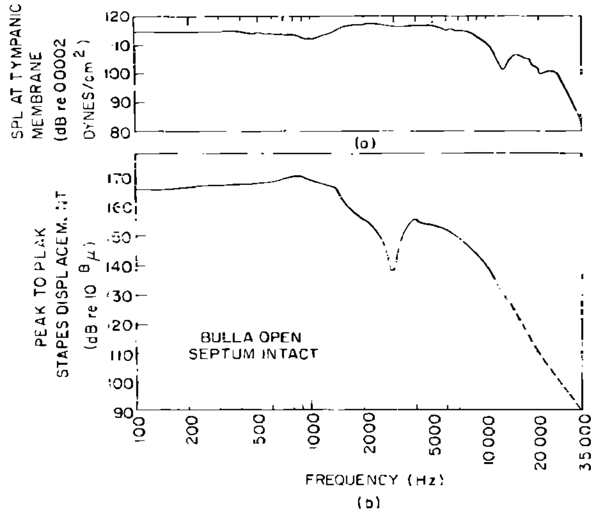

FIG. 2. (a) Sound-pressure levels at the tympanic membrane as a function of frequency for a sinusoidal input to the earphone. (Voltage level −10 dB *re* 200 V peak to peak.) Corrections have been included for the frequency response of the probe tube used in monitoring the sound pressure. (b) Peak-to-peak stapes displacement as a function of frequency for a sinusoidal signal at 120 dB rms *re* 0.0002 dyn/cm² (from Guinan and Peake, 1967). The solid part of the curve was obtained by averaging the experimental data from 25 cats. The dotted portion of the curve is based on calculations from a model of the middle ear proposed by Peake and Guinan (1966). The frequency of the sharp dip near 3 kHz varies by several hundred Hertz from cat to cat.

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Comments on "Interaction of the Auditory and Visual Sensory Modalities"

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In deriving an equation to test the independence of sensory processing systems, Brown and Hopkins (1967) appear to have built in an assumption of response patterns lacking generality. In addition, the performance of their subjects is in excess of predictions from alternatively derived independence models, as well as one derived from signal detection variables. These data can be accounted for only by assuming a high level of "internal noise."

BROWN AND HOPKINS (1967) CLAIM TO DEMONSTRATE THAT "redundant bisensory information produces improved human signal-detection performance," and that, when both visual and auditory channels were used, "the increased detectability of the signal resulted from the simple probabilistic adding of the responses of the two independent sensory systems." In addition, they claim, "there is no interaction between the visual and auditory sensory-information-processing systems."

They restrict their conclusion to the condition of signals of equal detectability on the two channels, but their method of deriving their main equation makes obscure the nature of the independence they demonstrate.

They define a "chance corrected probability of detection" $[P(D)]$ given by them as

$$P(D)=P(H)-P(F), \tag{1}$$

where $P(H)$ and $P(F)$ are the hit rate and the false-alarm rate, respectively (the probability of a signal being 0.5). This measure, as they point out, fails to compensate for variations in the acceptance criteria used by various observers, so they use an "optimum probability of detection" $P'(D)$ given by

$$P'(D)=2\int_0^{d/2} f_n(x)dx, \tag{2}$$

where $f_n(x)$ is the probability-density function of the interference noise.

Brown and Hopkins calculate $P'(D)$ from the values of d' derived from auditory and visual detection tasks separately for a range of signal-to-noise (S/N) levels. They then present their two observers with auditory and visual channels simultaneously using signal levels that gave rise to identical values of $P'(D)$ for the two modalities in isolation under conditions where the signals on the two channels were perfectly correlated. It is not stated whether or not the noises on the two channels were correlated. From the latter tests, they derived values of $P''(D)$ that they test against an "independence" model for which they derive the equation

$$P''(D)=P'(D)[2-P'(D)]. \tag{3}$$

Finding an excellent fit, they conclude that the channels are independent.

