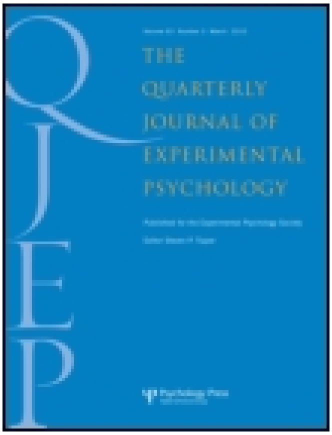

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The after-effects of ventriloquism

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THE AFTER-EFFECTS OF VENTRILOQUISM

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Subjects were tested for both ear–hand and eye–hand co-ordination before and after monitoring a synchronous series of noise bursts and of light flashes coming from the same spatial position, but with the virtual position of the flashes displaced 15° laterally by prisms. Attention was forced on both stimuli by the instruction to detect occasional reductions in intensity. No subject reported noticing the spatial discrepancy. Nevertheless ear–hand co-ordination was shifted in the direction of the prismatic displacement, and eye–hand co-ordination in the opposite direction. Both shifts were observed with instructions suggesting that the sound and the light came from one single source, with instructions suggesting two separate sources, and also with no information regarding the spatial relationship of sound and light. It is concluded that the resolution of auditory–visual spatial conflict involves recalibrations of both visual and auditory data and that these alterations last long enough to be detected as after-effects.

Introduction

When temporally correlated visual and auditory signals come from moderately separated locations, there is a strong tendency to perceive them as originating from a single source: the separation is either underestimated or completely unnoticed. The phenomenon has been called ventriloquism. It offers a striking example of the plasticity of perceived location and suggests an interesting relation with the mechanisms involved in interpreting the total sensory input in terms of unitary objects and events. There have been few systematic studies of ventriloquism as the review by Howard and Templeton (1966, pp. 360–2) shows.

The problem of main concern in the present paper is whether the changes which allow obliteration of the spatial discrepancy outlast the bisensory stimulation long enough to be observed as after-effects. In addition, we investigated whether such after-effects consist of alterations in the interpretation of auditory data only, or of both auditory and visual data.

Some recent studies of adaptation to prismatic displacement suggest that exposure to discordant auditory and visual stimulation produces after-effects. Radeau and Bertelson (1969) found that after pointing, with the hand invisible, at targets signalled by both a light whose virtual position was displaced by prisms and a non-displaced noise, ear–hand co-ordination was shifted in the direction of the prismatic deviation, and eye–hand co-ordination in the opposite direction.

The bisensory pointing task was ambiguous, since no instruction was given regarding where to point in case the discrepancy became apparent. In subsequent experiments by Radeau (1973) and by Canon (1970), instructions were given to point at the apparent position of the light, in one condition, and of the sound in the other. Radeau found shifts in both ear–hand and eye–hand co-ordination with both instructions, and Canon with the instruction to point at the sound: with the instruction to point at the light, Canon found shifts in auditory pointing only (also Canon, 1971).

The interpretation of these results is made difficult by the use of a pointing task during exposure to the intersensory conflict. It is not clear how much the observed shifts depend on the performance of the pointing movements. Moreover, giving instructions regarding which modality to take account of in pointing may suggest to the subject that there is a spatial dissociation, and the observed after-effects might then be the results of cognitive operations based on conscious perception. In the usual ventriloquism situation, the subject is typically not aware of a discrepancy.

It was felt that a better demonstration would be provided if pointing was used only for initial and final assessments of sensory–motor co-ordination, and not during exposure to the intersensory conflict. One had however to make sure that the subjects attended to both stimuli. This was achieved by giving them the task of monitoring a synchronous series of flashes and of noise bursts, with the instruction to detect changes in the intensity of either stimulus. The experiment which will be reported consisted of testing subjects for ear–hand and eye–hand co-ordination before and after performing a bisensory monitoring task involving spatially discordant auditory and visual stimuli. As in the authors' previous experiments on the subject, the discordance was created by displacing the visual image by prisms. To control for the possible effects of hypotheses regarding the source of the bisensory stimulation, different sets of instructions were used in different groups of subjects. One set suggested a single source, another suggested two separate sources and a third avoided any mention of the spatial relationship between sound and light.

