), denoted by "I"; the second represented the far-left region (−, +), denoted by "II"; the third and fourth were near-left (−, −), denoted by "III," and near-right (+, −), denoted by "IV."

SYSTEM OVERVIEW

System Architecture

We constructed a new CACTS architecture to support the analysis of attentional processes, using a visualized in-

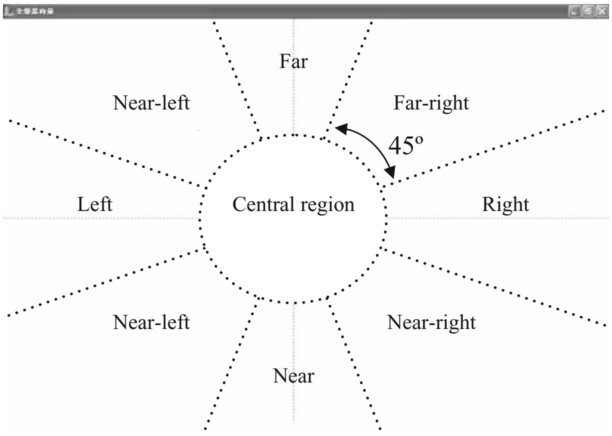

Figure 2. Labeled attentional regions.

terface. The former CACTS architecture was on an IBM-compatible PC running the Microsoft Windows XP operating system and connected to a 9 × 12 in. graphic tablet (WACOM PL-400) with a stylus pen for data input (Wang et al., 2006). CACTS was redesigned and implemented on a convertible tablet computer (screen size: 9 × 12 in.). CACTS uses the tablet computer's touch screen as "paper" and receives the writing signal from a pressure-sensitive stylus pen. When participants touch the target with the stylus pen, the system will automatically mark out the target with a blue circle symbol. Therefore, the participants experience the computer version of the cancellation tasks as marks on digital paper.

The CACTS architecture consists of four modules: a graphical interface, a user profile, an attention test, and an attention diagnosis. The graphical interface gives the task administrators a visualized representation of test performance and data analysis. Task administrators can select the items they are interested in and get more information using the graphical interface, such as their personal profile, test results, and visual search pattern. The user profile module stores participants' demographic data, such as identification number, name, age, gender, and education, for analyzing the relations between the participants' profiles and test results. The attention test module consists of various forms of cancellation tests with different types of stimuli (numerical, alphabetical, symbolic, and Chinese characters), and each form includes both structured and random arrays. The attention diagnosis module is composed of different diagnostic functions, such as attention performance and attentional center, for analyzing the participants' visuospatial functions.

System Implementation

We moved the hardware platform of CACTS from its original PC architecture to the tablet computer. CACTS uses a tablet computer with ambient light sensors to control the display of stimuli on the screen. The task was programmed using Borland C++ language. The stimulus shapes are displayed on a 14.1-in. LCD screen with 1,024 × 768 resolution. Four kinds of stimulus forms have been constructed in the system. The numerical form consists of 10 Arabic numbers (0–9); the alphabetical form consists of 26 uppercase alphabetical letters (A–Z); the symbol form consists of 52 different symbolic shapes, such as ☼ and •; and the Chinese form is composed of 26 traditional Chinese radicals (the basic components of Chinese characters), such as 日 and 工. In addition, task administrators can create a new test form freely on their own by appending new stimulus shapes to the system.

Collected data are classified into demographic data and test data. The demographic data include participant ID, name, age, gender, education, special conditions (such as diagnosis group), and so on. Test data are further classified into static and kinematic data. Static data contain information about the participant's attention performance, such as the number of correct responses, errors of commission and omission, completion time, the time and the location of the initial response, and the left- and right-hemispace dispersion of responses. The kinematic data are used for studying the dynamics of attentional processes from the beginning to the end of the test. Kinematic data, collected throughout the entire test process, include the visual scanpath, moving time, pause time, and so forth. All test data are recorded in a Microsoft Office 2003 Access database. We divided data into three groups in the database: the user table (i.e., demographic data), process table (kinematic data), and outcome table (static data).

