Development of a Computerized Visual Search Test

Denise Reid, Harsha Babani and Eugenia Jon

Visual attention and visual search are the features of visual perception, essential for attending and scanning one's environment while engaging in daily occupations. This study describes the development of a novel web-based test of visual search. The development information including the format of the test will be described. The test was designed to provide an alternative to existing cancellation tests. Data from two pilot studies will be reported that examined some aspects of the test's validity. To date, our assessment of the test shows that it discriminates between healthy and head-injured persons. More research and development work is required to examine task performance changes in relation to task complexity. It is suggested that the conceptual design for the test is worthy of further investigation.

Die visuelle Aufmerksamkeit und Suche sind Features der visuellen Wahrnehmung, die für die Beachtung und das Scannen des eigenen Umfelds bei der Alltagsbewältigung unerlässlich sind. Die vorliegende Studie beschreibt die Entwicklung eines neuartigen web-basierten visuellen Suchtests. Beschrieben werden die Entwicklungsinformationen und der Testaufbau. Der Test ist als Alternative zu den bestehenden Cancellation-Tests gedacht. Daten aus zwei Pilotstudien, die einige Aspekte der Gültigkeit des Tests untersuchten, werden angezeigt. Unsere bisherige Beurteilung des Tests zeigt, dass er zwischen gesunden Personen und Personen mit Kopfverletzungen diskriminiert. Daran müssen sich weitere Forschungs- und Entwicklungsarbeiten anschließen, um die Änderungen der Performance des Tasks hinsichtlich der Komplexität des Tasks untersuchen zu können. Es wird auf die Möglichkeit hingewiesen, dass die Test-Konzeption verdient, weiter untersucht zu werden.

L'attention et la recherche visuelles sont des caractéristiques de la perception visuelle, indispensables à l'observation et à l'interaction avec notre environnement lors des activités de la vie quotidienne. Cette étude décrit le développement d'un nouveau test de la recherche visuelle disponible sur Internet. Elle présente des informations sur son développement, ainsi que son format. Le test a été conçu pour offrir une alternative aux tests d'annulation existants. Les données de deux études pilotes examinant certains aspects de la validité du test sont présentées. À ce jour, notre évaluation du test indique qu'il distingue les personnes saines et les individus souffrant de traumatismes crâniens. Des travaux de recherche et de développement complémentaires sont nécessaires pour examiner les changements au niveau de l'exécution des tâches en relation avec leur complexité. Il est suggéré que la conception du test mérite un examen plus approfondi.

La atención visual y la búsqueda visual son componentes de la percepción visual, y son esenciales para poder prestar atención y efectuar búsquedas de estímulos visuales en nuestro entorno durante la realización de actividades de la vida diaria. Este estudio describe la creación de una prueba de búsqueda visual en línea. Se describe el proceso de creación de esta prueba y su formato. La prueba se concibió como una alternativa a las pruebas de cancelación existentes. Se presentan los datos obtenidos en dos estudios preliminares en los que se examinaron varios aspectos relativos a la validez de esta prueba. Hasta hoy, nuestra valoración de la prueba muestra variaciones de los resultados en personas sanas y en personas con traumatismos craneoencefálicos. Se necesitan más investigaciones y ajustes de la prueba para poder evaluar los cambios relativos a la realización de la prueba según la complejidad de la tarea asignada en ella. Se recomienda una investigación más minuciosa del diseño conceptual de la prueba.s *International Journal of Rehabilitation Research* 32:205–212 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Department of Occupational Science and Occupational Therapy, University of Toronto, Ontario, Canada

Correspondence to Dr Denise Reid, PhD, Department of Occupational Science and Occupational Therapy, 160-500 University Avenue, University of Toronto, Canada ON M5G 1V7
Tel: +1 416 978 5937; fax: +1 416 946 8570; e-mail: d.reid@utoronto.ca

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Introduction

Disorders of visual search are common after traumatic brain injury or a stroke. Visual search skills require attention and are necessary to carry out everyday activities such as trying to locate a can of soup from the canned goods aisle in the grocery store, or to locate flight departure information from an airport lounge screen. Searching for information in our visual environment is an activity which human beings are engaged in for most of their waking lives. Occupational therapists assess visual perceptual skills including visual search of clients with a variety of neurological disorders including stroke and traumatic head injury (Quintana, 1995; Zoltan, 1996; Cooke *et al.*, 2004). The impact of visual search deficits on activities of daily living, including navigating the environment, is great.

