Sensory direction in homogeneous binocular visual space*

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Shifts in subjective sensory direction (local signature) occur in all sense modalities, and the dynamics of these shifts are quite similar. This is also true for visual direction in homogeneous binocular space. Binocular vision may, therefore, be interpreted in accordance with principles of intersensory processing.

It is known that the localization of sensory experience in man is a function of both temporal and spatial variables. Not all sensory experiences are localized, but for those that are the patterns of coordination between time and intensity can be shown to bear striking resemblances across the modalities.

By using multiple stimuli, it is possible to analyze the operation of these parameters in their purest form. When two synergistic stimuli are presented to an appropriate sense organ in such a way that they are fused into one unified sensation, it can generally be specified where this sensation occurred. What are the dynamics governing this unification and this localization?

Békésy (1967) asked this question of several senses. Since his data have not been summarized previously, we have done so here in our Fig. 1, with his kind permission. All the curves, with the exception of the intensity curve under audition, have been redrawn from the original data. The legend gives the critical details. (The reader is referred to the sources for more complete descriptions.) The auditory intensity curve (bottom right) was taken on ourselves, because a search of the literature failed to reveal analogous data.¹ The method that we used is a standard one in audiometric research and need not be described in detail; however, our balancing was done with earphones rather than with speakers, shifting the localization through rather than around the head. The shape of the curve we have obtained generally confirms the shape of the curves in the other senses.

The curves show how subjective localization can shift continuously between two points of stimulation as a function of differences between the two in terms of time or intensity. When two separate, but

identically intense, stimuli are presented simultaneously, one unified sensation is experienced which is localized midway between the two. When one stimulus is sufficiently more intense or precedes the other sufficiently in time, lateralization occurs and localization shifts to the position of that stimulus. Between these end points, there exists a *fusional* region in which a single sensation occurs that is

localized at some intermediate position.

In general, one can control the apparent position of this unified sensation by a careful balancing of the times and the intensities at any synergistic site. And one can move the apparent localization of the sensation between these positions, continuously and at will (e.g., phi movements and the like), by properly changing the balance in accordance with the ordinates shown. The shapes for all modalities are similar.

Comparable localization curves for vision, the sense in which local signatures are most refined, have not been determined previously. The analogous experiment is difficult to devise because spatial vision is so acute. The constancy of visual direction, after all, is the cornerstone of all theories of spatial perception. Nevertheless, visual directions are reputed to have some malleability as, for example, in the clinical entity of anomalous correspondence. The problem, it seemed to us, was to construct

Fig. 1. A summary of data on shifts in localization in olfaction, gustation, taction, and audition.

Olfaction. Time: replotted from Békésy (1967, p. 104, Fig. 89)—several odors, “sniff triggered,” and special training. Intensity: replotted from Békésy (1967, p. 105, Fig. 90)—as above.

Gustation. Time: from Békésy (1967, p. 101, Fig. 87)—NaCl, delivered with a special pressure flow apparatus. Intensity: from Békésy (1967, p. 103, Fig. 88)—NaCl, as above.

Taction. Time: from Békésy (1967, p. 90, Fig. 79A)—3-mm-diam vibrators on arm, “plucked” (the unit, 1.2 msec, is given in Békésy, 1960). Intensity: replotted from Békésy (1967, p. 55, Fig. 41)—100-Hz vibration on lower arm.

Audition. Time: from Békésy (1967, p. 90, Fig. 79B)—clicks in series (the unit, 1.2 msec, is given in Békésy, 1960). Intensity: each point is a mean of at least three measurements. $N = 2$. We used a single oscillator of a calibrated Beltone No. 158 audiometer to randomly deliver bursts of 500-Hz tones ($\frac{1}{2}$ -sec duration) of approximately 60-dB sound-pressure level. The sounds were presented via earphones in an Industrial Acoustics sound-reduction chamber.