The attention diagnosis module offers a data management interface and a pattern management interface. The data management interface provides task administrators with performance information, such as user profiles, test results, and the ratio of correct to error responses. The pattern management interface (Figure 3) focuses on the administration and analysis of the visual search pattern, such as the click time and distance of the total search path, the sequence of the visual search, and so forth. A reduced-scale figure of the visual search pattern (upper left side of Figure 3) also shows the visual-scanning strategy of a participant. The right side of Figure 3 is the line graph that represents the distance or the moving time between any two marked stimuli during the whole test process.

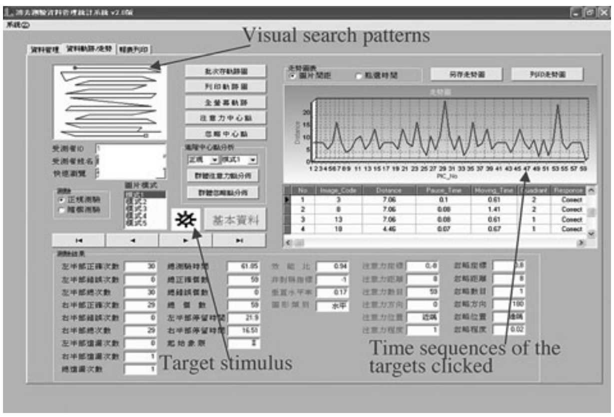

Figure 3. Pattern management interface.

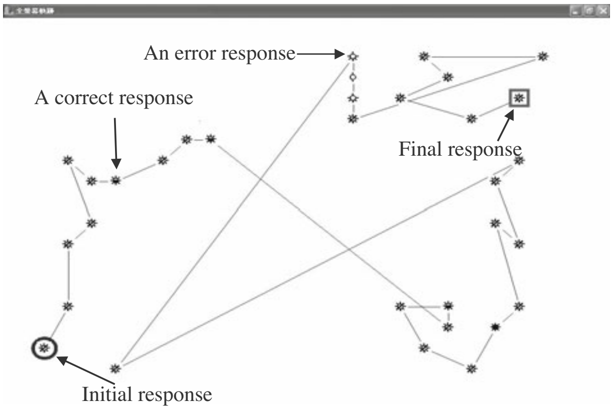

Figure 4. A visual search pattern.

CACTS is able not only to present the sequence of visual scanning of individual participants, either step by step or all at once, but also to provide information about every response (whether it was a correct or an error response, the stimulus shape, etc.). A visual search pattern for a participant is shown in Figure 4. The circle node denotes the location of the initial response, and the square represents the location of the final response. The nodes between the initial and the final responses are the sequential nodes of visual scanpaths. To present more information about the attentional center, the system indicates the location of the attentional center with the regional label or the coordinates. Finally, a screenshot (Figure 5) shows a participant's attentional center on the $(-7, -2)$ coordinates.

METHOD

Participants

We recruited 149 undergraduates (86 of them male, mean age = 20.2 years [57.7%]; 63 of them female, mean age = 20.0 years [42.3%]) to participate in the experiment. All the participants had normal or corrected-to-normal visual acuity and normal color vision. The students were assessed through health examinations and were free from any physical illness, neurological deficits, visual or motor problems, and perceptual disorders. Informed consents were obtained from the participants before they began the study.

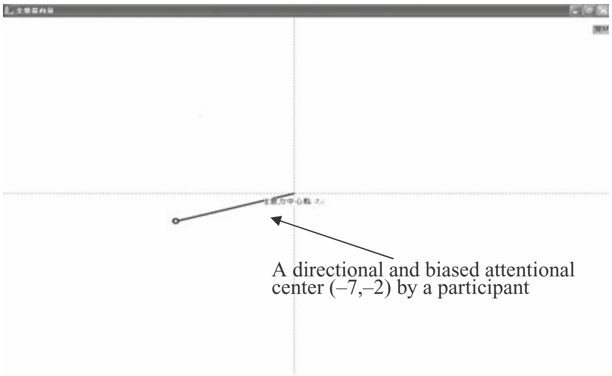

Figure 5. A biased attentional center.

