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Visual search in migraine and visual discomfort groups

Elizabeth Conlon *, Lyndel Humphreys

School of Applied Psychology, Gold Coast Campus, Griffith University, PMB 50 Gold Coast Mail Centre, Gold Coast 9726, Australia

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Abstract

Two experiments that investigate automatic and conscious attention among migraine and visual discomfort groups are reported. The prediction of a heightened sensory sensitivity producing a processing speed advantage in migraine was tested. In Experiment 1, an automatic attention task was conducted. There was no effect of migraine group, but the high visual discomfort group responded significantly more slowly than the low visual discomfort group when 16 distractors were presented. In Experiment 2, a conscious visual attention task was conducted. No processing-speed advantage was found for migraine groups. In all conditions, the high visual discomfort group performed significantly more slowly than other groups. It was concluded that heightened sensory sensitivity could not explain the processing speed advantage found previously in migraine but may explain the processing speed disadvantage found for the high visual discomfort group. Results are discussed in terms of disordered sustained attention in the high visual discomfort group. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Automatic attention; Conscious attention; Migraine; Visual discomfort

1. Introduction

The aim of this study was to determine if different forms of visual attention or symptomatology of visual discomfort could explain a previously reported processing speed advantage on a visual search task in a migraine with aura group. The primary focus was heightened sensory sensitivity indicative of visual discomfort, predicted also to be present in migraine.

Hyperexcitability of the cerebral cortex to sensory stimuli has been well documented in migraine (e.g. Hay, Mortimer, Barker, Debney, & Good, 1994; Afra, Cecchini, Sandor, & Schoenen, 2000). Welch, Barkley, Tepley, and Ramadan (1993) have predicted that migraineurs experience a generalised sensory sensitivity produced by a chronic state of central nervous system hyperexcitability. In the visual domain, some support for this is found in studies measuring subjective responses to grating patterns that stimulate V1 cortical neurons. A significantly higher proportion of a migraine group reported a greater subjective difficulty than a non-migraine group when viewing high contrast gratings with a spatial frequency of 3 c/deg (Marcus & Soso, 1989; Coleston & Kennard, 1993). Hypersensitivity due to visual discomfort, also predicted to occur because of visual system hyperexcitability, may provide an explanation (Wilkins, 1986).

Visual discomfort is a collection of somatic (sore, tired eyes or eye-strain) and perceptual (illusions of colour, shape and motion) effects induced with exposure to bright or intermittent light and/or grating patterns (Wilkins et al., 1984). Severity of visual discomfort is measured using the Visual Discomfort Scale (VDS) (Conlon, Lovegrove, Chekaluk, & Pattison, 1999). The high visual discomfort group report greater subjective unpleasantness and perform less efficiently than the low visual discomfort group on a number of tasks that involve exposure to square waves or square wave-like grating patterns. These include short-duration pattern observation tasks using gratings with spatial frequencies between 1 and 16 c/deg as the stimuli (Conlon et al., 1999). The high visual discomfort group also performs more slowly than the low visual discomfort group on visual search tasks in the presence of low spatial frequency grating pattern backgrounds requiring conscious (Conlon et al., 1998), or

* Corresponding author. Tel.: +61-755-528981; fax: +61-755-528291.

E-mail address: e.conlon@mailbox.gu.edu.au (E. Conlon).

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automatic visual attention (Conlon & Hine, 2000). Poorer performance in the high visual discomfort group was interpreted using McConkie and Zola's (1988) proposed four-level object hierarchy of visual attention. It was argued that the high visual discomfort group was unable to redirect their attention from the presentation of a global repetitive pattern to the salient individual components of the visual scene. Performance deteriorated further if a larger number of objects were presented in the array, or if the number of visually similar objects to discriminate between was increased from two to four. Both manipulations increased task difficulty.

Wray, Mijovic-Prelec, and Kosslyn (1995) demonstrated a response time advantage for a migraine with aura group over a control group in a detection task where the orientation of the target line differed from that of the 23 distractors. After viewing the array for 50 ms, participants were required to determine if the target was presented above or below a mid-point. Predicted high levels of visual discomfort in the migraine with aura group were used to explain the processing-speed advantage that was found. No formal measure of visual discomfort was obtained for participants in the study. Using migraine with aura, migraine without aura and a control group, Palmer and Chronicle (1998) failed to replicate this result. Woestenburg, Kramer, Orlebeke, and Passchier (1995) found a response time advantage for a migraine with aura over migraine without aura and control groups in a memory task when a target stimulus was located in the same position across trials. In addition, both migraine groups were more sensitive than the control group to presentation of gratings. The processing speed advantage found in the memory for position task was attributed to a separate 'more central mechanism' (Woestenburg et al., 1995) from that producing the heightened sensory sensitivity in both migraine groups. The nature of this mechanism was not elucidated.