Method

Apparatus

The apparatus is shown in Figure 1. It consisted of a vertical semicylindrical enclosure, 60 cm high and 40 cm in radius, resting on a 100-cm high table and divided in two compartments by a horizontal semicircular panel, 15 cm above the table. The upper compartment was limited by an opaque screen. The target was situated at the lower end of that screen, immediately above the horizontal panel. It was held by a metal plate, which passed through a narrow slot at the bottom of the screen, and was fastened to a vertical rod which could be rotated around the outer side of the screen by a pivot system. The lower compartment was limited by a transparent semicylindrical screen, whose inner circumference fell exactly below the course of the target. During pointing tests, the subject placed the tip of his index finger against the transparent screen. The experimenter who sat on the other side of the apparatus, read the position of the finger on a graduation painted on the screen. A pointer fastened to the rotating target holder came in contact with the same graduation, which could thus also be used to position the target.

The target consisted of a light box and a small loudspeaker. The light box contained a neon pea-lamp, which could be seen through a 4-mm circular aperture oriented towards the subject and was covered by a red filter. Narrow band light was used to prevent the formation of colour fringes when viewed through the prisms. The loudspeaker was a Philips EL 3775/00 earphone (diameter 3 mm). Auditory stimulation was produced by feeding it with 50 Hz a.c. During pointing tests, the light or the sound was controlled by the experimenter. For the bisensory monitoring task, the signals were controlled by an automatic programming system.

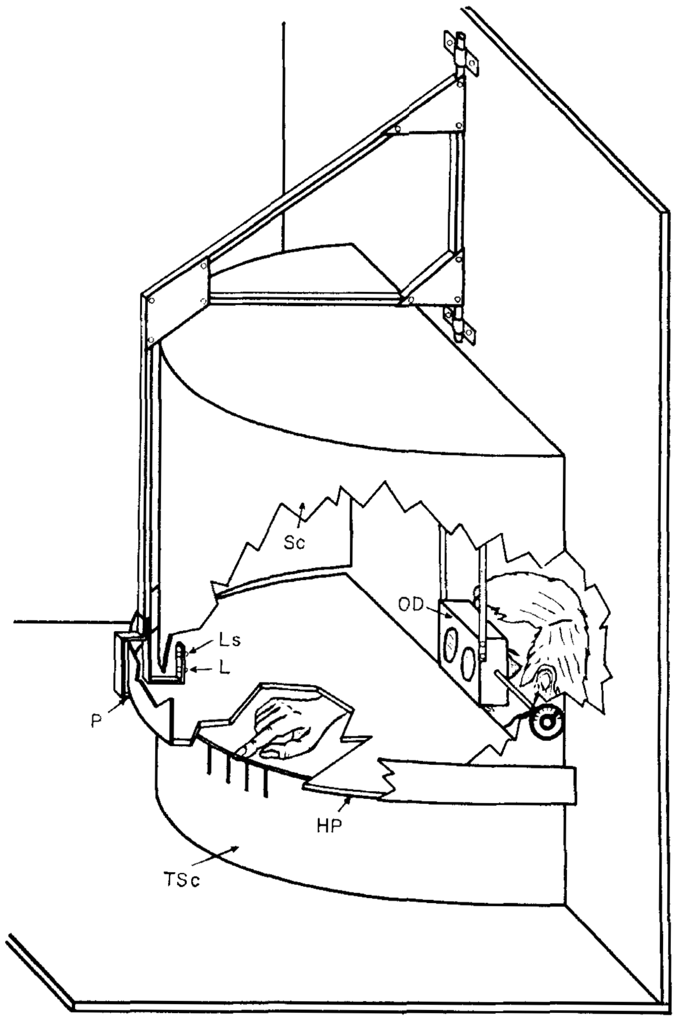

FIGURE 1. Schematic view of the experimental setup. Sc, opaque screen; TSc, transparent screen; HP, horizontal panel; OD, optical device; P, pointer; Ls, loudspeaker; L, light.

The optical device consisted of two pairs of rotating Hughes prisms, mounted side by side, and housed in an opaque rectangular box. The box was held in the axis of the cylindrical screen, just above the level of the horizontal panel. The apparatus provided a lateral displacement of the virtual image which could be adjusted by remote control from 15° left to 15° right.

During an experimental session, the subject was kept in complete darkness and received no visual stimulation other than the red luminous point provided by the target. This light did not make any other part of the apparatus visible. The subject wore a black cape attached around his neck which shielded his eyes from the faint light used by the experimenter on the other side of the apparatus. Throughout the session, the subject kept his eyes in contact with the eyepieces of the optical device. The room lights were on only at the beginning and at the end of the session. Care was taken to make the operation of the apparatus completely silent.

Subjects

Twenty-four university students, devoid of visual or auditory defect, served as subjects in four sessions given at a minimum intersession interval of two days. They were paid for their participation.

