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Short communication

Improved auditory spatial sensitivity in near-sighted subjects

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Abstract

There is a great deal of anecdotal and empirical evidence in favor of compensatory plasticity of the sensorial modalities when one of them undergoes a total deficit. Yet, while most research has focused on the development of spatial hearing in totally blind individuals, there are few works dealing with auditory compensation in the case of a partial visual deprivation. In the present study, three experiments show that subjects undergoing a visual deficit like myopia are more accurate at localizing sounds than normal-sighted subjects.

Theme: Sensory systems

Topic: Auditory systems: central physiology

Keywords: Cross-modal; Compensatory plasticity; Visual disabilities; Auditory localization

Do people with visual disabilities develop capacities of their remaining senses that exceed those of sighted individuals? This has been a question of debate for a long time within the disciplines of experimental psychology, sensory rehabilitation, and neuroscience. There is a great support from studies of humans and animals showing that auditory [1,7,9,10] or tactile [11] abilities develop in the absence of normal visual experience. For instance, it has been shown that cats deprived visually from birth show little overt impairment in their natural behavior due to improved auditory localization, and at least equal tactile behavior compared to normal controls. Electrophysiological recordings showed that compensatory plasticity and sensory substitution in the sensory cortices are presumably the neural basis of the overt sensory substitution. Sensory substitution in the cerebral cortex was also observed in blind humans [3,6]. For instance, a positron emission tomography (PET) study [3] demonstrated that Braille readers blinded in early life show activation of primary and secondary visual cortical areas during tactile tasks, whereas normal controls show deactivation.

Yet, research has mainly focused on total visual (early or late) deprivation and its implications in the development of tactile or auditory perception. However, it seems not unreasonable to hypothesize that any reduction in the accuracy and reliability of seeing, like myopia or other optical deprivations, may lead to greater relative reliance on and use of hearing. To test this hypothesis, we compared auditory localization performance of near-sighted and normal-sighted adults in three different tasks.

Eighteen subjects (nine normal and nine near-sighted) performed a pointing task, 16 (eight normal and eight near-sighted) a magnitude estimation task and 14 (eight normal and six near-sighted) a speeded 2 AFC task. Each subject participated only in one experiment. All reported normal hearing. Their ages ranged from 22 to 29 years. Near-sighted subjects reported having a visual deficit for at least 10 years. Myopia ranged from -6.75 to -1.25 D (diopters). Each near-sighted subject had approximately the same visual deficit at each eye. Eight of the near-sighted subjects were used to wear eye lenses (four in experiment 1, three in experiment 2, and one in experiment 3) while the others wore glasses. Two subjects reported being also astigmatic. None of them was amblyopic.

In the first experiment, subjects had to point with unseen finger to a brief repetitive sound. They were seated blindfolded at a table with head fixed in a combination chinrest and forehead restraint. A repetitive broad-band

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white noise was presented with a frequency of 2 sounds/s (20–20 000 Hz; 10 ms in duration and 60 dB sound pressure level as measured from the subjects' ear position). Sounds, displayed through a loudspeaker (4×8 cm oval cone, 4 Ohm, 3 W), were generated by a sound card (SoundBlaster, 16 bits). Background noise, caused by the computer fan, registered 40 dB. The ten target positions were located at ±10°, ±20°, ±30°, ±40° and ±50° laterally along the outer circumference of a semicircular shelf (0.50 m from subject), where 0° represents subjects' straight ahead. Subjects who were all right-handed did all the pointing with the right finger. They rested the left forearm on the tabletop, the hand gripping the holder of the chinrest. Between pointings, they were instructed to bring the right hand back to a resting position next to the left hand. The sound remained on until the subject completed his pointing response. However, subjects were informed that the sound would last only three seconds. All subjects responded before this limit and there was no significant response time difference between both populations. Subjects' pointing positions were recorded on graduations that were delineated directly on the table with a precision of 1°. A training procedure was used in which the subjects were presented ten practice trials. The target was presented twice at each location in a random order. Thus each response measure was estimated on the basis of 20 trials per subject. The whole session lasted approximately 10 min. No response time constraints were imposed on the subjects.