In this paper, two experiments are reported. The first measures automatic visual attention, and the second measures conscious visual attention in migraine with and without aura, non-specific headache and control groups. In addition, a measure of visual discomfort was obtained to determine if this classification could explain any response time differences found.

2. Experiment 1

In a task that measures automatic visual attention, a simple feature (e.g. orientation) defines the difference between a target and a set of distractors. The response time for target detection is independent of the number of distractors presented, showing that a parallel search has been conducted. The target 'pops' out from distractors in the pattern array (Triesman, 1986; Triesman & Gormican, 1988).

It was predicted that if increased sensory sensitivity occurs pre-attentively in the migraine with aura group, a processing-speed advantage would be found for this group on the automatic attention (parallel search) task. In addition, if visual discomfort explains the phenomena, performance in the high visual discomfort and the migraine with aura group should be the same.

2.1. Method

2.1.1. Participants

There were 72 volunteers with normal or corrected to normal visual acuity and no neurological anomaly other than migraine. Headache classification was determined using the diagnostic criteria of the International Headache Society (IHS, 1988). There were 17 in the migraine without aura group, 12 in the migraine with aura group, 22 in the non-specific headache group and 21 in the headache-free control group. The age range of the migraine without aura group was 18–47 years (mean = 31.9 years), the migraine with aura group 18–42 years (mean = 27.5 years), the non-specific headache group 17–44 years (mean = 26.5 years) and the control group 18–46 years (mean = 29.6 years).

Visual discomfort was assessed using the Visual Discomfort Scale (VDS), which has a reliability coefficient of 0.91 (Conlon et al., 1999). Participants in the high visual discomfort group had a score of at least 45% on the VDS, and the low visual discomfort group a score of less than 45%. The average VDS score for the low visual discomfort group was 21.01 (S.D. = 9.8) and the high visual discomfort group 54.8 (S.D. = 11.0). There were 17 participants in the high visual discomfort group, 10 from the migraine without aura group, five from the migraine with aura group and two from the non-specific headache group.

Participants did not have a headache for at least 72 h prior to, or in the 24 h following, testing. The study had Griffith University Ethics Committee clearance. All participants gave written consent prior to participation.

2.1.2. Stimuli

The stimuli consisted of four, eight or 16 lines presented as targets or distractors. Distractors were vertical black lines tilted 15° from vertical and appeared randomly in different locations on the display. A single vertical black line presented in half the trials was used as the target. On any one trial four, eight or 16 items appeared. At a viewing distance of 57 cm, the stimulus array subtended a visual angle of 8° horizontally and 6° vertically with target and distractors subtending a vertical visual angle of 1° vertically and 0.025° horizontally. Fig. 1 gives an example of the stimulus configuration used. The space average luminance of the display was 30 cd/m^2. A Power Macintosh was used to administer the task. Stimuli were generated and randomized by the VScope software package (Rensink & Enns, 1992).

2.1.3. Procedure

Participants were informed that the objective of the experiment was to respond to the presence or absence of the target as quickly as possible, without error. Prior to each trial, a square black fixation point subtending a visual angle of 0.3° appeared at the centre of the screen. This was replaced with an experimental trial when the space bar was depressed. If the target was present, participants were instructed to press the computer key marked 'P', otherwise the computer key marked 'A' was to be depressed. Following the response, the stimulus was removed from the screen, and response accuracy feedback was displayed.

A block of 18 practice trials was administered to familiarise participants with the study's procedure. Experimental trials consisted of two blocks of 24 trials with eight trials per condition. Participants were tested in a well-lit room with viewing distance controlled by means of a chin rest.

Mean correct reaction times and error rates were obtained. Error rates for all conditions were less than 2%, so no further analysis was conducted on this variable.