Research in visual search has examined the role of colour, size and orientation on target search in children and adults (Donnelly *et al.*, 2007). They found that children were slower than adults, and that children showed greater difficulty responding to size than to orientation targets and slower to orientation than to colour targets. Other researchers varied the saliency of distractors to targets and examined search strategy (Van Zoest and Donk, 2004). The results of the experiments of Van Zoest and Donk (2004) were that performance was better in cases where the irrelevant distractor was not a salient item in the search display and did not look similar to the target. Other research on distractors showed that the use of similar features to generate the distractors influenced the search strategy (Takeda *et al.*, 2007). Spatial frequency and orientation feature dimensions were used to generate the distractors.

Another dimension to visual search is referred to search pattern or visual search behaviour. Visual search behaviour has been shown to range from random to systematic (Melloy *et al.*, 2006). Systematic search is usually described as being organized, as it follows a right–left or left–right, top–down or bottom–up approach for task performance. It has been reported that healthy adults use a systematic approach to complete cancellation tests, and deviation from standard approaches might suggest disorders of planning, organization or neglect (Lowery *et al.*, 2004). Random search is often described disorganized and follows no pattern. A systematic search pattern takes less time and is more accurate (Melloy *et al.*, 2006). It seems logical that systematic searches take less time and are more accurate, as the visual coverage is maximized. Examining search behaviour or pattern is useful, as it can be used to explore the effectiveness of an individual's search performance.

Cancellation testing is a common method for assessing visual spatial search quality and the visual neglect syndrome (Hills and Geldmacher, 1998; Lindell *et al.*, 2007). Some common paper-based cancellation tests used in the field of occupational therapy are the Mesulam Battery (Mesulam, 1985) and the Bells Test (Gauthier *et al.*, 1989). Both tests use letters or abstract symbols as stimuli and distractors. The Mesulam Test has four different test forms of random and structured letters and symbols. The Bells Test has one form with symbols and bell shapes. Cancellation tests have also been designed to be computer based; for example, Reid and Jutai (1995) and Wang *et al.* (2006).

The advantage of a computer-assisted cancellation test is that the computer can record visual search paths as well as the response time and accuracy of responses to provide an objective analysis of the visual search quality. Potter *et al.* (2000) found that by using a computer with individuals with stroke and without stroke, a significant difference in the process of carrying out visual search tasks such as the time between cancellations, the starting point in the search and the premovement time between the two groups is observed.

Recently, occupational therapists, Wang *et al.* (2006), developed the computer-based cancellation test to be used with school children. Their test was developed in Taiwan and used symbols or Chinese characters as stimuli. Reid and Jutai (1994) (unpublished observation) developed the computerized Componential Assessment of Visual Perception for assessing adults with neurological disorders. One of the test's modules was a cancellation test that had nine levels of difficulty on the basis of number of targets and type of distractors. The test was designed to assess the contribution of visual memory and attention on visual search strategies. Memory load was varied by increasing the number of targets from one to three. Attention was examined by having two different test displays that included different distractors. The types of distractors were classified as low or high. Low distractors were stimuli whose features (shapes) differed from the target stimuli. High distractors were similar to targets in features (shapes). This approach to design is similar to the results of Van Zoest and Donk's (2004) research.