A comparison between normal-sighted and near-sighted subjects was made on the basis of two behavioral measures: mean localization judgement and trial-to-trial variability. Trial-to-trial variability provides a measure of subjects' consistency, while mean localization judgement provides a measure of localization veridicality form trial to trial. For each trial, the response location was subtracted from the true target location. The absolute value of this signed error was used to calculate the mean of the absolute values of error (M.A.E.). The standard deviation of error (S.D.E.) represents the trial-to-trial variability.

Mean M.A.E. and S.D.E. scores of the pointing task are shown in Fig. 1a for both normal-sighted and near-sighted group. Fig. 1b displays absolute error for each speaker position. Near-sighted subjects made smaller pointing errors than subjects with normal vision $t(16)=2.83$, $P<0.05$. The error variability was also less pronounced with near-sighted than with normal-sighted subjects, $t(16)=2.61$, $P<0.05$. Analysis of signed errors showed no significant bias effect.

In order to test whether a different eye movement strategy or a higher accuracy in ear–hand coordination may account for the difference of performance between near-sighted and normal-sighted subjects, a second experiment was conducted. In this experiment subjects made magnitude estimation and were instructed either to make eye movements or keep their eyes fixed on a reference point. The two groups were also compared in a visual localization task to make sure that near-sighted subjects are specifically more accurate in auditory localization and not in any localization modality. Subjects were seated 1 m from a semicircular shelf with head fixed in a combination chinrest and forehead restraint. The visual target was a red light emitting diode (LED) illuminated with a luminance of 4.6 cd/m^2 and 100 ms in duration. The visual reference point was a green LED, 100 ms in duration with a luminance of 10 cd/m^2. Viewing was binocular. The auditory target was a white noise (100 ms duration, 65 dB SPL). The auditory reference point was a pure tone (2000 Hz, 100 ms in duration and 65 dB SPL). Background noise registered 40 dB. The target locations were at ±5°, ±10°, ±15° and ±20° relative to the subjects' straight ahead and in the horizontal plan. Reference points were presented at the 0° position (i.e. subjects' straight ahead). The entire experiment took place in the dark. Reference points, either visual (in the visual task) or auditory (in the auditory task), were presented for 100 ms at the 0° position and were immediately followed by the target. Subjects were instructed to use the number zero to denote the location straight ahead of their nose, positive numbers for locations to their right, and negative numbers for locations to their left. Prior to the trial session, the visual target was displayed twice in the +20° and −20° locations and subjects were asked to use the largest numbers, positive and negative, for these extreme locations. In the 'no eye-movement' condition, subjects were instructed to maintain their eyes straight-ahead and to inhibit eye movements in the direction of the target. In the 'eye-movement' condition, subjects were asked to make eye movements from the straight-ahead position to the target position. Each subject performed both tasks (i.e. visual and auditory stimulus localization) in either 'eye-movement' vs. 'no eye-movement' condition. Thus each subject participated in four experimental conditions which were presented in a random order. A training procedure was used in which the subjects were presented ten practice trials with targets across the entire 40° range. The target was presented three times at each location in a random order. Thus each response measure in each condition was estimated on the basis of 24 trials per subject.