3. Results and discussion

A square root transformation was performed on the data to stabilise the variances and satisfy all assumptions of the mixed factorial analysis of variance. A significant interaction between target present or absent and distractors was found ($F(2,132) = 24.16$; $P < 0.0005$). Regardless of the number of distractors presented, no differences were found in response time for the target present condition. In the target absent condition, there was an increase in response time with increasing numbers of distractors presented. These results replicate the 'pop-out' effect found previously by Triesman (1986).

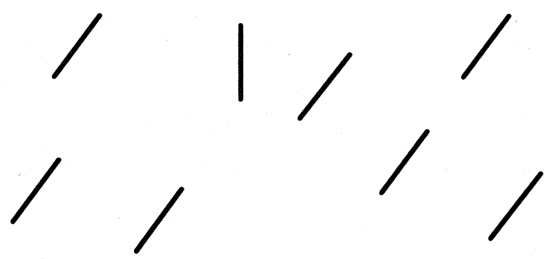

Fig. 1. Example of target present stimulus presentation from Experiment 1.

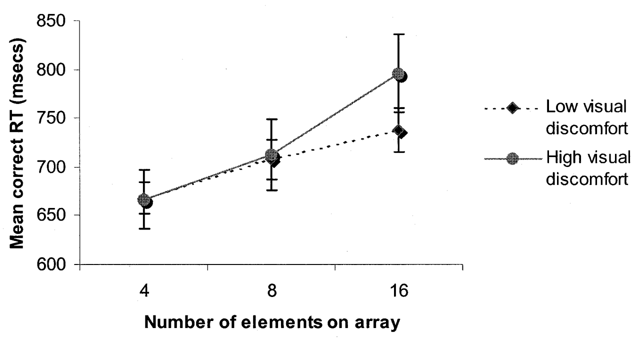

Fig. 2. Mean correct response times to four, eight and 16 distractors for the high and low visual discomfort groups. Standard errors bars represent ±1 standard error for each group. Experiment 1.

A significant interaction between visual discomfort group and number of distractors ($F(2,132) = 3.93$; $P < 0.025$) was found. In the 16-item condition, the high visual discomfort group performed more slowly than the low visual discomfort group. This result demonstrated that as task difficulty increased, the high visual discomfort group performed less efficiently (see Fig. 2). This finding is in the opposite direction to that expected if visual discomfort accounts for the processing speed advantage found by Wray et al. (1995) for the migraine with aura group.

No processing-speed advantage was found for the migraine with aura group, showing that automatic attention does not explain the processing speed advantage reported by Wray et al. (1995). One explanation of this is that conscious visual attention is required to produce the effect. This explanation was tested in Experiment 2.

4. Experiment 2

In a conscious visual attention task, a systematic search of individual display elements is conducted to determine if the target feature is present or absent. The difference between target and distractors is less salient than in an automatic attention task, so the target feature does not 'pop out' from distractor items. These features are detected at a later level of visual processing and are processed serially (Triesman & Gormican, 1988). Recent evidence has demonstrated that processing of this form of stimulus takes place in the posterior parietal cortex (Ashbridge, Walsh, & Cowey, 1997).

4.1. Method

4.1.1. Participants

There were 64 volunteers with normal or corrected to normal visual acuity and no history of neurological symptomatology other than migraine. Headache and visual discomfort were classified in the same way as Experiment 1. There were 15 in the migraine with aura group, 22 in the migraine without aura group, 12 in the non-specific headache group and 16 in the headache-free control group. Ages ranged from 18 to 46 years in the migraine with aura group (mean = 34), 17 to 50 years in the migraine without aura group (mean = 31),

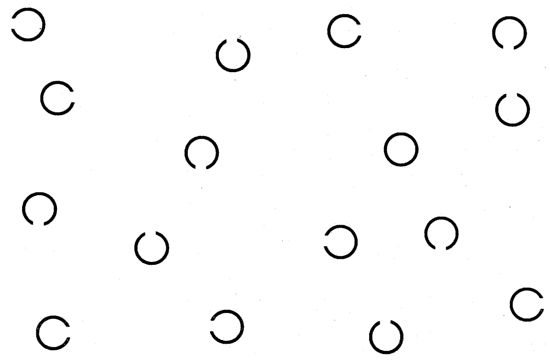

Fig. 3. Example of target present stimulus presentation from Experiment 2.