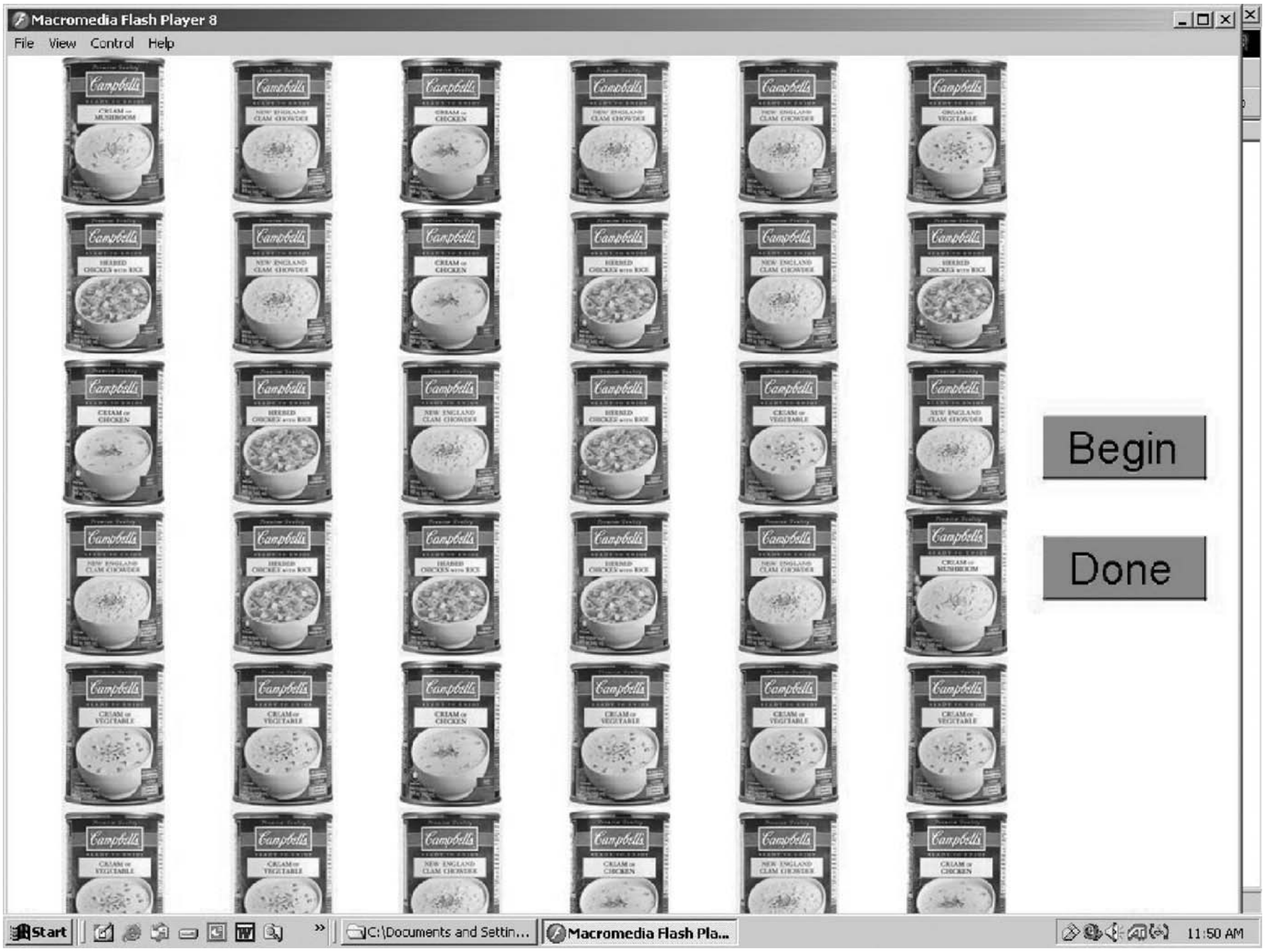
The purpose of this study was to describe the visual search soup can test and provide results of pilot validation studies that compared this new test against two traditional cancellation tests, and compared and described the performance of healthy young adults and young adults with a head injury.