The S.D.E. and the M.A.E. scores of the magnitude estimation task were entered into an analysis of variance, with the kind of subject (normal-sighted vs. near-sighted) as a between-Ss variable and with 'eye-movement' and 'localization task' two within-Ss variables. Mean M.A.E. is shown in Fig. 2a. Absolute errors of auditory localization are presented for each speaker position in Fig. 2b (no eye movements) and Fig. 2c (eye movements). Near-sighted subjects had significantly lower M.A.E. scores than normal-sighted subjects in the auditory localization task, $F(1,14)=7.01$, $P<0.05$. On the other hand, in the visual localization task, M.A.E. scores did not differ significantly between normal-sighted and near-sighted subjects (near-

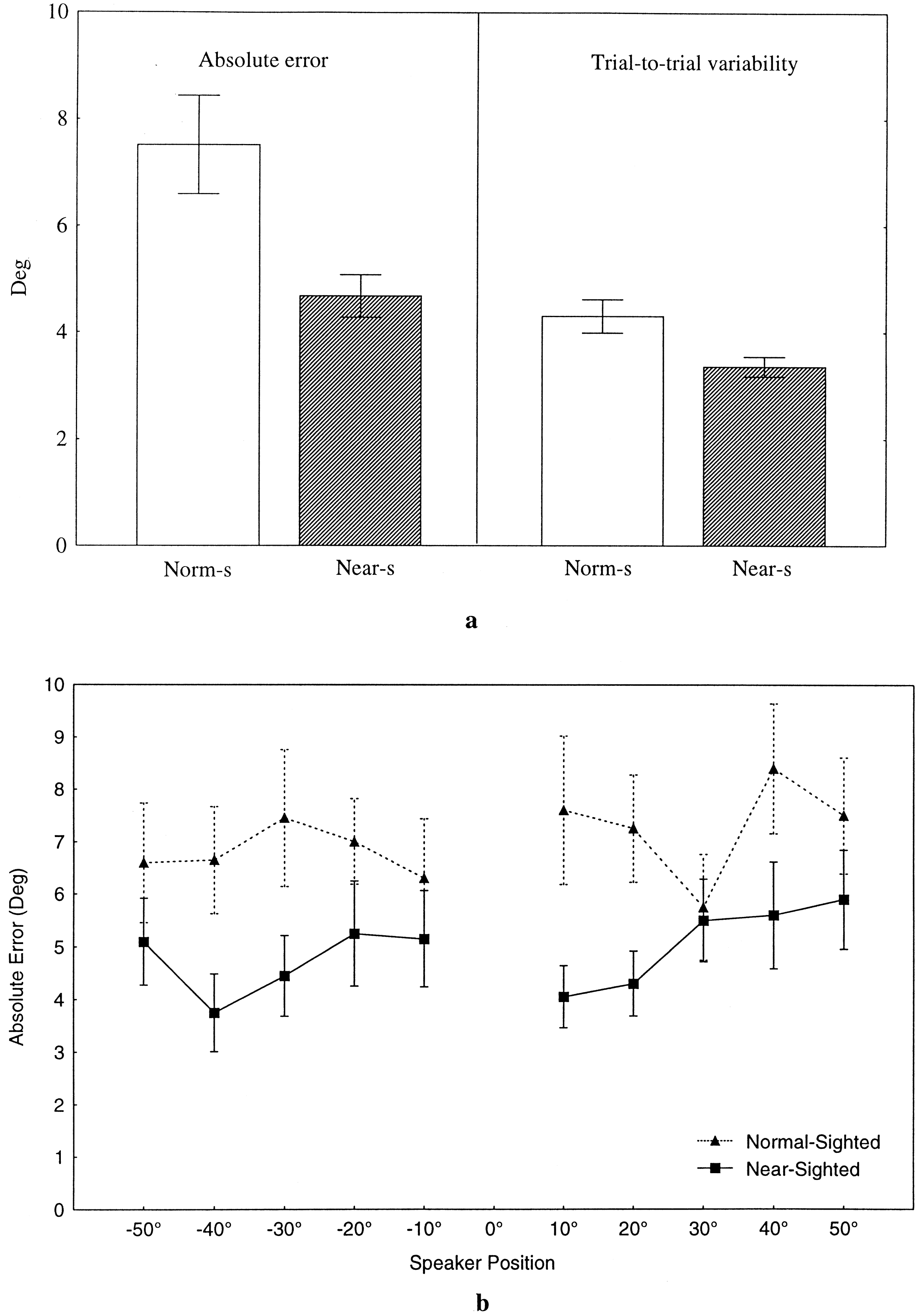

Fig. 1. (a) Mean absolute error and standard deviation of error for nine normal-sighted (Norm-s) and nine near-sighted (Near-s) adults. Error bars represent standard deviation of the mean. (b) Mean absolute error for each speaker position. Error bars represent standard errors of the mean.