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Fig. 2. Schematic of the *Ganzfeld*. Solid lines show the actual *Ganzfeld*s; dotted lines show the entrance and exit ports, which are thus contiguous.

a visual environment in which, while resolution might be poor and unification facile, some semblance of visual direction might still be discerned. This led us to *Ganzfeld*, or whole-field homogeneous stimulation.

In a totally homogeneous visual field, where voluntary or involuntary eye movements are unable to change the retinal stimulation, the image is said to be stopped. This is analogous to touches on the arm, clicks in the ears, chemicals on the tongue, and scents in the nose (as in Fig. 1).

METHOD

In the vision laboratory, one typical way to obtain a *Ganzfeld* is to place a homogeneous translucent diffuser over the eyes, such as one-half or two-thirds of a ping-pong ball, and to transilluminate this from the outside. Since the degree of homogeneity which we could obtain by such a simple means was not sufficient, we designed a *Ganzfeld* based upon the principles of the integrating sphere and show this schematically in Fig. 2. The spheres are imperfect, but this merely attenuates the integration according to established principles (by the ratio of the surface area of apertures to the inner surface area of the total sphere) and does not in any way imperil our principle.

The integrating sphere and the lamp holder were constructed in one piece, out of plaster of paris, and were molded on the inside for sphericity. Smoothing was completed by sanding. The inside was painted flat white. Since the S lay supine on an examining table, the *Ganzfeld*s were simply lowered onto the face and

held there gently by an elastic cloth bandage. Uniform contact with the face was achieved with white rubber padding, and the apparatus was effectively light tight. The *Ganzfeld* size was chosen as a compromise between minimizing the aperture-surface ratio and maximizing the illuminance per unit surface. The maximum available luminance was 150.6 cd/m^2 ($92 \text{ dB re } 10^{-10} \text{ L}$). The two light sources were matched Sylvania R1131C glow modulator tubes. The entrance port of each integrating sphere was made large enough to hold the lamp securely. The source was placed as near as possible to the back surface of the sphere (11 cm), while still giving a homogeneous field. As far as we could tell, moving the eyes freely over the central 60-deg cone resulted in no visible inhomogeneities. Dilation of the pupil did not change our results and was not used during the experiment.

The bulbs were controlled by means of a Grason-Stadler flicker fusion apparatus, No. E622, one directly and the other through a Tektronix 160/161 series delay circuit, a Hewlett-Packard Harrison 6209B dc power supply, and some additional control circuitry for the purpose of balancing pulse waveforms. The pulses to the lamps were monitored at all times on a Tektronix 502 dual-beam oscilloscope. The pulses were square, and the lights followed them to well below a millisecond. The pulse duration was fixed throughout at 10 msec, significantly shorter than pupil or eye-movement reflexes. The delay between the pulses was obtained from the Tektronix 161 and read directly to 0.5 msec on the oscilloscope. The intensity

difference between the pulses was obtained by varying the lamp current, and the light output was calibrated with a 520-M Photovolt photometer to an accuracy of half a decibel.

The O was dark adapted for 10 min before the experiment began with the *Ganzfeld*s in place. Preliminary trials were then run and the criteria were established. The time measurements were taken in one session and those with intensity in another. A given session lasted about 1 h. The O's task was to indicate when the unified *Ganzfeld* appeared straight ahead (the 0 position on the graph), midway (or 45 deg) to the right (+) and to the left (−), or straight ahead of either or both the right (R) and the left (L) eyes; thus, there were five positions in all. Six measurements were taken at each position: L, R, 0 deg, −45 deg, +45 deg, in that order. We used the method of average error, approaching the criterion alternately from each side three times, except at the extreme lateral intensities, beyond which it was impossible to move. Reversals were allowed but seldom occurred. Subjectively, the sensation was poorly externalized. It appeared to lie a few centimeters from the face and was partly somesthetic (an "Organgefühl," cf. Enoch, Goldmann, & Sunga, 1969). A phi component in these observations was apparent, but it was not sufficient to hinder the criteria. For our best O, S.R., the standard deviation in time was approximately 1 msec, and the standard deviation in intensity was approximately half a decibel. Despite some initial uneasiness about the phenomenal visual direction in a homogeneous binocularly unified visual field of some 180 deg horizontal and some 120 deg vertical extent, the judgments possessed quite acceptable reliability.