Procedure

Each session involved blocks of pointing tests and blocks of work on the bisensory monitoring task. For a pointing test, the experimenter switched either the light or the sound on, and the subject indicated its apparent position by placing the index finger of the right hand underneath, against the transparent screen. The stimulus was terminated as soon as the finger was positioned, and the following test started 5–7 s later. Tests were organized in blocks of 15, all in the same modality. Three positions of the target were used. For the auditory tests, they were straight ahead, 15° to the left and 15° to the right; and for the visual tests straight ahead, 15 and 30° to the right, for the session with prisms oriented base-right, and straight ahead, 15 and 30° to the left, for the sessions with base-left orientation. The virtual positions of the visual target were thus always distributed symmetrically around the median plane. In each block of 15 trials, five were run with each target position.

For the bisensory monitoring task, the target was made to produce a synchronous sequence of flashes and sound bursts, each lasting 0·5 s, separated by 2-s intervals. On a random 10% of the trials, either the flash or the sound was weaker than on the remaining 90% (0·5 instead of 5·0 ml for the flash, 50 instead of 55 dB for the sound) and the task was to signal these occasions by pressing a switch held in the left hand. Between trials, the target was moved from one position to another. The same stimulus positions were used as on visual positioning tests in random order with a rectangular frequency distribution. Virtual visual targets were thus distributed symmetrically around the median plane but auditory targets were displaced to the side opposite that of the prismatic displacement.

A session started with four blocks of test-trials, called pre-tests, two of auditory and two of visual pointing (in the order A-V-A-V or V-A-V-A). Four 5-min blocks of bisensory monitoring (120 trials) were then given, each block being followed by one block of test trials, called post-tests. Two blocks were followed by auditory post-tests, two by visual post-tests, in either the order A-V-A-V or V-A-V-A. During a session, the same setting of the prisms, either 15° base-left or 15° base-right, was kept throughout, for both test blocks and bisensory monitoring blocks. Each subject participated in four sessions, two with prisms base-left and two with prisms base-right, in alternate order. For each prism orientation, the tests followed the order A-V-A-V in one session and V-A-V-A in the other. The four types of sessions were given to subjects in balanced order.

Both the pre- and the post-tests were thus carried out with prismatic displacement. Our measure of visual after-effect corresponds to what Canon (1970, 1971) calls "adaptation". We have checked that it was impossible to discriminate between say the visual target 15° to the left seen through the prisms with a 15° right setting and the same stimulus in the median plane seen through the prisms with a 0° setting. Hence bringing the device to 0° for the tests was considered an unnecessary complication.

The subjects were divided into three groups of eight. The groups received different information regarding the relationship between sound and light in the bisensory monitoring task. Group SO (Same Origin) were shown, under room illumination, the interior of the setup where the target holder was visible and a few visual and a few auditory signals were demonstrated. It was explained that since the light box and the loudspeaker were held by the same fixture, the two signals would always come from the same origin during bisensory monitoring. For group DO (Different Origin), the interior of the setup was shown with two target holders visible: the actual target holder which was used during the rest of the session, and a mock-up one, of identical appearance. This mock-up target holder was positioned 15° to the left (for sessions with base-right prism orientation) or to the right of the actual target. The demonstration involved sounds coming from the actual target and flashes coming from the mock-up one. It was explained that during bisensory monitoring the sound would also come from one target and the light from the other one. The mock-up target holder was removed, unknown to the subject, as soon as the room lights were off, and it was put back at the end of the session, before switching the lights on. In the control group, the target was never visible with the room lights on: it was placed in an extreme lateral position, where it was shielded from view by a screen. The signals were demonstrated with the room lights off. The instructions involved no reference to the spatial relationship between sound and light. No mention was made of the function of the optical device in any of the groups.

At the end of the last session, all subjects were asked (1) if, in the bisensory task, the light and the sound appeared to come from the same or from different positions, and (2) what the optical device was for.

Results

The answers given to the questions regarding the spatial relationship between sound and light appear in Table I. Most subjects reported perceiving both signals as coming from the same place and the remainder simply could not say;

TABLE I

Answers to the question "In the bisensory task, did the sound and the light appear to come from the same or from different places?"

Group	Answers		
	Same place	Different places	Cannot say
SO	5	0	3
DO	5	0	3
Control	6	0	2

none reported a perception of spatial separation. It may seem strange that even the subjects of group DO did not notice the displacement. It must be remembered, however, that the instructions given to them did not say that the sources would always be separated spatially: it simply suggested the possibility of a separation, by showing two target holders actually separated. The ventriloquism effect was apparently of sufficient strength to convince the majority of these subjects that the targets had been put close together during the bisensory task.

