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The Audioocular Response: Intersensory Delay[1]

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The characteristics of eye movements elicited by auditory stimuli, the audioocular response (AOR), differ from those made in response to a visual target. Saccadic latency to a visual stimulus increases, while the AOR latency decreases as a function of the displacement of the stimulus from the starting position of the eyes. This indicates that the inherent retinotopic variation of saccadic latency to visual inputs is independent of starting eye position, but the somatotopic variation of the AOR is altered. The accuracy of AOR was only slightly less than latency of response to a visual stimulus at all stimulus and starting positions.

We reported previously that the latency of saccadic eye movements to auditory stimuli (audioocular response, AOR) was longer than to visual stimuli (Zahn, Abel, & Dell'Osso, 1978). Moreover, unlike the latency to visual stimuli, which increased as a function of the lateral distance of the stimulus from primary position, the AOR decreased (i.e., the latency for a stimulus at 10° was longer than one at 20°). The results established that when the head and eyes were fixed at primary position, the latency to a lateral visual stimulus was directly dependent upon the retinal distance of the stimulus with respect to the fovea, whereas the AOR latency was inversely dependent upon the location of the sound with respect to the midline between the ears. In order to define further the interaction of these two spatially disparate systems, the present experiment was designed to separate the retinotopic frame of reference of the visual system from the somatotopic frame of reference of the auditory system by utilizing different initial ocular fixation positions along the horizontal meridian while the head remained fixed straight ahead. If the saccadic latency to a visual stimulus depends on the distance of the image to the fovea, then there would be an increase in the latency as a function of the lateral displacement of the retinal image regardless of the starting position of the eye movement. If the saccadic latency to an auditory stimulus is dependent solely on the position of the sound with respect to the head, then there would be longer latencies at the 10° than at the 20° stimulus positions regardless of the starting position of the eye movement. These assumptions were tested in the present experiment.

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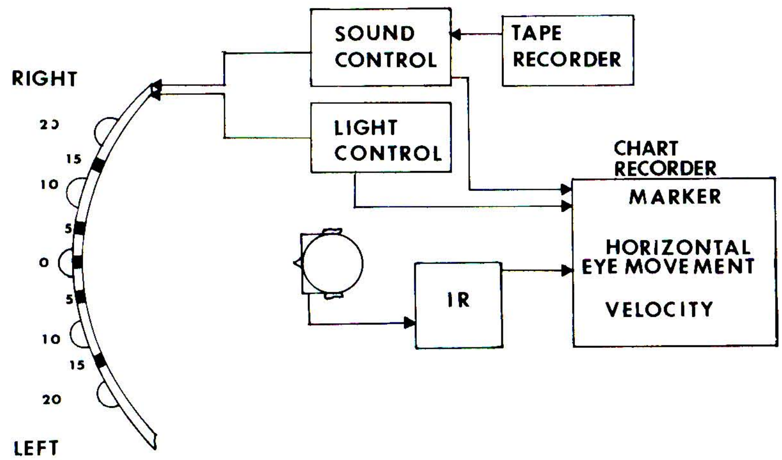

FIG. 1. Block diagram of the experimental apparatus.

METHODS

Six subjects (four women and two men) between the ages of 24 and 32 with normal auditory, visual, and ocular motor function participated in this experiment. The experimental arrangement is shown in Fig. 1.

The subjects were seated in a modified dental chair at the center of a 228-cm-diameter perimeter. The head was firmly fixed in a straight-ahead position by a head brace and chin cup. This procedure served to reference the auditory system via the ears at the 0° position of the perimeter. Five separate starting positions (0°, and at 5 and 15° right and left of 0°) were used as fixation points for the eyes.

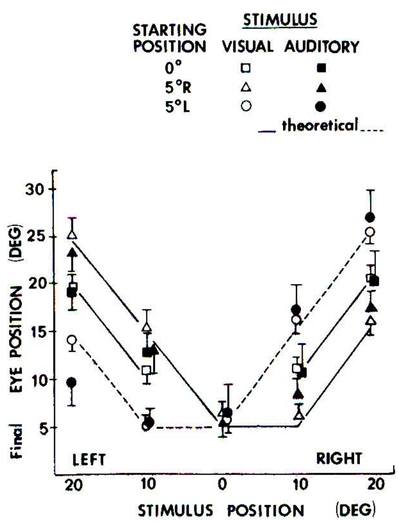

FIG. 2. Final eye position, as measured from initial eye position, for both visual (open symbols) and auditory (closed symbols) stimuli for starting positions of 0 and 5° right and left. X-axis, stimulus position; Y-axis, final eye position. Broken and solid lines represent theoretically perfect eye movements. Each point represents the mean across all subjects (54 responses). In this and succeeding figures, one vertical bar is one standard deviation.