Test Administration

Each participant completed the symbol cancellation tasks with structured and random arrays. Both tasks consisted of 52 different symbolic shapes, such as ☼ and •, with a ✲ target. Sixty targets were equally distributed in four quadrants (n = 15 in each), with 314 distractors arranged in lines or scattered randomly in the visual scene, which contained 374 stimuli total. For the structured array, the spacing of any 2 adjacent stimuli in a row or column was equivalent, but for the random array, the spacing varied between any 2 adjacent stimuli.

Procedure

During the test, the participants were seated upright in straight-backed chairs, with their midsagittal planes aligned with the screen. The screen was placed at a 30º tilted angle and at a distance of 20–30 cm in front of the participant. The procedures and recording process of the experiment were as follows. The participant's demographic data was first obtained, and then the test form and layout were selected. Before the test, each participant was given detailed instructions and a practice trial to make sure the test was fully understood. The participants were asked to search for and, using a stylus pen on the screen, to mark all the targets as quickly as possible. There were no time limits and no restrictions on head or eye movements during the test. A test was terminated when the participants pressed any key on the keyboard. Normally, a single test took less than 5 min to complete, and each participant should have been able to finish all the tests within 10 min. Two test layouts (structure and random arrays) were given in a counterbalanced order to avoid any practice effects.

Data Collection and Analysis

For this experiment, the CACTS system automatically collected the following data.

Attention performance. Attention performance was represented by the Q score, shown in Equation 3.

Correct response. A correct response was scored when a participant successfully marked one target.

Error response. An error response was counted when a participant marked a nontarget (commission) or missed a target (omission).

Total response time. Total response time was defined as the time between the first marking and the termination of the test.

Initial location. Initial location was the location of the first stimulus marked by the participant. The location of the initial marking was represented by either a coordinate value (e.g., [3, 5]), to locate its specific position on the screen, or a Roman numeral (I, II, III, or IV) to represent its position in a quadrant of a 2-D Cartesian coordinate system.

Attentional center. The attentional center was a spatial vector or simply a vector that was an arrow pointing from the center point to the endpoint on the x–y plane. The endpoint of the attentional center was obtained by summing up all the coordinate values of all the marked stimuli.

Pattern type. A pattern type that represented a visual search graph was automatically classified as a horizontal, vertical, or mixed pattern by the pattern identification algorithm.

We used SPSS 12.0 (SPSS Institute, Chicago, IL) for data analysis. Independent and paired t tests were used to compare the attention performance between genders and tests. Nonparametric analyses of related samples were used to compare the lateralization of visual-processing patterns and the association between the attentional center and performance.

RESULTS

There were no significant differences in the completion time ($t_{structured} = -0.531, p = .596; t_{random} = -0.755, p = .451$) or Q scores ($t_{structured} = 0.421, p = .674; t_{random} = 0.508, p = .612$) between males and females.

Table 1
Paired *t* Test of Attention Performance on Two Different Symbol Tests ($N = 149$)

Measure	Array: Structured *M*	*SD*	Random *M*	*SD*	*t*	*p*
Performance score (*Q*)	0.77	0.25	0.83	0.25	−3.902	.000**
Correct response (score = 0–60)	59.3	1.1	59.5	1.0	−1.264	.208
Error response	0.05	0.21	0.03	0.18	0.576	.565
Completion time (sec)	85.6	32.3	81.5	33.2	2.193	.030*

*$p < .05$. **$p < .001$.

Table 1 summarizes the attention performance on both symbol cancellation tasks. There was no significant difference between the performances on structured and random arrays regarding the correctness of the task, but completion times and *Q* scores were significantly different. The participants spent more time on the structured array ($t = 2.193$, $p < .05$), which resulted in a lower *Q* score ($t = -3.902$, $p < .001$).