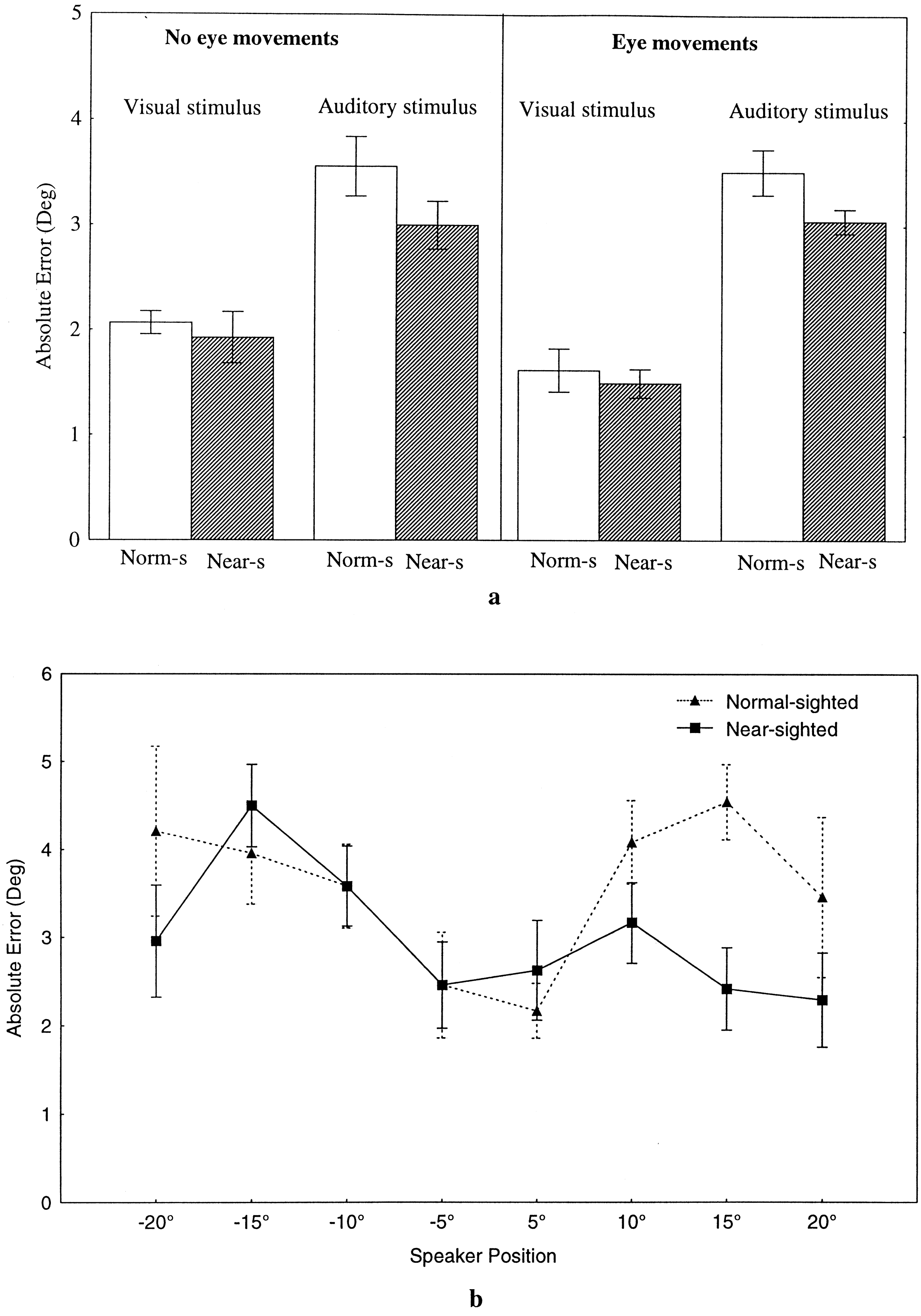

Fig. 2. (a) Mean absolute error for eight normal-sighted (Norm-s) subjects and eight near-sighted (Near-s) subjects in either 'eye-movement' vs. 'no eye-movements' conditions. Error bars represent standard errors of the mean. (b) Mean absolute error for each speaker position: eight normal-sighted (Norm-s) subjects and eight near-sighted (Near-s) subjects in the 'no eye-movements' condition. Error bars represent standard errors of the mean. (c) Mean absolute error for each speaker position: eight normal-sighted (Norm-s) subjects and eight near-sighted (Near-s) subjects in the 'eye-movements' condition. Error bars represent standard errors of the mean. (d) Mean standard deviation of error for eight normal-sighted (Norm-s) subjects and eight near-sighted (Near-s) subjects in either 'eye-movement' vs. 'no eye-movements' conditions. Error bars represent standard errors of the mean.