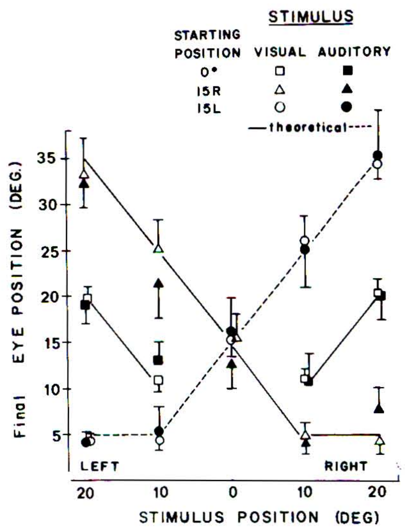

FIG. 3. Final eye position, as measured from initial eye position, for both visual (open symbols) and auditory (closed symbols) stimuli for starting positions of 0 and 15° right and left. Broken and solid lines as in Fig. 2.

The subject's task was to fixate a continuously illuminated red light-emitting diode until a sound occurred, then to "look" as quickly and as accurately as possible to the position of the sound. He was to hold his eyes at this position for about 1 sec, then refixate the starting position and await the next stimulus. The sequence was the same for the visual stimuli.

The auditory stimulus was a narrow-band burst of noise (2 octaves wide at the 3-dB points) centered at 1500 Hz with an intensity at ear level of 65 dB (General Radio Co. sound level meter Type 1565A). The stimulus was generated by an Amplaid 300 audiometer (reference at 0.0002 μbar, sound pressure level) driving a Teledyne Model R-618 amplifier and recorded on a Teac Model A-440 cassette deck. The prerecorded stimulus was presented for approximately 1 sec at an average interval of 5 sec.

The visual stimuli (red light-emitting diodes) and auditory stimuli (presented through 9-cm loudspeakers), were located on a specially designed perimeter (Dell'Osso, Troost, Patterson, & Saccrio, 1974) at 0° and at 10 and 20° to the right and left. At no time during calibration or testing were the loudspeakers visible to the subject.

Eye movements were recorded with an infrared eye monitoring system (Biometrics, Model 200), linear to ±20°, and an eight-channel dc-coupled recorder (Beckman Instruments, Inc., Type R Dynograph) with a 100-Hz bandwidth. It was possible to measure the latency and accuracy to 10 msec and 0.5°, respectively.

For each subject, a complete block of trials consisted of 10 presentations per stimulus position for each starting fixation position. Calibration was checked and a rest period given prior to each new starting position. Testing of each subject required two 45-min sessions.

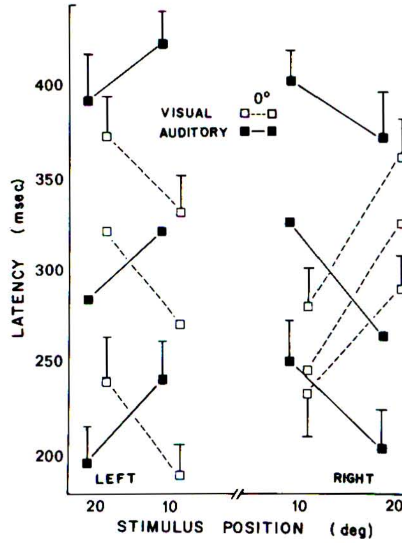

FIG. 4. Latency of saccadic eye movements initiated from 0° starting position. For this and succeeding figure, overall mean represents 54 responses, points with standard deviation (vertical bars) represent 9 responses per stimulus position for the fastest and slowest subjects, and the visual data have been shifted along the abscissa.

RESULTS

Figures 2 and 3 show the accuracy of saccadic eye movements elicited by auditory and visual stimuli from starting positions at 0°, and 5 and 15° to the right and left. These data indicate that saccades elicited by auditory stimuli were slightly less accurate and more variable than saccades elicited by visual stimuli for all stimulus and starting positions. A four-factor analysis of variance (Kim & Kohout, 1975) revealed no significant difference; however, for the 5 and 15° to the right starting positions, there was a trend for the errors to be shifted in the direction of the starting position; that is, eye movements to the right overshot and eye movements to the left undershot the stimulus position.

Figures 4 and 5 contain both the mean saccadic latencies and latencies for the fastest and slowest subjects to visual and auditory stimuli. Taken together, these data indicate that saccadic latency was greater the closer the auditory stimuli and further the visual stimuli were from the starting *fixation position*. The differences between the auditory and visual stimuli were highly significant ($F[6,/008] = 28.15$, $p < .001$) for stimulus positions close to the starting position. Thus, the starting position of the eyes in the head influences the time taken to "look" at an auditory stimulus. Furthermore, the AOR latency for stimuli close to the midline was longer than for those which were further away (i.e., latency for a 10° stimulus was longer than for a 20° stimulus).