Computerized Visual Search Test development

The Computerized Visual Search Test (CVST) was developed using Flash MX 2004 (*www.macromedia.com*) by the first author. The development tool was used to make the graphic objects and arrange them on the screen accordingly. Action Script programming language was used to control the flow of the application such as determining what frame to display depending upon the user's input. The requirements for running the test include Macromedia Flash Plugin (*http://www.macromedia.com/shockwave/download/download*.cgi? P1_Prod_VersionShockwaveFlash&promoid = BIOW) and Microsoft Word.

The test comprises six tasks that vary according to the type of distractor background used (low and high) and the number of targets (memory load). Each task layout

Fig. 1



Level 1, low-distraction task.

comprises 30 stimuli in a 6×5 matrix on the computer screen. There are two levels, 1, 2 and 3 tasks, each having a low-distractor task and a high-distractor task format. Level 1 tasks require one target to be located, whereas level 2 and 3 tasks require two and three targets, respectively, to be located in the matrix.

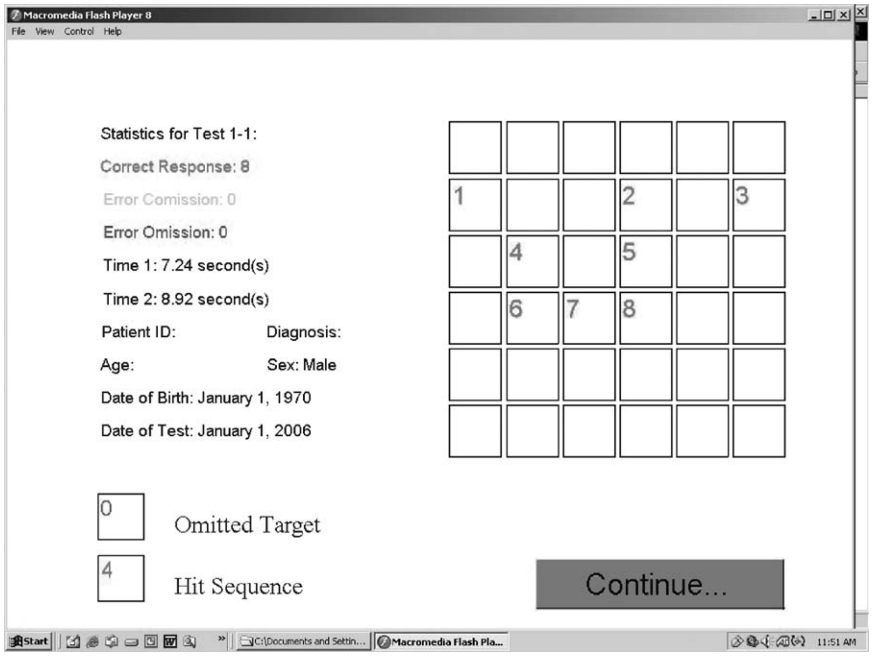
In the low-distractor level 1 task, there are eight soup cans (either red or white) and 22 distractors that are of the opposite colour of the target soup. The target soup can is displayed on the computer screen for a set preview time (the time can be set as desired, e.g. 30 s). After the target disappears the matrix of stimuli appears. A BEGIN button is required to be clicked before the computer records the choices. At the end of selections, an END button is clicked (Fig. 1). The target soup can is herbed chicken with rice and is a red soup and the distractor soups are white soups such as clam chowder and cream of chicken.

Scoring information is generated showing timing information, selection time (time 1) and total test time (time 2) which includes premovement time and accuracy information (correct responses and errors of omission and commission) (Fig. 2). Hit sequence is also shown by the colour coding of hits. The hit sequence is shown through a search pattern that shows the path taken from start to finish to complete the task (Fig. 3).

In the level 1 high-distractor task, there are eight soup cans (either red or white) and 22 distractors of the same colour as that of the target soup (Fig. 4). The target in this case was clam chowder and the distractors were other white soups including cream of chicken and cream of mushroom. The scores and search pattern are displayed in the same way as in the level 1 low-distractor task.

