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Visual search and eye movements in patients with chronic solvent-induced toxic encephalopathy

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Abstract

Various aspects of visual perception have been found to be impaired in patients with occupational chronic solvent-induced toxic encephalopathy (CSE). The purpose of the study was to characterise the changes in eye movements and visual search performance in CSE patients. We measured eye movements of 13 CSE patients and 22 healthy controls during dynamic visual search task by using a fast video eye tracker. The task was to search for and identify a target letter among numerals presented in a rectangular stimulus matrix (3×3–10×10 items). Threshold search time, i.e. the duration of stimulus presentation required for identifying the target with a given probability was determined by using a psychophysical staircase method. The visual search times of the CSE patients were clearly longer, and they needed considerably more eye fixations than healthy controls to find the target. Thus, their reduced performance in this task was mainly related to the reduction in the number of items which could be processed during a single eye fixation (*perceptual span*). This reduction probably reflects a limited capacity of visual attention, since visual acuity, contrast sensitivity, and the oculomotor saccade velocity were found to be normal. The results suggest that motor slowness or low-level visual factors do not explain the poor performance of CSE patients in visual search tasks. The results are also discussed with respect to the effects of education, and compared to the performance in the widely used neuropsychological Trail Making Test, which uses similar stimuli and requires visual search.

Keywords: Attention; Eye movements; Main sequence; Perceptual span; Solvent exposure; Trail Making Test; Visual search

1. Introduction

Long-term occupational exposure to organic solvents can cause a psycho-organic syndrome, chronic solvent encephalopathy (CSE), which includes a combination of neurological complaints, perceptual and cognitive impairments, as well as an increased incidence of anxiety and mood symptoms (Condray et al., 2000; Juntunen, 1993; van der Hoek et al., 2000; White and Proctor, 1997). Most frequently documented deficits related to chronic solvent exposure are cognitive impairments, such as deficits in attention, short-term memory, associative learning, and psychomotor speed (see, e.g. Anger, 1990; Baker, 1994). The further characterisation of each separate cognitive and perceptual process that can be impaired in chronic solvent exposure is important in order to better understand the nature of the toxic effects, and to develop a set of sensitive screening tests for early detection of nervous system dysfunction.

1.1. Long-term solvent exposure and visual system

In vision, chronic solvent exposure can be associated with partially sub-clinical defects in colour vision (Mergler et al., 1987; Muttray et al., 1997; for reviews, see Gobba and Cavalleri, 2003; Iregren et al., 2002). Contrast sensitivity can also be affected, especially in medium spatial frequencies (Donoghue et al., 1995; Mergler et al., 1991). However, defects in different visual functions are not concurrent, that is, some of the CSE patients may have defective colour vision but normal contrast sensitivity, whereas others may have normal contrast sensitivity and colour vision but be slow in visual search (Näsänen et al., 2005). Therefore, several aspects of visual perception must be investigated in order to characterise the neurotoxic effects.

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1.2. Visual search task in investigating attentional and visual impairments in CSE

It has been proposed that the deficient cognitive performance of CSE patients may be mainly related to a difficulty of allocating attentional resources, especially with increasing processing load, which in turn affects the ability to acquire information at the same rate as healthy controls (Akila et al., in press; Morrow et al., 1992; Stollery, 1996; see also Reinvang et al., 1994).

The performance in some neuropsychological paper-and-pencil tests can be affected by low-level factors such as uncontrolled visual acuity of the patient (see Skeel et al., 2003) or motor slowness. Therefore, the use of psychophysical experimental setting designed to take into account some of these confounding variables could be useful in addition to traditional tests. More generally, these experimental methods may provide new possibilities for the characterisation of early neural effects of solvents by providing means for more specific hypothesis testing about the cognitive and perceptual processes that are thought to be affected.

Recently, Näsänen et al. (2005) used a psychophysical computerised visual search task in investigating visual perception of CSE patients. They found that patients performed poorly in both pre-attentive pop-out search task as well as in a serial letter search task requiring eye movements and quick processing of visual information. Since the letter contrast sensitivity of the patients (i.e. contrast transfer and letter recognition per se) was only slightly impaired in comparison to age-matched control subjects, Näsänen et al. suggested that the poor performance of CSE patients in visual search may be mainly related to the impaired speed of visual information processing, and/or limitations in attentional capacity. However, since eye movements were not measured, further characterisation of the dysfunction could not be made.

1.3. Eye movements and visual search

Eye movement parameters measured during an intensive visual information processing task can give further information about various factors which affect performance, such as the speed of information processing, global search strategy, capacity of spatial visual attention, as well as integrity of low-level oculomotor processes.

Information for visual analysis is mostly gathered during eye fixations (see, e.g. Ross et al., 2001), in which the fovea, the retinal area of the highest visual resolution, is fixated momentarily to a given spatial location. Thus, during visual information processing task, eye fixations take most of the time. In visual search task, the duration of single eye fixation in healthy people is about 200 ms (Näsänen et al., 2001), although there is considerable variation depending on the task and stimuli. Since visual resolution strongly decreases with increasing eccentricity (Curcio and Allen, 1990; Curcio et al., 1990; Wertheim, 1894), fast saccadic eye movements are needed to shift the foveal area to successive locations in the stimulus matrix while searching for targets. Together the sequences of saccades and fixations form the scan path, which is related to search strategy.

The number of eye fixations needed to find the target depends on the number of items that can be processed during a single eye fixation (i.e. the size of the *perceptual span* or *visual span*) (Legge et al., 1997; in reading, see O'Regan et al., 1983; Rayner, 1998). The ultimate limits of perceptual span are anatomically determined and depend on the factors affecting stimulus visibility, such as contrast of the stimuli and visual acuity of the subject (Legge et al., 1997; Näsänen et al., 2001). However, if the stimulus visibility is good, the higher-level factors, such as task demands and attentional capacity begin to affect the perceptual span more strongly.

1.4. Purpose of the study

In this paper, we investigate the visual perception of CSE patients as measured by a computerised visual search task and simultaneous eye movement recordings. The experimental setting allows us to exclude the effects of motor reaction speed from the speed of perceptual information processing during visual search. If the CSE patients need markedly more eye fixations to find a target than healthy controls, it would suggest that the area around the point of eye fixation from which information can be acquired (i.e. perceptual span) is reduced. If, on the other hand, their fixation durations are substantially increased in comparison to controls, the speed of information processing during a fixation could be reduced. In addition, we analysed the eye movement data with respect to a global visual search strategy, and oculomotor properties of saccadic eye movements. Finally, we investigated whether the size of the perceptual span of the subjects is related to their performance in the Trail Making Test, a paper-and-pencil test, which is widely used in behavioural neurotoxicology, and which is considered to measure visual search and effectiveness of attention switching (Lezak et al., 2004).

2. Materials and methods

The enrolment of the subjects in this study adhered to the tenets of the declaration of Helsinki. All subjects gave their informed consent to participate in the study. The experimental protocol was accepted by the Ethics Committee for Research on Occupational Health and Safety in Work of the Helsinki and Uusimaa Hospital District.

2.1. Patient group

There were 13 voluntary patients, 12 of them were male (see Table 1). Their mean age was 56.2 (standard deviation; S.D. 4.8) years. Education years in the patient group were on average 8.7 (S.D. 1.4). All patients had previously received a diagnosis of chronic solvent-induced toxic encephalopathy caused by a long-term occupational exposure to mixtures of several organic solvents. Consecutive CSE patients were taken to the study when they came to their regular yearly follow-up visit at the Finnish Institute of Occupational Health during the year 2002.