Table 2 gives a descriptive analysis of visual search patterns and attentional centers. More than 95% of the participants started their visual search from the left side, rather than from the right side, and this was consistent in both test arrays ($Z = -1.137$, $p = .257$). The attentional center was in the center (0, 0) for most participants ($n = 94$ [63.1%] for structured and $n = 109$ [73.1%] for random arrays). Sixty-two (41.6%) participants had different attentional centers between different arrays, and 87 (58.4%) participants maintained the same ($Z = -0.889$, $p = .374$). A horizontal search strategy was used by 91 (61.1%) in the structured array and by 77 (51.7%) in the random array. A vertical search strategy was used by 48 (32.2%) in the structured array and by 45 (30.2%) in the random array. A mixed search strategy (i.e., a combination of horizontal and vertical search strategies) was used by 10 (6.7%) participants in the structured array and 27 (18.1%) in the random array (Table 2). This shows that more participants used horizontal than vertical search strategies with both the structured and the random arrays. In addition, some participants ($n = 34$, 22.8%) changed their search strategies from one pattern to another (horizontal, vertical, or mixed patterns) between different test layouts (random and structured arrays), and the rest ($n = 115$, 77.2%) remained the same. The change of search patterns between structured and random arrays is called an *inconsistent search pattern*. We also analyzed the within-subjects difference in search patterns between the two test layouts, which was statistically significant ($Z = -2.229$, $p = .026$) in the present study, which suggested that the search patterns of some participants changed as the test layouts changed. The initial location of the visual search was not affected by the test layouts in this study ($p > .05$), however.

The total left/right errors were 40 ($n = 33$)/65 ($n = 46$) in the structured array and 38 ($n = 29$)/46 ($n = 31$) in the random array. We found a significant difference between the left- and right-side errors [structured array, χ^2 (16, 149) = 32.906, $p < .01$; random array, χ^2 (8, 149) = 35.402, $p < .001$].

Using repeated measures, we further compared the *Q* scores and the completion times between participants with consistent and inconsistent search patterns and found no between-group differences in these two variables (*p*s = .734 and .967). To see whether there was any association between the attentional center and performance, we further categorized the participants into three groups. The attentional center was on the left side of the screen for Group 1 ($n = 26$), in the center point (0, 0) for Group 2 ($n = 109$), and on the right side for Group 3 ($n = 14$). For the random array, a one-way ANOVA showed significant between-group differences in *Q* scores [$F(2) = 5.904$, $p < .005$]. A post hoc analysis showed that Group 1 had a statistically significant higher *Q* score (mean difference = .186, $p < .005$) than did Group 2. For the structured array, however, we found no significant differences.

Table 2
Visual Search Patterns of the Participants ($N = 149$)

	Array: Structured No.	%	Random No.	%	*Z*	*p*
Attentional Center						
Center point	94	63.1	109	73.1	−0.889	.374
Right side	18	12.1	14	9.4		
Left side	37	24.8	26	17.5		
Pattern Type						
Horizontal	91	61.1	77	51.7	−2.229	.026*
Vertical	48	32.2	45	30.2		
Mixed	10	6.7	27	18.1		
Initial Location						
Right side	7	4.7	4	2.7	−1.137	.257
Left side	142	95.3	145	97.3		

*$p < .05$

DISCUSSION

We found that the participants in the present study had search strategies similar to those of the participants in previous studies (Dawes & Senior, 2001; Wang et al., 2006) in terms of initial location of marking, search strategy, and completion time difference in both test layouts. The random-symbol test took less time to complete than did that with structured arrays. More than 90% of the participants started searching from the left side and used a horizontal search strategy. When the test layouts (i.e., structured or random arrays) changed, the initial locations almost always remained the same, but the visual search patterns changed significantly.

Woodward (1972) predicted that visual search patterns would change because, he suggested, the distal/proximal factor would affect not only the total time of the visual search, but also the orientation of the searching behavior. In the present study, the distances between lines and columns were constant in the structured array but varied significantly in the random array. Given that the distance between two stimuli influences the visual search orientation, an individual tends to search for the closest next target. This explains why some participants in this study changed their search patterns between the two layouts.