17 to 45 years in the non-specific headache group (mean = 28) and 18 to 45 years in the control group (mean = 25). Of the 15 participants with high visual discomfort, there were seven from each of the migraine with and without aura groups and one from the non-specific headache group. The average visual discomfort scores were 54.58% (S.D. = 14.0) for the high visual discomfort group and 23.84% (S.D. = 10.3) for the low visual discomfort group. Participants were free of headaches for at least 72 h prior to, and in the 24 h following, testing. The study had Griffith University Ethics Committee clearance. All participants gave written consent prior to the study.

4.1.2. Stimuli

Targets were circles and distractor's circles with a gap located at randomly designated points on each circle's circumference. At a viewing distance of 57 cm, each circle subtended a visual angle of 0.5° with the gap for distractors subtending a visual angle of 0.15° (see Fig. 3). The target, present for half of the trials, was randomly presented in different locations in the pattern array. In any one trial four, eight or 16 stimuli were presented. All displays subtended a visual angle of 8° horizontally and 6° vertically. Equipment and other stimulus parameters were the same as those used in Experiment 1.

4.1.3. Procedure

The procedure and number of trials presented were the same as those used in Experiment 1. Mean correct reaction times and error rates were obtained. Error rates were less than 2%, so no further analysis was conducted on this variable.

4.2. Results

Apart from some violation of the assumption of sphericity where the Huynh–Feldt correction was applied to the degrees of freedom, all assumptions of the mixed factorial analysis of variance were met. A significant interaction between target present or absent and number of distractors was found ($F(1.6,101) = 93.76$; $P < 0.0005$). A trend analysis demonstrated that slopes differed from 0 in both target present and absent conditions. Slopes were less steep in the target present condition, showing that the search terminated when the target had been successfully located. In the target absent condition, the linear increase in response time with increasing numbers of distractors showed that all items in the array were searched prior to the response. This task successfully reproduced a serial search reported by Triesman and Gormican (1988).

No significant main effects or interactions were found for the headache groups. This demonstrates that alone, migraine symptomatology fails to influence response time on a conscious attention task (see Table 1).

There was a significant main effect for visual discomfort group (($F(1,62) = 11.28$; $P < 0.0015$) and a significant interaction between visual discomfort group,

Table 1
Means and standard deviations for the mean correct response times (ms) to target present and absent conditions for the headache groups in Experiment 2

Headache group	Number of distractors					
	4		8		16	
Target present						
Migraine with aura	822.3	(201)	967.7	(241)	1404.9	(369)
Migraine without aura	844.4	(169)	1020.7	(192)	1525.6	(365)
Non-specific headache	773.6	(136)	969.2	(191)	1351.9	(301)
Control	768.6	(156)	914.7	(200)	1278.9	(344)
Target absent						
Migraine with aura	1134.9	(264)	1682.2	(501)	2483.4	(759)
Migraine without aura	1161.4	(239)	1709.0	(476)	2558.8	(830)
Non-specific headache	1003.7	(154)	1541.0	(465)	2484.6	(789)
Control	1036.9	(184)	1509.7	(401)	2321.0	(605)

Standard deviations are presented in brackets next to the mean correct response times.

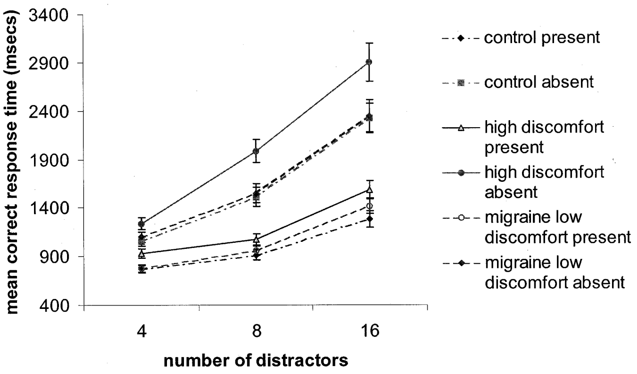

Fig. 4. Targets present and absent by visual discomfort group. The results of two control groups are included. The first contains all participants with low scores on the visual discomfort scale, and the second contains those with low visual discomfort scores and headache. Standard errors bars represent ± 1 standard error for each group. Experiment 2.

target present or absent and number of distractors ($F(1.6,99.73) = 3.88$; $P < 0.04$). Performance of the high visual discomfort group deteriorated as the number of distractors increased in both target present and absent conditions. The interaction is explained by a steeper increase in response time for the target absent condition for the high visual discomfort group (see Fig. 4).

