
Auditory stimulus detection is not suppressed during saccadic eye movements

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Abstract. Auditory detection and pitch discrimination thresholds were measured during saccades and during periods of fixation. The accuracy of auditory localisation under these two conditions was also measured. These thresholds were unaffected by whether the sound was presented during a saccade or during periods of steady fixation: there is no evidence for saccadic suppression of auditory processing.

1 Introduction

During saccadic eye movements the detection threshold for flashed visual stimuli is increased (Dodge 1900; Holt 1903). The reduction in visual sensitivity during an eye movement is known as saccadic suppression and can be easily demonstrated by trying to watch the movements of one's own eye in a mirror. Under normal viewing conditions saccadic suppression can be partly explained simply by the blurring that results from high-speed image movement (Dodge 1905). Careful experiments, however, have shown that saccadic suppression is more than just blurring: blurring cannot account for the extent of the reduction in visual sensitivity (Burr et al 1994). Furthermore, saccadic suppression can be demonstrated in the absence of any blur, implying a central suppressive process (Riggs et al 1974; Volkman 1962, 1986). Might the neural mechanism responsible for saccadic suppression result in corresponding changes in other brain processes? As an extreme possibility perhaps saccadic eye movements are associated not only with a reduction in visual sensitivity but a dip in consciousness! To investigate the possibility of saccadic suppression being more general than just a visual phenomenon, we compared auditory detection and discrimination thresholds measured during saccades and during periods of fixation. We also compared the accuracy of auditory localisation during eye movements and during fixation.

2 Methods

2.1 *Measurement of auditory detection and pitch discrimination thresholds*

We measured two psychophysical parameters to quantify the perception of brief sounds that were presented through binaural headphones either during steady fixation or during 30 deg saccadic eye movements. Subjects sat with their heads lightly restrained in a chin rest, looking at a row of three LEDs spaced 15 deg apart. Eye movements were monitored by an infrared reflection technique and digitised by a CED 1401 interface. The procedure is illustrated diagrammatically in figure 1. All three lights flashed to indicate the beginning of a trial. Trials were of two types: fixation (figure 1, left) and eyes moving (figure 1, right). Each trial was divided into two identical periods during only one of which the auditory target was presented. The trials were randomly intermingled. For fixation trials the centre light was illuminated alone. The subject maintained fixation for 2 s and then the light went off for 2 s before coming on for the second presentation period. The presentation of the auditory stimulus was triggered by the light going out. For eyes-moving trials the right light came on for 2 s and the subject looked at it. When this went out, a target 15 deg on the other side of the fixation point was illuminated and the subject made a saccade to it. The presentation

of the auditory stimulus was triggered by the saccade (see below and figure 3). The target light stayed on for 2 s and then went out; 2 s later the right light came on again and the presentation was repeated.

Thresholds (70.7% correct levels) were obtained in three separate experiments by a two-alternative forced-choice (2AFC) staircase procedure (Levitt 1971; Wetherill and Levitt 1965). There were two identical periods to each trial (figure 1) and the subject was asked, "in which period was the sound presented, first or second?" (auditory detection) or, "which sound was highest, first or second?" (pitch discrimination). Subjects indicated their response by pressing one of two buttons. Four staircases were randomly interleaved: two starting above the expected values and two starting below for each of the eyes-moving and eyes-still conditions. Two consecutive correct responses resulted in a 20% decrease in the amplitude or frequency level of the sound, and one incorrect response caused the sound amplitude or frequency to increase by 20%. The mean of the last four out of eighteen reversals was recorded as threshold. Seven subjects took part in this study.