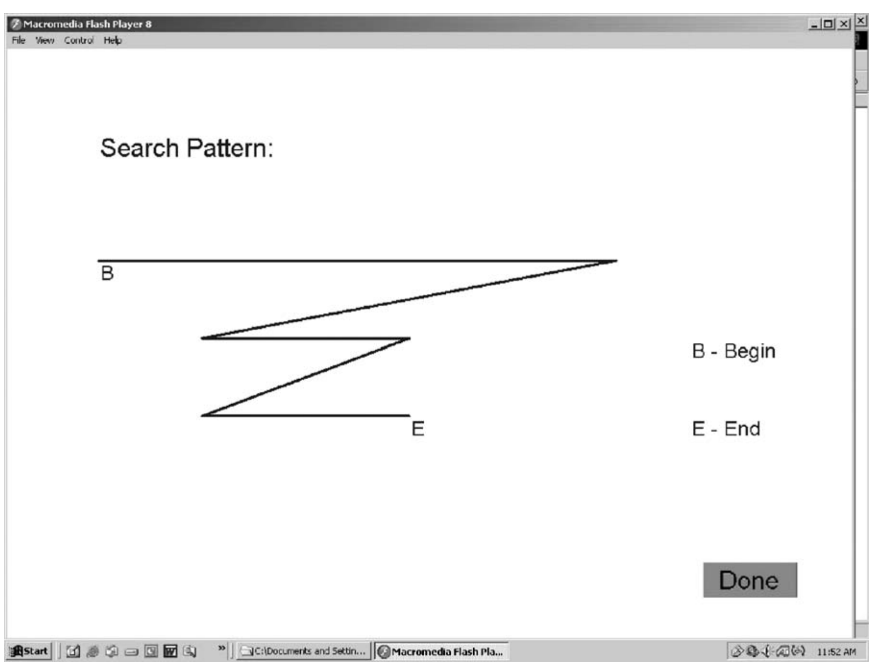
In the level 2 and 3 tasks, there are two or three targets to preview. Low-distraction and high-distraction types of