Following the usual convention, errors were called negative when they were in the direction of the prismatic displacement. Mean errors in successive visual and auditory pointing tests are shown in Figure 2. Substantial shifts occurred between pre-tests and the first post-tests, but, except perhaps for visual pointing in group DO, no systematic variations were produced in succeeding post-tests. The full effect of the bisensory monitoring task is obtained by the end of the three first 5-min

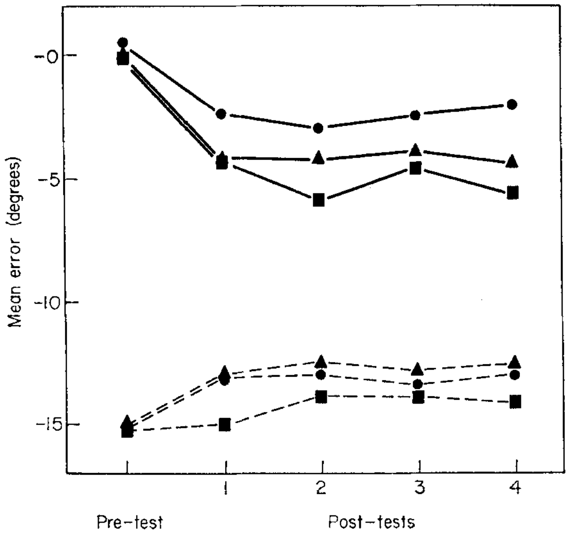

FIGURE 2. Mean errors in pre- and post-tests. Errors are called negative when they are in the direction of the prismatic displacement. Visual control group, ● - - - ●; auditory control group, ●———●; visual SO group, ▲- - - ▲; auditory SO group, ▲———▲; visual DO group, ■ - - - ■; auditory DO group, ■———■.

blocks. In consequence, in the following analysis, the results from the four post-tests have been pooled (Table II).

Under all three sets of instructions, the shifts from pre- to post-tests are in the direction of the prismatic displacement for auditory pointing and in the opposite direction for visual pointing in all subjects: hence, the occurrence of both visual and auditory after-effects is established with $P < 0{\cdot}004$, by a one-tailed sign-test, in all three groups.

TABLE II

Mean errors in pre- and post-tests, in degrees, with intra-subjects' standard deviations (in parentheses)

Modality	Test	Group SO	DO	Control
Visual	Pre-tests	−14·93 (4·49)	−15·36 (5·18)	−15·09 (3·06)
	Post-tests	−12·80 (4·54)	−14·30 (5·61)	−13·19 (2·78)
	Difference	+2·13	+1·06	+1·90
Auditory	Pre-tests	+0·07 (9·82)	+0·01 (9·21)	+0·44 (9·35)
	Post-tests	−4·23 (7·06)	−5·15 (8·42)	−2·52 (7·29)
	Difference	−4·30	−5·16	−2·96

Errors are called positive when they are in the direction opposite that of the prismatic displacement.

Mean individual shifts between pre- and post-tests were submitted to an analysis of variance, the sign of the auditory shift being inverted. Since the between-groups variation is non-significant, no effect of the instructions on the total after-effect was demonstrated. Both the modality ($F = 41{\cdot}0$; $df = 1,21$; $P < 0{\cdot}001$) and the Modality × Groups interaction ($F = 5{\cdot}6$; $df = 2{\cdot}21$; $P < 0{\cdot}025$) are significant. The auditory after-effect is on the whole larger than the visual one but the size of the difference varies with the instructions.

Mean within-subjects standard deviations are given in Table II. They show that visual pointing is more accurate than auditory pointing.

Since the positions of the target during the bisensory task were so arranged as to preserve visual symmetry, the distribution of auditory stimulation was biased 15° to the side opposite the prismatic displacement. Part of the auditory after-effect might thus be due to stimulation asymmetry. To control for that possibility, eight subjects were tested for ear–hand co-ordination, following the same procedure as in the main experiment, before and after performing an auditory monitoring task involving a sequence of sounds identical to those used in the bisensory task. Each subject did two experimental sessions, one with the bias to the left and one with the bias to the right. A mean shift of $+0{\cdot}17°$ was observed, i.e. a small, non-significant, shift in the direction opposite to that which would be expected on the basis of stimulation asymmetry.