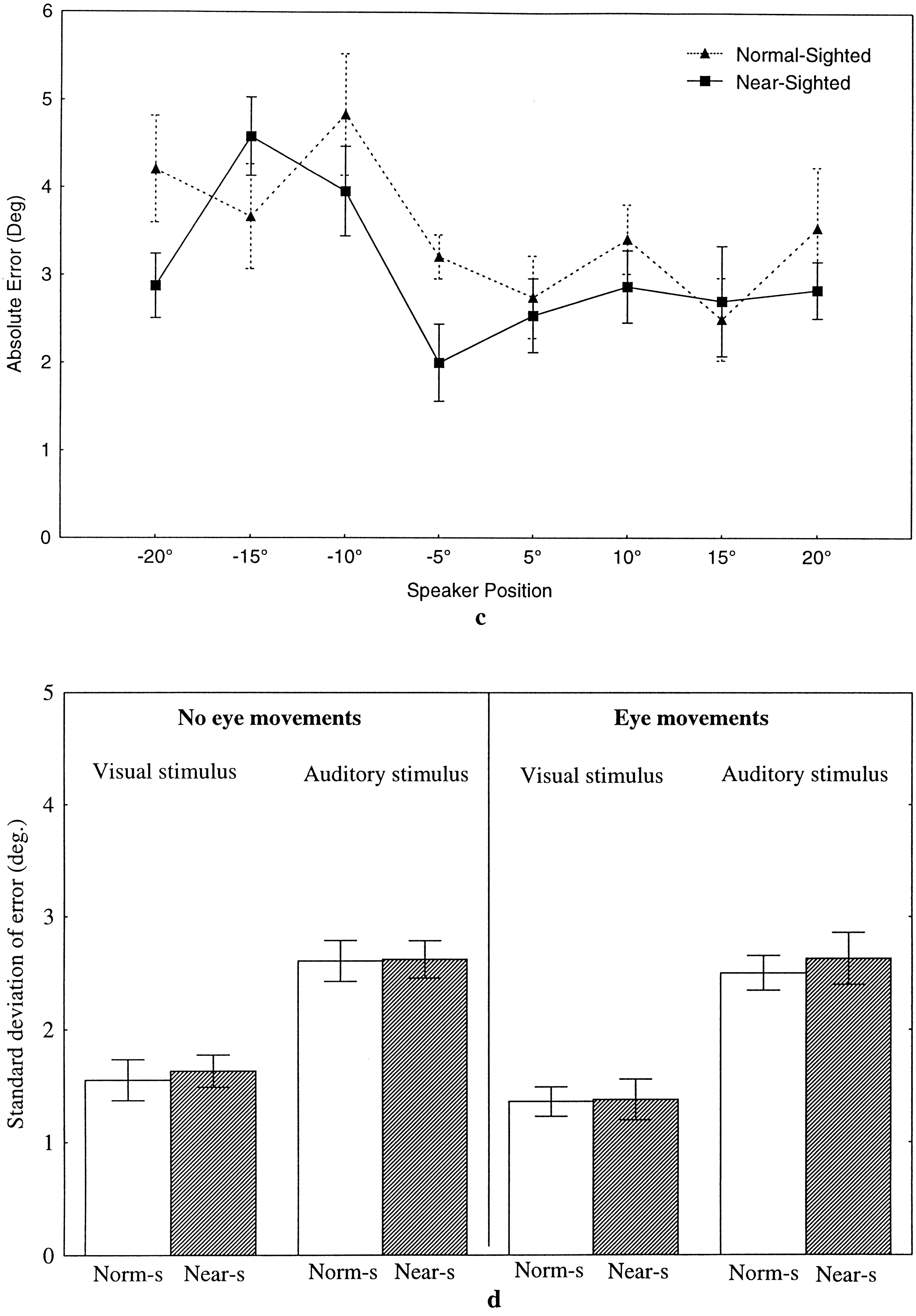

Fig. 2. (*continued*)

sighted subjects wore their glasses during the experiment). When eye movements were allowed, subjects were more accurate than when fixation was required in the visual localization task, $F(1,14)=6.73$, $P<0.05$. This replicates previous findings in visual and auditory localization research [5,8,12]. However, the eye-movement effect did not interact with the 'normal-sighted vs. near-sighted' factor. In the auditory localization task, M.A.E. did not differ significantly whether eye movements were allowed or not.

Mean S.D.E. are shown in Fig. 2d. Scores do not differ significantly between the normal-sighted and near-sighted subjects. S.D.E. seem to be lower when eye movements were allowed than when fixation was required in the visual target localization task. However, this difference was not statistically significant.

In the preceding experiments, we did not control the time subjects took to give their answer. Consequently, the difference of performance between normal and near-sighted subjects may be in the response strategy elaborated by either group. In order to acquire more evidence regarding the difference in auditory localization performance between near and normal-sighted subjects we conducted a third experiment. Subjects, performing a speeded two-alternative-forced choice task, were asked to judge whether a brief sound emanated from the left or the right of the fixation point (red LED) (i.e. subjects' straight ahead). The sound was delivered immediately after the fixation LED was