Fig. 2



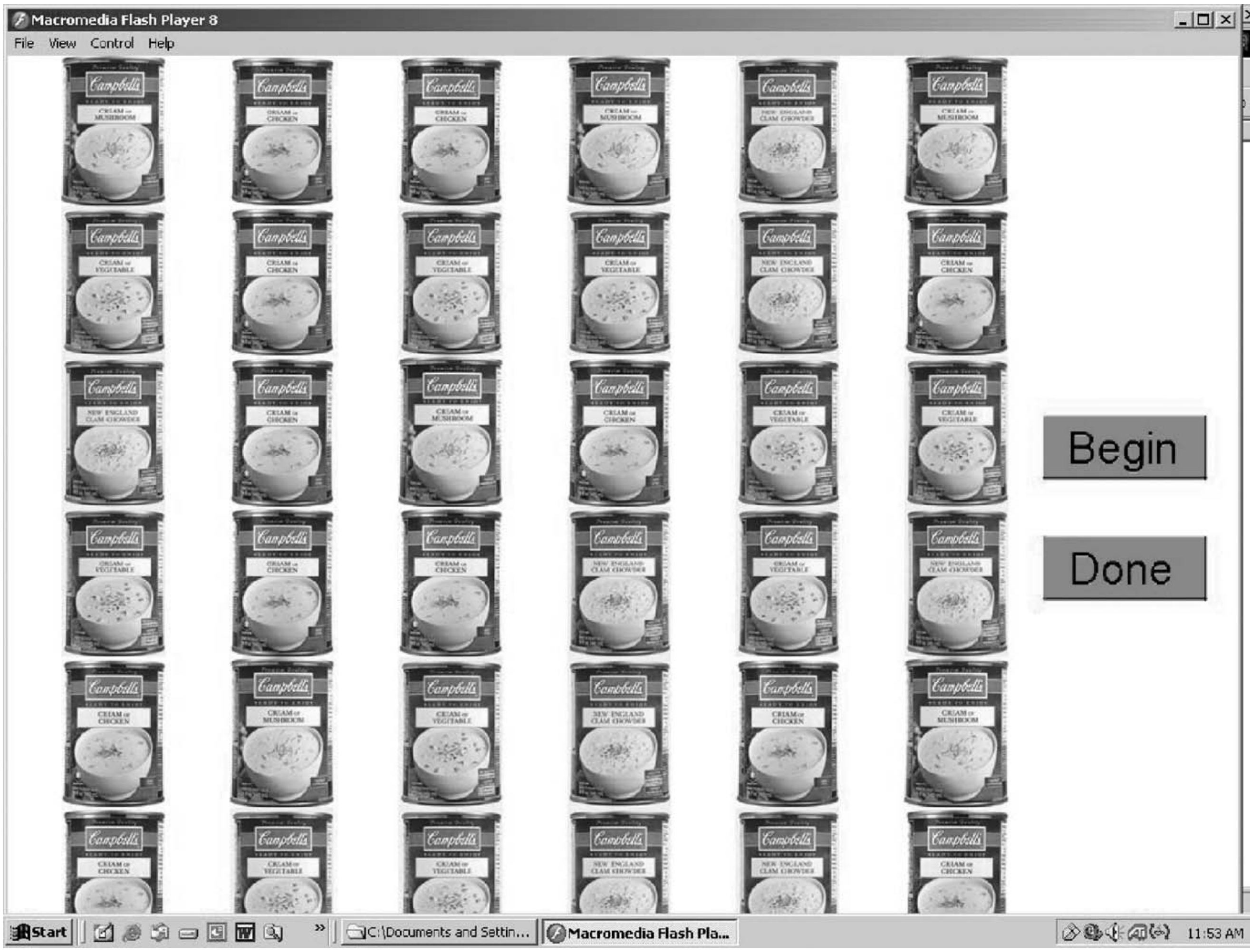
Time and accuracy results from level 1 low-distractor task.

Fig. 3



Search pattern for level 1 low-distractor task.

Fig. 4



Level 1, high-distraction task.

tasks for each level have been created following the same design principles as above.

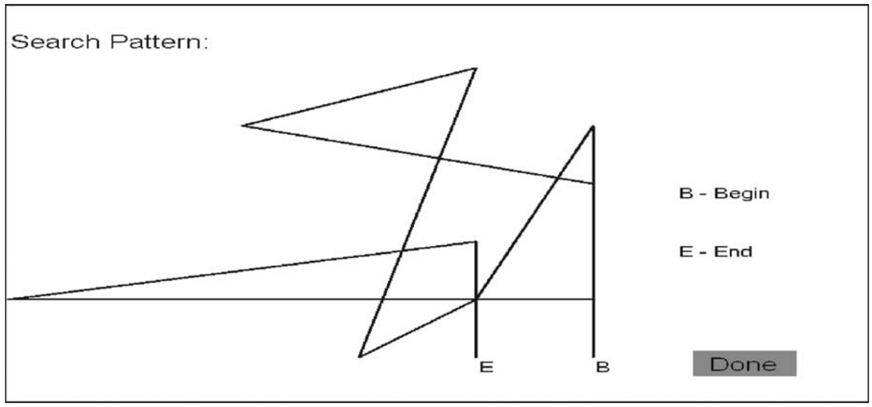
The high-distractor level tasks were designed to require more conscious attention and take more time than the low-distractor tasks. Attention to specific features such as the name written on the soup can and the added features displayed on the soup are required to locate the targets. In the low-distractor tasks, search happens faster because a primitive feature such as colour is easier to recognize (Treisman and Gelade, 1980).