Discussion

Although reports obtained at the end of the last of four sessions may not be a very sensitive reflection of original reactions to the spatial separation, the fact that no subject mentioned the separation implies that a conflict was never strongly experienced. Ventriloquism was thus evoked by the bisensory monitoring task. The results yield clear answers to the two questions asked in the introduction: ventriloquism involves recalibrations of sufficient duration to be observed as after-effects, and these after-effects occur in both the visual and the auditory modalities.

The after-effects are comparable to those obtained in previous experiments after bisensory pointing. Expressed in per cent of the prismatic deviation, the shift in eye–hand co-ordination in group SO is of the same order of magnitude as that observed by Radeau and Bertelson (1969) (14 against 17%) and the shifts in ear–hand co-ordination is larger (29 against 19%). The results of group SO are used for the comparison because the previous study was run with instructions similar to those given to that group. It is thus probable that, contrary to Canon's (1970) efference hypothesis, pointing movements played no important part, beyond that of forcing attention to the stimuli, in bringing about the effects of bisensory pointing.

Clear after-effects occurred not only when, as in previous experiments (Radeau and Bertelson, 1969; Radeau, 1973), the subjects had been told that the sound and the light came from the same place, but also with no prior information regarding the spatial arrangement of the sources, or even with instructions suggesting separate sources. Manipulation of prior knowledge apparently does not prevent some recalibration from taking place. This finding, taken together with the fact that the spatial separation was never reported, seems to rule out any interpretation of the after-effects as due to some intellectual correction applied on the basis of a consciously perceived conflict.

We are apparently dealing with a process which operates before the stage of conscious recognition. When data collected by different sensory modalities fulfill the conditions for being interpreted as manifestations of a single event, except that their spatial values do not coincide, the spatial information provided by the corresponding modalities is recalibrated.

It should be possible to specify the conditions for single event interpretation, though the present study was not designed to analyse them. The bisensory task was chosen on the assumption that temporal simultaneity is an important condition. This hypothesis has received support from the results of Thomas (1940) who showed his subjects two lights flickering on and off at different rhythms, while an invisible buzzer situated between the lamps emitted an intermittent sound at the rhythm of one of the lamps. The position of the buzzer tended to be judged nearer to the synchronous lamp.

Our main reason for giving different instructions was to control for the possibility that after-effects occur only under some particular cognitive set. From that point of view, the results are clear and support the conclusions developed in the two preceding paragraphs. However it is also true that the size of the after-effects was significantly influenced by the instructions. The observed after-effects might thus depend both on the kind of perceptual recalibration we have just been discussing and on cognitive factors. The latter influence is difficult to interpret. The results for eye–hand co-ordination, where the largest after-effect is obtained under condition SO, the smallest under condition DO, with the control condition in between, create no difficulty. But for ear–hand co-ordination, conditions SO and DO produce about the same after-effect, and the control condition a much smaller one. There is no ready explanation for the finding of different patterns in the two modalities.

It is often supposed that vision dominates other modalities in intersensory conflicts (e.g. Rock and Harris, 1967). The present results support that hypothesis to the extent that recalibration affected audition to a larger extent than vision. On the other hand, the finding of a significant recalibration of vision runs counter the more extreme version that vision completely dominates other modalities. Many students of ventriloquism have attributed it to an influence of vision on auditory localization (see Howard and Templeton, 1966, p. 361). The interpretation was in many cases aribitrary, as it was applied to data which only showed an altered correspondence between points in auditory and visual space (Thomas, 1940; Jackson, 1953).

A more convincing argument for visual dominance comes from the experiment by Pick, Warren and Hay (1969) where the subjects localized auditory targets in the presence of conflicting visual information and visual targets in the presence of conflicting auditory information. Vision was found to influence auditory localization to a considerable extent, while the opposite influence was small and non-significant. Of course, the experiment dealt with the immediate reaction to the conflict, not with its after-effects, and it is conceivable, although unlikely, that immediate reactions and after-effects do not obey the same pattern. A possible explanation for the discrepancy is that the visual input was much richer in Pick's situation than in ours: his subjects saw the whole setup illuminated, with the target loudspeaker in position, while the present subjects saw only a single luminous point in an otherwise completely dark field. The auditory input, trains of clicks or of tones, was comparable in both situations. The studies by Radeau and Bertelson (1969) and by Radeau (1973) where significant visual adaptation was demonstrated were also run with a single luminous point, while that by Canon (1970) where visual recalibration was found only after auditory pointing and not after visual pointing involved a full view of the apparatus. If the extent to which recalibration takes place in one modality is inversely related to the amount of spatial information available in that modality, the two sets of data can be reconciled. More analytical studies are needed to validate and develop this suggestion.

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