Wang, Huang, and Yang (2004) reported that a computerized version of the cancellation test took longer than the paper-and-pencil version to complete and was more difficult (i.e., the error rate was higher) for a population 50 years of age and older. This agrees with the comparison of our computerized version findings with those for the paper-and-pencil-version in Dawes and Senior (2001). Previous studies (Dawes & Senior, 2001; Lowery et al., 2004) have shown no association between gender and completion time or performance, which is consistent with our CACTS results. Researchers also have suggested that age is related to completion time on a cancellation task. When this study is compared with our previous studies on schoolchildren (Wang et al., 2006) and the elderly (Wang et al., 2004), the completion times are significantly different ($p < .001$), ranking the lowest in college students ($n = 149$; $M_{structured} = 85.55$ sec, $SD = 32.25$; $M_{random} = 81.52$ sec, $SD = 33.21$) and then the elderly ($n = 33$; $M_{structured} = 132.18$ sec, $SD = 79.99$; $M_{random} = 127.88$ sec, $SD = 63.72$) and the highest in schoolchildren ($n = 82$; $M_{structured} = 187.93$ sec, $SD = 79.74$; $M_{random} = 158.90$ sec, $SD = 62.7$). We found that completion time was associated with age-related processing speed. Information-processing speed increases as a child matures, reaching its apex in early adulthood, and gradually declines with age (Kail & Bisanz, 1982; Salthouse & Kail, 1983). Previous studies on visual attention have suggested that the process of attentional shifts and cognitive attention toward various attention tasks in visual performance may be affected by age differences (Curran, Hills, Patterson, & Strauss, 2001; Geldmacher & Riedel, 1999; Kail, 1991; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000).

We found that most participants started their spatial search from the left side and used a left-to-right search pattern on both arrays. The participants made fewer errors on the left side of the screen than on the right, which implied a left-side advantage, findings consistent with those in previous studies on a Chinese population (Dawson & Tanner-Cohen, 1997; Wang et al., 2006). Our results also supported the findings of several related studies using diverse methods to demonstrate a right-hemisphere dominance in visual search performance (Geldmacher et al., 1994; Mesulam, 1985; Vingiano, 1991; Weintraub & Mesulam, 1988). Vingiano found that nonverbal stimuli were associated with right-side inattention, and with a leftward rather than a rightward performance bias on timed cancellation tasks in English-reading college students. Other studies also have suggested that the reading directions of some languages (e.g., Hebrew and Arabic languages; Chokron & Imbert, 1993; Geldmacher & Alhaj, 1999) and intrinsic motor behavior (Schwartz, Adair, Na, Williamson, & Heilman, 1997) may have an interaction effect on the left-advantage phenomenon. Further investigations that consist of samples with a wider educational background, various neurological conditions, and a combination of other assessments with CACTS would provide more evidence for understanding the visuospatial performance of an individual.

CONCLUSION

Many traditional assessment tools are being replaced by computer-assisted assessments because they are time-saving, less biased, more precise, and more efficient to process and because they have more storage capacity. In the present study, we found that a computerized assessment system obtained more detailed information than a traditional paper-and-pencil assessment did about an individual's attentional processes and performance. A visualized tool was presented to locate the attentional center and monitor the visual scanpath in order to understand shifts in visual attention.

We found that the CACTS offered preliminary data about visuospatial attention and a visual scanpath for the target search task, which may have implications for the understanding of visual reading patterns on a screen. We also found that the visuospatial attention performance of the participants was as good as was expected.

AUTHOR NOTE

This work was supported in part by Grant NSC93-2614-S-151-001 from the National Science Council (NSC), Taiwan. We thank the NSC for their financial support and all the research members involved in this project. We also thank the reviewers for the valuable comments and suggestions. Correspondence concerning this article should be addressed to T.-Y. Wang, Department of Occupational Therapy, National Cheng Kung University, 1 University Road, Tainan 701, Taiwan (e-mail: michwang@mail.ncku.edu.tw).

REFERENCES

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, **97**, 523-547.

Bundesen, C., Habekost, T., & Kyllingsbaek, S. (2005). A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychological Review*, **112**, 291-328.

Byrd, D. A., Touradji, P., Tang, M. X., & Manly, J. J. (2004). Cancellation test performance in African American, Hispanic, and White elderly. *Journal of the International Neuropsychological Society*, **10**, 401-411.

Chokron, S., & Imbert, M. (1993). Influence of reading habits on line bisection. *Cognitive Brain Research*, **1**, 219-222.