turned off. Six loudspeakers (4×8 cm oval cone, 4 Ohm, 3 W) were aligned horizontally at a distance of 1 m from the subject's head position. They were placed 4°, 8°, 12° to the left and the right of the fixation point (0° position). The LED was turned on for 800 ms and, immediately after it was turned off, a brief sound (white noise, 50 ms duration, 65 dB SPL) was randomly delivered from one of the loudspeakers. Subjects gave their answer by pressing the right or left arrow keys of the computer keyboard.

Results (Fig. 3) showed that near-sighted subjects responded significantly (Student–Newman–Keuls test) faster than normal-sighted subjects when sounds emanated from the speakers with less eccentricity relative to the midline (i.e. leading to maximum uncertainty). Percentage of error did not differ significantly between both groups, showing that the faster responses made by the near-sighted group were not accompanied with an increase of errors.

These results support our proposal that partial visual deficit like myopia leads to greater relative reliance on and use of hearing which in turn leads to improvement of spatial auditory sensitivity. Several psychophysical studies of humans have attempted to verify experimentally the notion of intermodal compensation [2]. Early observers frequently concluded that when humans are deprived of stimulation through one or more senses compensatory increases in acuity are evident in the intact system [4]. This point of view has also prevailed in the development of rehabilitative procedures designed to enhance and substi-