RESULTS AND DISCUSSION

The results are shown in Fig. 3 for the two trained Os. These curves for vision are quite similar to those for the other senses. Although there are reliable differences between the two Os, the dynamics of the shifts in localization are all basically the same (cf. Fig. 1). They resemble the integral of a Gaussian distribution turned on its side.

It is thus possible to derive this curve from a nearly linear weighting of the spread in the localization of the synergistic sensations, provided only that the rise time of this localization is slow with respect to the rise time of the stimulus (e.g., see Roufs, 1963, on visual brightness). With due consideration of parameters, this must also mean that the rise time in vision is considerably slower than it is in the other senses, which is in keeping with the

Fig. 3. Shifts in localization in homogeneous binocular visual space. See text for description of the experiment. Filled circles, O.T.S.; open circles, O.S.R.

objective electrophysiological evidence (e.g., Quarton, Melnechuk, & Schmitt, 1967). Whether or not, as the data imply, one can really resolve the midposition between the nostrils with the same reliability as one can resolve the midposition between the two eyes remains to be examined. The 0.3-msec time required for the lateralization in olfaction does seem inordinately fast. The rather large times in vision, on the other hand, are in keeping with its relatively modest prowess in temporal resolution.²

How these observations can be fitted into a generalized theory of visual local signatures for sharply outlined and externalized stimuli is a problem we have not resolved. However, they are pertinent to the theory of apparent movement. The synergistic neurological excitations upon which the localization of phi movements (both monocular and binocular) is based must embody a continuous change of phase. We think this explanation is compelling.³ Two lights in fixed physical phase must evoke synergistic excitations (not just two, but an unresolvable number, since phi is always smooth) which are continuously changing their neurological phase with respect to each other. Thus, Wertheimer's "moving across" takes on a testable physiological meaning.⁴ This suggests that, with some special stimulus

condition, we might be able to inhibit this neurological phase shifting and freeze the externalized phi lights at any arbitrary position along the phi path. We have not yet determined how to do this. It may well entail some stimulus intrusion within the path rather than simply some change at its end. Julesz & Payne's (1968) finding of a binocularly frozen image with phi from random-dot stereograms may hold a clue.

Finally, it becomes clear how one might create phi in the other senses. Since their neurology preserves the phases of the physical inputs, one must present synergistic stimuli that are continuously and systematically changing in phase. The sound sensation will then move back and forth through the head; the taste sensation will then move to and fro across the tongue; and the prickle sensation will then move up and down along the leg or the arm or creep up along the back of the neck. Sparsely scattered in the literature (e.g., Johansson, 1950; Békésy, 1967) are references to just such effects, though no systematic studies have been done. It is now also clear why many of the early attempts to create phi in the senses other than vision have not been entirely successful (cf. Boring, 1942).

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NOTES

1. Perhaps the closest qualitative observation is by Johansson (1950).

2. The problem of two-pulse resolution in vision has recently been reexamined with new methods, but it still comes out slower than the other senses (Kietzman & Sutton, 1968).

3. In line with this is the early observation of Bruckner (1901), that two weak pressures may summate to one strong pressure when separated by 2-30 mm, whereas they may inhibit each other at greater distances, such as 62-84 mm. Békésy observed the same thing and included it in his description of the neural unit. Wertheimer (1967) has found a loosely analogous situation in vision.

4. See Wertheimer (1912). The important observation of Bridgemen and Smith (1945) does not disprove the need for a synergy in phi; it only says that this synergy can somehow take place in the absence of the corpus callosum.

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