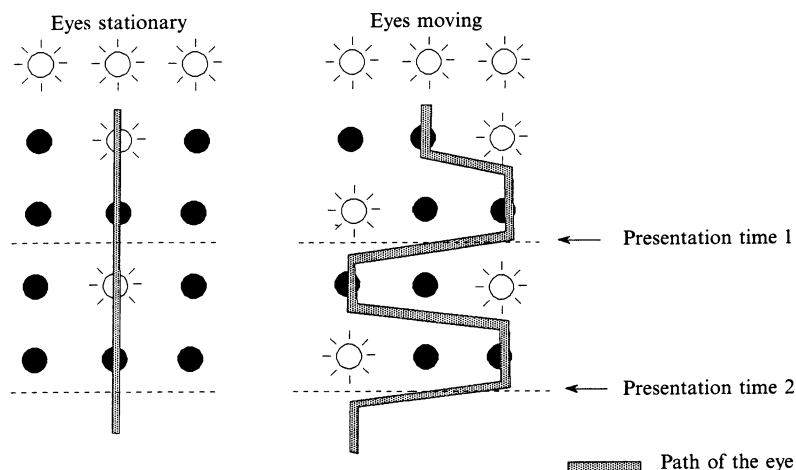


Figure 1. The experimental procedure for measuring auditory psychophysical thresholds during saccades. The open circles represent lit LEDs, the filled circles represent LEDs that were off. Time goes from the top to the bottom of the figure. The thick shaded line represents the direction of gaze. Trials were of two types: fixation (left side of diagram) and eyes moving (right side of diagram). The presentation of the auditory stimulus was triggered by a saccadic eye movement in the eyes-moving condition or by the light going out in the fixation condition.

2.2 Measurement of auditory localisation

The accuracy of auditory localisation during saccadic eye movements was measured with the subjects looking at the display shown in figure 1. Details of the timing are as for the earlier experiments, except that there was only one part to each presentation during which the stimulus was always presented, either following the extinguishing of a target light (eyes-still condition) or triggered by the saccade (eyes-moving condition). The subject reported, by means of pressing either the button in their left hand or the button in their right hand, whether the sound was to the left or to the right of the midline respectively. Accuracy of auditory localisation was measured for tones presented during saccades and during fixation. Four staircases were randomly interleaved, two starting with the left ear leading by 400 μ s (72° phase lead) and two starting with the right ear leading by 400 μ s. The rules were the same as in the earlier experiments. There were five subjects.

2.3 Generation, control, and calibration of the auditory stimuli

Auditory waveforms were generated digitally on a PC and downloaded to a 1401 Cambridge CED interface from whence they were played out through two DACs at a rate of 70 MHz through impedance-matching circuits into the left and right channels of a conventional audio amplifier (Nikko STA-8080) and presented through stereo headphones (Pioneer SE 80A). Sounds were calibrated in dB with a sound level meter (H H Scott type 412). The delivery of the sound could be triggered internally (when the appropriate LED went out) or in response to an eye movement. Eye position was sampled through an ADC at 250 Hz. The sound was delivered when the eye crossed a position threshold. For most of the experiments this level was one-third of the way to the target light. This corresponded to the sound being delivered 25 ms after the saccade had started, which is close to the time of maximum saccadic velocity. For some experiments, the level was set higher, such that the sound was delivered 60 ms into the saccade—close to the end of the saccade. The reason for this longer delay is explained in the discussion.

3 Results

3.1 Measurement of auditory detection and pitch discrimination thresholds

The parameters we assessed were auditory detection of a 20 ms burst (40 cycles) of 2 kHz sound and pitch discrimination of this same burst. Pitch discrimination was from a base of 2 kHz. The data are summarised in figure 2. For the auditory-detection task the stimulus was presented either 25 ms or 60 ms into the saccade. For the pitch-discrimination task the stimulus was presented 25 ms into the saccade. There was no significant difference in sound detection or pitch discrimination between when the eye was stationary and when the sound was presented during a saccade.