A further analysis was conducted using headache sufferers with high and low visual discomfort only. There was a significant main effect for the visual discomfort group ($F(1,35) = 5.85$; $P < 0.05$) and a significant interaction between the visual discomfort group, target present or absent and number of distractors ($F(1.5,53.7) = 3.5$; $P < 0.05$). The same pattern of performance was found to that reported when the headache-free control group with low visual discomfort was used as the control. Performance of the high visual discomfort group was slower across all conditions compared to the low visual discomfort group. This result provides further evidence that high visual discomfort, rather than headache, explains poorer performance. This result is illustrated in Fig. 4.

5. General discussion

The results of these experiments failed to reproduce the processing speed advantage found in the migraine with aura group by Wray et al. (1995) but corresponded to the lack of differences found between migraine groups by Palmer and Chronicle (1998). In addition, high interictal visual discomfort produced a processing-speed disadvantage when 16 distractors were presented in the automatic attention (parallel search) task and in all components of the conscious attention (serial search) task. This is the first study that has shown less efficient performance among the high visual discomfort group without the presence of background interference gratings. The results are discussed using a framework of difficulties sustaining conscious visual attention among those with high visual discomfort.

The processing-speed advantage found for the migraine with aura group by both Woestenburg et al. (1995) and Wray et al. (1995) was not found in the current visual search studies. This may have occurred because the focus in the former studies was to determine the location of the stimulus, not discrimination among distractors located in random positions in a visual array. Attention to location has previously been found to enhance visual search for relevant visual stimuli (Corbetta & Shulman, 1998). The different task requirements across studies may explain the processing-speed advantage found for the migraine with aura group. Experience of high interictal visual discomfort does not explain this processing-speed advantage as predicted by Wray et al. (1995). It may, however, explain the processing-speed disadvantage found.

Using the hierarchical attention allocation system proposed by McConkie and Zola (1987), reduced processing efficiency in high visual discomfort has previously been explained by poor attention to the target (object level) because of an inability to direct attention away from the global pattern percept. This study shows that less efficient processing in the high visual discomfort group is not restricted to conditions where gratings or grating-like patterns are critical components of the experimental stimulus. Less efficient performance is also found when attention to detail is required, that is, the presence or absence of a gap in a circle or the presentation of an increased number of distractor items in a parallel search task. Poorer performance associated with the high visual discomfort group cannot be attributed to an increased level of global interference due to the presence of grating patterns only. This demonstrates that processing difficulties for the high visual discomfort group extend beyond extreme sensory hyperexcitability at cortical area V1.

A number of recent studies have demonstrated different forms of visual processing in parallel and serial search tasks (Ashbridge et al.,1997; Corbetta & Shulman, 1998). Interference with spatial attention is found when transcranial magnetic stimulation is applied to the posterior parietal cortex. Disruption of processing occurs in a serial, but not in a parallel, search task. The inability of the high visual discomfort group to sustain spatial attention at this level may explain the poorer performance on the serial search task and possibly on the more difficult components of the parallel search task where performance becomes more like a serial processing task. When four or eight distractors were presented in the parallel search task, the high visual discomfort group performed with the same speed and accuracy as the low visual discomfort group. With presentation of 16 distractors, however, performance deteriorated. The interference produced by the larger number of distractors may produce serial search-like behaviour in this group. Previous research has demonstrated that when task demands are high, greater visual attention must be directed to the salient aspects of a visual scene (Ward, 1982). If a serial search is required for the high visual discomfort group to successfully perform the task with presentation of 16 distractors, a poor ability to focus spatial attention is implicated.

Vidyasagar (1999) has argued that both magnocellular and parvocellular visual pathways are involved when undertaking visual search tasks. The faster-acting magnocellular stream acts as a 'gating mechanism' to spotlight areas of the visual scene to which spatial attention should be directed for serial search tasks. The parvocellular system acts to sustain conscious attention. Poorer performance for the high visual discomfort group can be explained in two ways. First, overload in the magnocellular system due to heightened sensory sensitivity to pattern and light may reduce efficiency within the attentional spotlight. Sensory sensitivity is increased to presentation of multiple stimuli, not just gratings. This increased sensitivity may act to produce slower search times for the high visual discomfort group. Second, focusing spatial attention, a parvocellular process may be less efficient in this group. A previous study that has measured spatial contrast sensitivity to spatial frequencies between 1 and 12 c/deg has found a reduced sensitivity across the spatial frequency range for the high visual discomfort group, in comparison to those experiencing moderate and low levels of visual discomfort. This suggests that the high visual discomfort group may have processing difficulties in the parvocellular pathway (Conlon, Lovegrove, Barker, & Chekaluk, 2001). Further research investigating attentional mechanisms in the magnocellular and parvocellular streams will differentiate between these two explanations.