Pilot evaluation

To assess the test's validity, Jon (2007) (unpublished thesis) compared the CVST against the Mesulam and Weintraub, noncomputerized cancellation test (Mesulam, 1985). The structured formats of the Mesulam Test were chosen because they most closely resembled the configuration of the CVST. In the structured format of the two tests, 60 target stimuli were embedded in a 17×22 matrix of distractor letters or symbols. Jon (2007) (unpublished thesis) found that in 20 healthy adults the number of correct responses or errors was not correlated between the CVST and the Mesulam Tests. Using Kendall's tau-b, there was a trend towards statistically significant correlations on the number of correct responses and errors of omission between the CVST and Mesulam letters ($P = 0.05$, $b = 0.381$). The Spearman's ρ found statistically significant correlations between the errors of commission between the CVST and Mesulam symbols ($P = 0.01$) for two subtests. Significant correlations were found for the time taken on the CVST and the Mesulam symbols and Mesulam letters ($P = 0.01$).

Qualitative analysis of visual search patterns of all participants showed that almost all participants used

Fig. 5



Example of a disorganized search pattern of one participant.

the same search strategy while completing the CVST or the Mesulam. Head-injured participants exhibited more disorganized search patterns (Fig. 5), whereas healthy participants used only organized search patterns as in Fig. 3.

To further examine the CVST's ability to discriminate between disabled and healthy populations, Babani (2007) (unpublished thesis) examined the ability of the test to discriminate performance on the CVST between healthy and head-injured groups. Five adults with head injury were compared against a healthy group ($n = 20$). The mean age of healthy participants was 25.50 years and the average age of head-injured participants was 26.60 years. Mann–Whitney U test (with Bonferonni's correction) showed that head-injured participants made more errors of commission on all subtests but made statistically significant errors on one subtest (three target-high distraction test) ($P = 0.000$), and head-injured participants took significantly more time to complete all subtests but showed a statistically significant increase in time on the two target-low-distraction tests ($P = 0.001$).

Discussion

A novel assessment has been developed for healthcare professionals who assess visual search skills in persons with neurological disability. The stimuli used in this test are designed to be more ecologically valid than the abstract stimuli, letters and shapes that are used in most cancellation-type tests. The CVST is simple, quick to administer and easy to complete. Conceptually, this assessment values the contribution of memory load and saliency in distractors on visual search skills. Results of our pilot studies show that remembering more targets takes more time to find them and that low-distractor tasks are not as difficult as high-distractor tasks.

There were no conclusive correlations between the CVST and the Mesulam Test. There were trends towards statistically significant correlations across subtests with only a few subtests showing significant correlations. The small sample size could contribute to the lack of statistically significant findings. In contrast, the results of this study could be indicating that the CVST and the Mesulam Test are in fact very different tests even though their test formats are similar. The fundamental difference between the CVST and Mesulam Test is that the target symbols were different. In the Mesulam-letters format, participants have to select the target letter 'A' out of a matrix of distractor letters. In the symbols format, they had to select a simple abstract shape.

In contrast, participants had to select a picture of a target soup can out of a matrix of many other soup cans. They had to pay attention to a lot more details, including words, colour and pictures on the soup can. In addition, there is no visual memory involved in completing the Mesulam Test. Participants are able to refer back to their target symbol once they have circled the first one. In the CVST, participants are given 5 s to remember the target soup can for its features and then must find it in the matrix. Once they select a target out of the presented matrix, it becomes blurry so that the target becomes undistinguishable. This means that one must be able to remember the target soup can for the entire duration of the test.

As mentioned earlier, the CVST allows for a graded assessment of the working memory and selective attention as the number of targets (one to three targets) and the level of distraction (low or high) can be adjusted. As the tasks become more difficult (as the number of targets increase and from low to high distraction), the CVST tests the memory and attention capacity at a much higher level than the Mesulam Test was designed to assess. These preliminary results indicate that the CVST is a more sensitive assessment of attention and tests different cognitive components than the Mesulam Test.