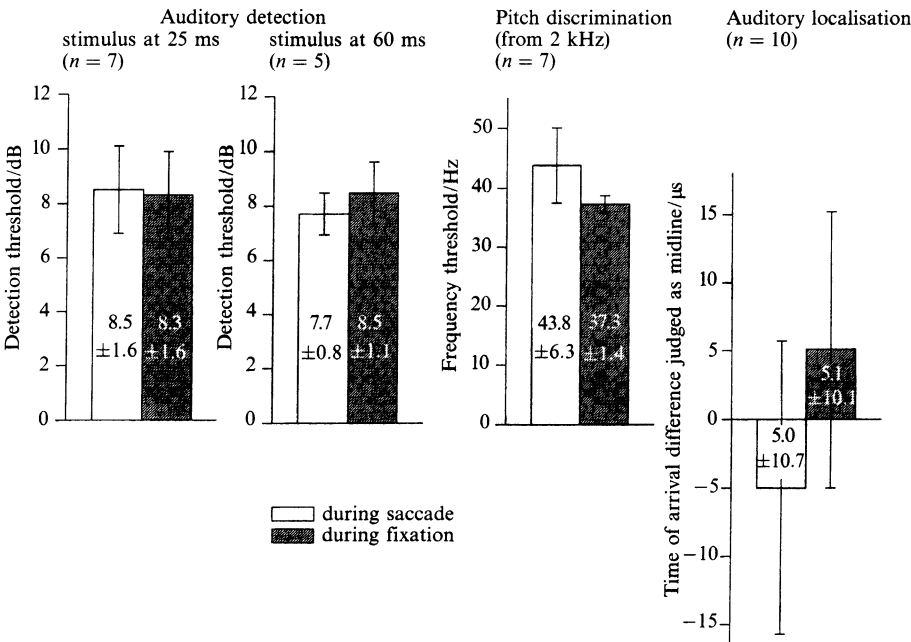


Figure 2. The values of each of the auditory parameters tested in this study during a saccade (open bars) or during fixation (shaded bars). The standard errors are also shown. None of the parameters showed a significant difference between the conditions (detection 25 ms: $F_{1,12} = 0.09$, $p = 0.771$; 60 ms: $T = 0.351$, $df = 9$, $p = 0.734$; pitch discrimination: $F_{1,12} = 0.95$, $p = 0.345$; sound localisation: $T = -0.966$, $df = 6$, $p = 0.371$).

3.2 Auditory localisation

The difference in the time of arrival of a sound in the two ears is a major cue in auditory localisation. Using binaural presentations with a variable time-of-arrival difference between the two ears we found that the standard error for the assessment of when a 10 ms burst of a 500 Hz sound was on the midline was 10.1 μ s during fixation and 10.7 μ s when the sound was presented 25 ms into a saccade. The data are summarised in figure 2. There is no evidence for saccadic suppression of the ability to localise sounds.

4 Discussion

The results reported in this paper have shown that there is no evidence for the suppression of auditory perception during a saccadic eye movement. Measurements of auditory detection, pitch discrimination, and localisation accuracy were not significantly different whether the presentation was made during a saccade or with the eyes still. Our conditions were chosen so as to optimise saccadic suppression of visual stimuli. Although there is a great deal of evidence to support the existence of saccadic suppression (Gross et al 1967; Matin 1974), no suppression is detected under complete darkness (Latour 1962; Mitrani et al 1970), of intense stimuli (Chase and Kalil 1972), or if criterion-free choice methods are not used (Brooks and Fuchs 1975). Our experiments were carried out in a normally lit environment, the stimuli were not intense (close to threshold in the case of the detection task, of course), and the forced-choice method was chosen as being criterion free.

4.1 Relative timing of auditory and visual processing

Saccadic suppression, defined as the time during which the detection of a light is impaired, starts about 20–40 ms before a saccade (Latour 1962; Volkman 1986; Volkman et al 1969) and lasts to the end of the movement or beyond (Burr et al 1982).