References

Afra, J., Cecchini, A. P., Sandor, P. S., & Schoenen, J. (2000). Comparison of visual and auditory evoked cortical potentials in migraine patients between attacks. *Clinical Neurophysiology*, *111*, 1124–1129.

Ashbridge, E., Walsh, V., & Cowey, A. (1997). Temporal aspects of visual search studied by transcranial magnetic stimulation. *Neurospychologia*, *35*, 1121–1131.

Coleston, D. M., & Kennard, C. (1993). Visual changes in migraine: indications of cortical dysfunction. *Cephalalgia*, *13*, s1311.

Conlon, E., & Hine, T. (2000). The influence of pattern interference on performance in migraine and visual discomfort groups. *Cephalalgia*, *20*, 708–713.

Conlon, E., Lovegrove, W., Barker, S., & Chekaluk, E. (2001). Visual discomfort: the influence of spatial frequency. *Perception*, *30*, 571–581.

Conlon, E., Lovegrove, W., Chekaluk, E., & Pattison, P. (1999). Measuring visual discomfort. *Visual Cognition*, *6*, 637–663.

Conlon, E. G., Lovegrove, W. J., Hine, T., Chekaluk, E., Piatek, K., & Hayes-Williams, K. (1998). The effect of visual discomfort and pattern structure on visual search. *Perception*, *27*, 21–33.

Corbetta, M., & Shulman, G. L. (1998). Human cortical mechanisms of visual attention during orientating and visual search. *Philosophical Transactions of the Royal Society*, *London B*, *353*, 1353–1362.

Hay, K. H., Mortimer, M. J., Barker, D. C., Debney, L. M., & Good, P. A. (1994). 1044 Women with migraine: the effect of environmental stimuli. *Headache*, *34*, 166–168.

Headache Classification Committee of the International Headache Society (1988). Classification and diagnostic criteria for headache disorders, cranial neuralgias, and facial pain. *Cephalalgia*, *8*(Supplement 7), 1–96.

McConkie, G. W., & Zola, D. (1987). Visual attention during eyefixations while reading. In M. Coltheart, *Attention and performance XII* (pp. 385–401). Hillsdale, NJ: Lawrence Earlbaum.

Marcus, D. A., & Soso, M. J. (1989). Migraine and stripe-induced visual discomfort. *Archives of Neurology*, *46*, 1129–1132.

Palmer, J. E., & Chronicle, E. P. (1998). Cognitive processing in migraine: a failure to find facilitation in patients with aura. *Cephalalgia*, *18*, 125–132.

Rensink, R. A., & Enns, J. T. (1992). *Reference manual for Vscope and Emaker*. Vancouver: Micropsych Software.

Triesman, A. (1986). Features and objects in visual processing. *Scientific American*, *255*, 114–125.

Triesman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychological Review*, *95*, 15–48.

Vidyasagar, T. R. (1999). A neuronal model of attentional spotlight: parietal guiding the temporal. *Brain Research Reviews*, *30*, 66–76.

Ward, L. M. (1982). Determinants of attention to local and global features of visual forms. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 562–581.

Welch, K. M., Barkley, G. L., Tepley, N., & Ramadan, N. M. (1993). Central neurogenic mechanisms in migraine. *Neurology*, *43*, s21–s25.

Wilkins, A. J. (1986). What is visual discomfort? *Trends in Neuroscience*, *9*, 343–346.

Wilkins, A. J., Nimmo-Smith, I., Tait, A., McManus, C., Sala, S. G., Tilley, A., Arnold, K., Barrie, M., & Scott, S. (1984). A neurological basis for visual discomfort. *Brain*, *107*, 989–1017.

Woestenburg, J. C., Kramer, C. J., Orlebeke, J. K., & Passchier, J. (1995). Methodological considerations related to ERP's in migraine: differences in pathophysiology or central processes? *Perspectives of Event Related Potentials Research*, *EEG Supplement*, *44*, 405–413.

Wray, S. H., Mijovic-Prelec, D., & Kosslyn, S. M. (1995). Visual processing in migraineurs. *Brain*, *118*, 25–35.