Curran, T., Hills, A., Patterson, M. B., & Strauss, M. E. (2001). Effects of aging on visuospatial attention: An ERP study. *Neuropsychologia*, **39**, 288-301.

Dawes, S., & Senior, G. (2001, October-November). *Australian normative data and clinical utility of the Mesulam and Weintraub Cancellation Test*. Paper presented at the 21st Annual Conference of the National Academy of Neuropsychology, San Francisco.

Dawson, D. R., & Tanner-Cohen, C. (1997). Visual scanning patterns in an adult Chinese population: Preliminary normative data. *Occupational Therapy Journal of Research*, **17**, 264-279.

Donnelly, N., Guest, R., Fairhurst, M., Potter, J., Deighton, A., & Patel, M. (1999). Developing algorithms to enhance the sensitivity of cancellation tests of visuospatial neglect. *Behavior Research Methods, Instruments, & Computers*, **31**, 668-673.

FRIEDMAN, P. J. (1992). The star cancellation test in acute stroke. *Clinical Rehabilitation*, **6**, 23-30.
GAUTHIER, L., DEHAUT, F., & JOANETTE, Y. (1989). The bells test: A quantitative and qualitative test for visual neglect. *International Journal of Clinical Neurosychology*, **11**, 49-54.
GELDMACHER, D. S., & ALHAJ, M. (1999). Spatial aspects of letter cancellation performance in Arabic readers. *International Journal of Neuroscience*, **97**, 29-39.
GELDMACHER, D. S., DOTY, L., & HEILMAN, K. M. (1994). Spatial performance bias in healthy elderly subjects on a letter cancellation task. *Neuropsychiatry, Neuropsychology, & Behavioral Neurology*, **7**, 275-280.
GELDMACHER, D. S., & RIEDEL, T. M. (1999). Age effects on random-array letter cancellation tests. *Neuropsychiatry, Neuropsychology, & Behavioral Neurology*, **12**, 28-34.
HALLIGAN, P. W., BURN, J. P., MARSHALL, J. C., & WADE, D. T. (1992). Visuo-spatial neglect: Qualitative differences and laterality of cerebral lesion. *Journal of Neurology, Neurosurgery, & Psychiatry*, **55**, 1060-1068.
HILLS, E. C., & GELDMACHER, D. S. (1998). The effect of character and array type on visual spatial search quality following traumatic brain injury. *Brain Injury*, **12**, 69-76.
HOGEBOOM, M., & VAN LEEUWEN, C. (1997). Visual search strategy and perceptual organization covary with individual preference and structural complexity. *Acta Psychologica*, **95**, 141-164.
HUANG, H. C., & WANG, T. Y. (2005, July). *Toward a graphical analysis tool for computer-assisted assessment of visual search patterns*. Paper presented at the Fifth IEEE International Conference on Advanced Learning Technologies, Kaohsiung, Taiwan.
JOHNSON, A., & PROCTOR, R. W. (2004). *Attention: Theory and practice*. Thousand Oaks, CA: Sage.
KAIL, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, **109**, 490-501.
KAIL, R., & BISANZ, J. (1982). Information processing and cognitive development. In H. W. Reese (Ed.), *Advances in child development and behavior* (pp. 45-81). New York: Academic Press.
LOWERY, N., RAGLAND, D., GUR, R. C., GUR, R. E., & MOBERG, P. J. (2004). Normative data for the symbol cancellation test in young healthy adults. *Applied Neuropsychology*, **11**, 216-219.
MARK, V. W., & MONSON, N. (1997). Two-dimensional cancellation neglect: A review and suggested method of analysis. *Cortex*, **33**, 553-562.
MARK, V. W., WOODS, A. J., BALL, K. K., ROTH, D. L., & MENNEMEIER, M. (2004). Disorganized search on cancellation is not a consequence of neglect. *Neurology*, **63**, 78-84.
MESULAM, M. M. (1985). Attention, confusional states, and neglect. In M. M. Mesulam (Ed.), *Principles of behavioral neurology* (pp. 125-168). Philadelphia: Davis.