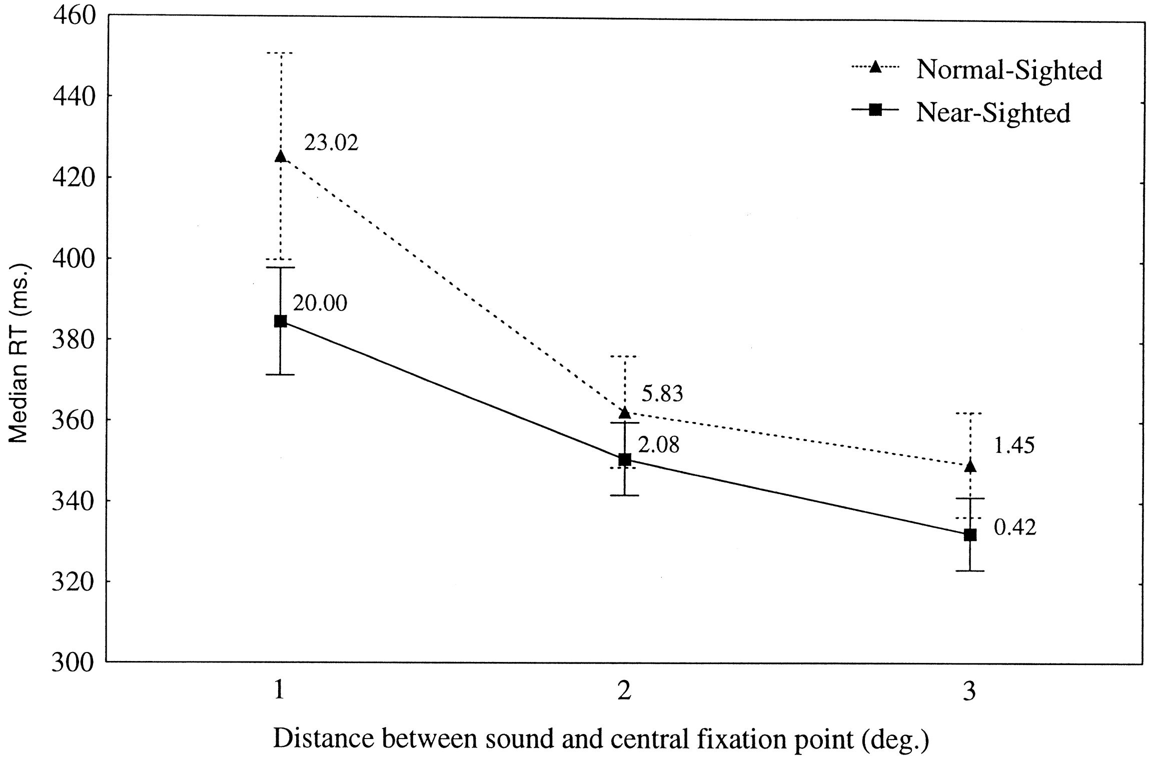

Fig. 3. Mean median RT (ms) for eight normal-sighted and six near-sighted subjects as a function of the absolute distance between the LED (midline) and the loudspeakers. Percentages of errors are in brackets. Error bars represent standard errors of the mean.

tute an intact modality for a missing one. The present study shows that increases in acuity in intact systems not only occur when other sensory systems undergo total deprivation but also in the case of only partial deficits. Although our study was restricted to near-sighted adults, it seems reasonable to hypothesize that auditory compensation is not restricted to myopia but to other visual impairments. The question arises as to why a visual deficit which is corrected by wearing glasses or lenses from the start of myopia would need to be compensated by a better auditory localization behavior. A plausible explanation might be that, during infancy, myopia is generally corrected by wearing glasses rather than lenses. Glass rims might shrink the visual field and this might lead near-sighted subjects to rely more on auditory information than normal-sighted subjects do. Under such assumption one might expect to observe greater differences between both populations as sounds sources reach visual eccentricity. Although our results did not show such a tendency, we believe that further research in this direction should provide precious information about the nature of this auditory improvement. Current neuroimaging measures may add further information to this question.

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