DISCUSSION

The purpose of the present experiment was to determine whether the latency of saccadic eye movements depended solely on the distance from the fovea for visual stimuli and from the midline (head) for auditory stimuli. Our data indicate that

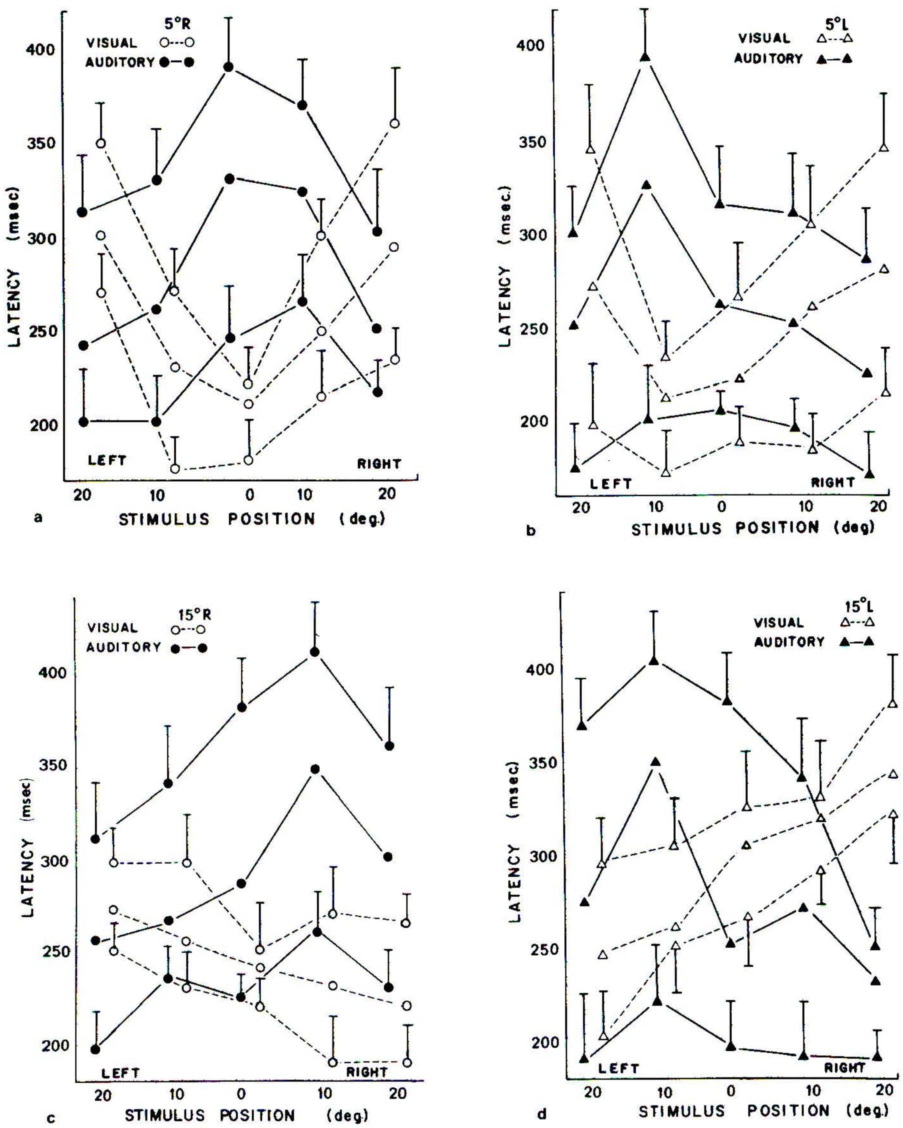

FIG. 5. Latency of saccadic eye movements initiated from the starting positions of (a) 5° R, (b) 5° L, (c) 15° R, and (d) 15° L.

saccadic latency to a visual stimulus *increases*, while the AOR latency *decreases* as a function of the angular displacement of the stimulus from the *starting position* of the eye. The AOR latency is related to both the position of the auditory stimulus with respect to the ears and to the position of the eyes in the head. These data indicate an influence of the ocular motor system on auditory localization.

The position of the visual image on the retina (relative to the fovea) influences the latency of the refixation saccade when the eyes start from primary position, implying a spatial influence on saccadic latency (Robinson, 1973; Zahn *et al.*, 1978), but the variation of the delay in the saccadic response to a visual stimulus with different eye positions in the head has not been reported previously. Our data indicate that the spatial influence is not changed by the position of the eyes in the head.

Given that the variation in starting eye position did not affect the retinotopically organized ocular motor system mapped in the superior colliculus, our data suggest that the transformation from the auditory system, somatotopically mapped in the inferior colliculus, is affected by the relative positions of the reference points of each system. Thus, the AOR contains an additional processing delay which is a function of this misalignment of the two spatial orientations. In making an ocular motor response to an auditory stimulus, we are utilizing a system normally responsive to an absolute visual input (i.e., image distance from the fovea) to respond to a differential acoustic input (i.e., sound difference to the two ears). While it would have been difficult to predict the results of this experiment, it is not surprising that part of the response time is determined by the relative alignment of the different reference points of each sensory modality.

Our previous observations (Zahn *et al.*, 1978) that the accuracy of the AOR was only slightly less than the accuracy of response to visual stimuli at all stimulus positions was confirmed and extended to various starting positions. Furthermore, the accuracy of the initial saccadic eye movement to visual and auditory stimuli may be better than the accuracy of the final eye position as reported; in our analyses for both studies we measured the final eye position obtained within 1 sec after the stimulus cessation, thus permitting the subject to correct the initial eye movements with subsequent eye movements in both the auditory and visual conditions. For the AOR, the subject did not have visual feedback and, further, may have been influenced by the ocular motor instability manifested in the dark (Becker & Klein, 1973).

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