MÜLLER, H. J., & FOUND, A. (1996). Visual search for conjunctions of motion and form: Display density and asymmetry reversal. *Journal of Experimental Psychology: Human Perception & Performance*, **22**, 122-132.
POSNER, M. I., & PETERSON, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, **13**, 25-42.
POSNER, M. I., & RAFAL, R. D. (1987). Cognitive theories of attention and the rehabilitation of attentional deficits. In M. Meier, A. Benton, & L. Diller (Eds.), *Neuropsychological rehabilitation* (pp. 182-201). New York: Guilford.
POTTER, J., DEIGHTON, T., PATEL, M., FAIRHURST, M., GUEST, R., & DONNELLY, N. (2000). Computer recording of standard tests of visual neglect in stroke patients. *Clinical Rehabilitation*, **14**, 441-446.
ROBINSON, D. L., & KERTZMAN, C. (1990). Visuospatial attention: Effects of age, gender, and spatial reference. *Neuropsychologia*, **28**, 291-301.
SALTHOUSE, T. A., & KAIL, R. (1983). Memory development through the lifespan: The role of processing rate. In P. B. Baltes & O. G. Brim (Eds.), *Life-span development and behavior* (Vol. 5, pp. 89-116). New York: Academic Press.
SCHARROO, J., STALMEIER, P. F., & BOSELIE, F. (1994). Visual search and segregation as a function of display complexity. *Journal of General Psychology*, **121**, 5-17.
SCHWARTZ, R. L., ADAIR, J. C., NA, D., WILLIAMSON, D. J., & HEILMAN, K. M. (1997). Spatial bias: Attentional and intentional influence in normal subjects. *Neurology*, **48**, 234-242.
SCIALFA, C. T., JENKINS, L., HAMALUK, E., & SKALOUD, P. (2000). Aging and the development of automaticity in conjunction search. *Journals of Gerontology*, **55**, P27-P46.
SNOWDEN, R. J., WILLEY, J., & MUIR, J. L. (2001). Visuospatial attention: The role of target contrast and task difficulty when assessing the effects of cues. *Perception*, **30**, 983-991.
TREISMAN, A. M. (1991). Search, similarity, and integration of features between and within dimensions. *Journal of Experimental Psychology: Human Perception & Performance*, **17**, 652-676.
TREISMAN, A. M., & GELADE, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, **12**, 97-136.
VINGIANO, W. (1991). Pseudoneglect on a cancellation task. *International Journal of Neuroscience*, **58**, 63-67.
WANG, T. Y., HUANG, H. C., & HUANG, H. S. (2006). Design and implementation of cancellation tasks for visual search strategies and visual attention in schoolchildren. *Computers & Education*, **47**, 1-16.
WANG, T. Y., HUANG, H. C., & YANG, H. C. (2004, December). *Visual attention performance on computerized and paper–pencil cancellation test measures*. Paper presented at the Biomedical Engineering Society Annual Symposium, Tainan, Taiwan.
WEINTRAUB, S., & MESULAM, M. M. (1985). Mental state assessment of young and elderly adults in behavioral neurology. In M. M. Mesulam (Ed.), *Principles of behavioral neurology* (pp. 71-123). Philadelphia: Davis.
WEINTRAUB, S., & MESULAM, M. M. (1987). Right cerebral dominance in spatial attention: Further evidence based on ipsilateral neglect. *Archives of Neurology*, **44**, 621-625.
WEINTRAUB, S., & MESULAM, M. M. (1988). Visual hemispatial inattention: Stimulus parameters and exploratory strategies. *Journal of Neurology, Neurosurgery, & Psychiatry*, **51**, 1481-1488.
WILSON, B., COCKBURN, J., & HALLIGAN, P. (1987). Development of a behavioral test of visuospatial neglect. *Archives of Physical Medicine & Rehabilitation*, **68**, 98-102.
WOLFE, J. M. (2001). Asymmetries in visual search: An introduction. *Perception & Psychophysics*, **63**, 381-389.
WOODWARD, R. M. (1972). Proximity and direction of arrangement in numeric displays. *Human Factors*, **14**, 337-343.

(Manuscript received March 29, 2007;
revision accepted for publication September 11, 2007.)