This head-injured group was less accurate, made more errors and took a longer time to complete all subtests of the CVST. One of the head-injured participants (who took a long time to complete each subtest) stated, 'I can't remember which soup can I'm supposed to look for'. This indicates that the time taken to complete the test may be affected by a participant's inability to recall the target soup can. This may indicate a problem with storage or retrieval of information and not encoding, because all participants were able to select some targets correctly. Furthermore, as the memory load (i.e. number of targets) and attentional demands (low vs. high distraction) increased, head-injured participants' performance worsened. Therefore, the CVST allows for fine-graded assessment of visual memory and selective attention. In a high-distraction environment, individuals are required not only to recall the target(s) but also to selectively attend to the targets. As head-injured participants made significantly more errors of commission (i.e. selecting incorrect targets) in the level 3 tasks requiring the most highest memory load and attentional resources, the CVST points to impairments in memory and attention that become more apparent when the environmental demands increase. These participants are more likely to make similar errors in day-to-day activities that require a high memory capacity and large attentional resources. When health professionals are able to accurately assess such impairments, treatment decisions can be made more accurately and appropriately. Increasing the ability to remember relevant environmental stimuli and increase selective attention can be targeted through remedial and compensatory strategies. For example, if a healthcare professional finds that an individual is able to easily remember one target but has difficulty in remembering multiple targets, the professional can recommend making a list as a compensatory technique. In this way, the CVST allows a healthcare professional to assess more complex memory and attentional deficits.

Head-injured participants also showed a more disorganized pattern of scanning when compared with healthy young adults on the CVST. Therefore, we can conclude that in this study, healthy participants had a more efficient visual search strategy than head-injured participants. This may be another reason why head-injured participants took longer to complete the tests and made more errors. Functionally, an inefficient search strategy can decrease accuracy and increase the chances of errors when individuals are scanning the environment for relevant stimuli. They are also more likely to spend more time on a task when they have an inefficient search strategy. Therefore, the CVST shows preliminary evidence that it can detect if an individual has an inefficient search strategy or not. Remediation can then be provided to work on developing a more organized and efficient pattern of scanning to increase accuracy and decrease time when scanning the environment for relevant stimuli. Healthcare workers can provide some strategies and recommendations to increase efficiency of visual search.

It has been suggested in earlier work that individuals with brain injury do not show clinically significant impairments on current paper-and-pencil visual search tools (Habekost and Rostrup, 2006) and that more sensitive assessment tools are required. The CVST's sensitivity is enhanced by the fine-grained variations in dependent measures.

The CVST may offer clinicians a more objective and sensitive means of assessing impairments in visual memory, attention and visual search. In addition, the recording of scores is more objective and accurate with the CVST when compared with standard paper-and-pencil visual search tests. Therefore, a computer-based tests offers various advantages that are apparent during the course of this study.

One of the major limitations of this study is the small sample size of head-injured participants. In addition, the group sizes were grossly unequal, which prevented the investigators from using parametric tests. Therefore, this study should be replicated with a larger sample size in future.

Conclusion

The CVST shows promise in being a sensitive tool to detect memory and attention deficits as well as visual search strategy in young adults with varying levels of cognitive abilities. Variations in the number of targets and level of distraction allow for graded assessment of memory and attention demands, which increases the tool's sensitivity. The CVST provides many advantages over traditional paper-and-pencil tests including increased accuracy and objectivity of the recorded scores. On the basis of more accurate assessment results, occupational therapists can make better treatment decisions that are more appropriate to a client's needs. In addition, the CVST provides clinicians with a more functional way of measuring visual search impairments compared with traditional paper-and-pencil tests that use abstract and/or meaningless symbols.

The current version of the CVST is Internet based, which means that clinicians can easily access this test in the hospital or in a client's home if the Internet is available. However, a few changes need to be made to improve its clinical utility. Images on the screen will need to be made sharper or enlarged, as many participants indicated that the words on the soup cans were too blurry, making the CVST less enjoyable. The next version of the CVST will include a save function that automatically stores the results into a database for easy access and safe storage of information. This research version of the test is on the Web for public use and to receive feedback (*http://individual.utoronto.ca/DTReid/aboutus.html*). Click on projects and then on visual search test to run.

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