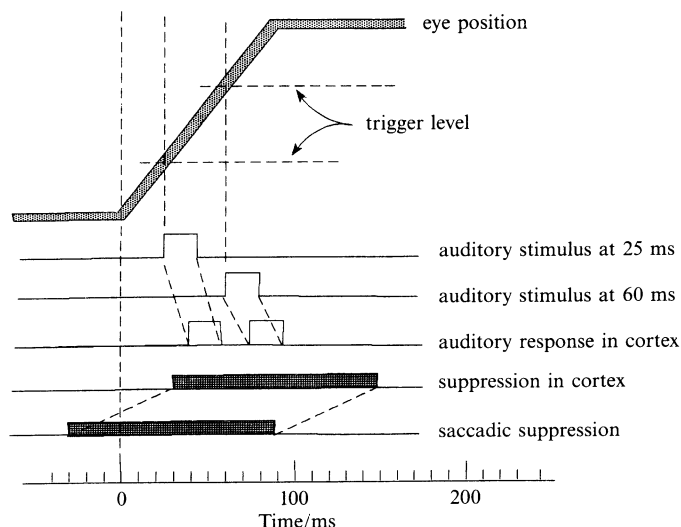


Figure 3. The relative timing of the events. The trace labelled 'eye position' shows diagrammatically the time course of the 30 deg saccades used in this study along with the trigger levels used to trigger the auditory stimuli. The traces labelled 'auditory stimulus' at 25 ms and 60 ms show the times at which the auditory stimuli were presented. The trace labelled 'auditory response in cortex' shows the expected arrival time in the cortex of auditory responses (see text). The bottom trace, labelled 'saccadic suppression', shows the time course of saccadic visual suppression, defined as the time during which detection of a light is impaired. The trace labelled 'suppression in cortex' shows the expected arrival time in the cortex of visual information that is subject to saccadic suppression (see text).

Because of the transduction and conduction times, the visual response normally takes at least 60 ms to arrive at the cortex (Jeffreys and Axford 1972; Lesevre 1982). That means that, if visual suppression is cortical, the suppressive effect does not start until at least some 20–40 ms after the onset of a saccade. This is shown diagrammatically in figure 3. Auditory transduction times are much faster and auditory responses can be measured in the cortex with a latency of around 15 ms (Celesia 1976; Liegeois-Chauvel et al 1991). Auditory responses arrive in the cortex at the same time as visual responses to stimuli delivered some 45 ms earlier. This means that the response to an auditory stimulus occurring 20 ms before a saccade might pass through the system before visual saccadic suppression was active, even though a visual stimulus delivered at the same time would be suppressed. To ensure that auditory responses to our stimuli were processed during the period when visual saccadic suppression was active we used sounds delivered 25 and 60 ms into the saccade. As shown in figure 3, the processing of sounds at either of these delays would have been affected if visual saccadic suppression extended into the auditory domain. Auditory detection thresholds remained unaffected, however.

4.2 *Detection versus localisation*

The aspects of vision that are most suppressed during saccadic eye movements are those related to the position and movement of the stimuli (Bridgeman et al 1975; Bridgeman and Stark 1979; Burr et al 1982, 1994; Ilg and Hoffmann 1993; Shioiri and Cavanagh 1989). Indeed Burr et al (1994) have shown that saccadic suppression of a central inhibitory origin, that is independent of the blur factor, only works for luminance-defined, low-spatial-frequency stimuli—features that carry most position information. Arguing that perhaps, analogously to vision, auditory information pertinent to the position of the stimulus might be specifically suppressed during a saccade we compared the accuracy of sound localisation for sounds presented during saccades with the accuracy with which a sound could be localised with the eyes stationary. Figure 2 shows that there was no significant difference.

5 **Conclusions**

The data presented here show that during saccades one sense (vision) is being attenuated but another (hearing) is unaffected. What might be the consequences of this differential treatment of the senses? If a visual event and matching sound are presented during a saccade, the light is likely to be undetected because of blur consolidated by saccadic suppression although the sound is heard as usual. Events short-lived enough to occur entirely within the duration of a saccade are very rare: normally objects are present both before and after a saccade and have a continuity to their perception and a constant position in space despite their voyage across the retina. We have shown that sound localisation is not disrupted during saccades: sounds can be unambiguously assigned a spatial location even if they occur right in the middle of an eye movement—even though their visual correlate might not be visible at that time.

One curious feature of saccadic suppression is not so much that it exists—assigning a spatial location to a light seen only during a saccade is bound to be hard—but that one is unaware of these regular disruptions. Perhaps auditory continuity is helpful in smoothing over the gaps.

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