Their proposed model (diagrammed in their Fig. 5) "indicates the detection of a signal any time that either of the sensory channels independently indicates the presence of a signal," i.e., it is an inclusive-disjunctive device operating on YES inputs and producing a YES output. They write an equation for the resulting "bisensory optimal probability of detection" $P''(D)$ as

$$P''(D)=P_a(Y)+P_v(Y)-P_a(Y)P_v(Y), \tag{4}$$

where $P_a(Y)$ and $P_v(Y)$ are the probabilities of a YES response arriving from the auditory and visual signal detectors, respectively. They then claim

$$P_a(Y)=P_a'(D) \tag{5}$$

and

$$P_v(Y)=P_v'(D) \tag{6}$$

and for their tests

$$P_a'(D)=P_v'(D)=P'(D), \tag{7}$$

whence Eq. 3. However, in general,

$$P(Y)=\tfrac{1}{2}[P(H)+P(F)], \tag{8}$$

since the signal probability is 0.5, whereas from Eq. 1,

$$P(D)=P(H)-P(F), \tag{9}$$

therefore, Eqs. 4–6, equating $P(Y)$ and $P(D)$, only hold for the condition

$$P(H)=3P(F) \tag{10}$$

TABLE I. (i) Single channel data derived from Eq. 1 for given values of $P'(D)$. (ii) Estimates of two-channel performance from Eq. 3. (iii) Predictions of two-channel performance from Eqs. 11 and 12. (iv) Single-channel requirements to give data in (ii). (v) Double-channel prediction from signal detection theory with maximally favorable assumptions.

	(i)			(ii)				(iii)			(iv)			(v)
$P'(D)$	$P'(H)$	$P'(F)$	d'	$P''(D)$	$P''(H)$	$P''(F)$	d_2'	$P(H)$	$P(F)$	d_2'	$P(H)$	$P(F)$	d'	d_2'
0.2	0.6	0.4	0.51	0.36	0.68	0.32	0.93	0.84	0.64	0.64	0.44	0.18	0.75	0.72
0.4	0.7	0.3	1.05	0.64	0.82	0.18	1.83	0.91	0.51	1.31	0.58	0.015	1.50	1.48
0.6	0.8	0.2	1.68	0.84	0.92	0.08	2.81	0.96	0.36	2.01	0.72	0.04	2.31	2.38

and for optimum responding. Under such conditions, $P(Y)=0.5$, therefore, $P(H)=0.75$ and $P(F)=0.25$ are the only values for which Eqs. 4–6 and, thus, Eq. 3, are valid.

The correct derivation from the independence model as Brown and Hopkins *describe* it would involve considering hits and false alarms separately. The probabilities of such YES responses from the inclusive–disjunctive system they suggest are given by

$$P''(H)=P'(H)[2-P'(H)], \tag{11}$$

$$P''(F)=P'(F)[2-P'(F)]. \tag{12}$$

We cannot assume that

$$P''(D)=P''(H)-P''(F), \tag{13}$$

since this equation assumes optimum responding and it is easy to demonstrate that a two-channel system responding optimally on two channels separately will not respond optimally when the two channels are combined under the condition of an inclusive–disjunctive YES. Indeed, given that Eq. 3 is satisfied by the data and that the observers behaved in a nearly optimal fashion (indicated by their Figs. 3 and 4), both the hit rate and the false-positive rate must be considerably less than that predicted from their model. Neither is it possible for the system to behave according to these predictions with an adjustment of the criteria on the primary channels to achieve optimal performance on the combined output. In Sec. i of Table I, values for $P'(H)$ and $P'(F)$ are given for three values of $P'(D)$ using Eq. 1. Values of $P''(D)$ are calculated from Eq. 3, which is regarded as being an empirical description of their results, and values of $P''(H)$ and $P''(F)$ are determined from these. Values for d_2' are calculated from $P(H)$ and $P(F)$ that should then correspond to the data. These bisensory estimates are in Sec. ii.

In Sec. iii of the Table, values for $P(H)$ and $P(F)$ are calculated from Eqs. 11 and 12. The resulting values for d_2' are much too low. A model by which a YES response is only made finally if both channels give a YES response, i.e., a conjunctive device, gives the same values of d' as the inclusive–disjunctive model. A further possibility is that the criteria of the individual channels are adjusted to that nonoptimal value which would give rise to optimal over-all performance following application of a disjunctive YES device. This can be tested by calculating values of $P'(H)$ and $P'(F)$ from those of $P''(H)$ and $P''(F)$ using Eqs. 11 and 12 in reverse. The values of d' required of the individual channels, given in Sec. iv of the Table, are greater than those derived from the values of $P'(D)$.

If the situation is equated with a multiple-look signal-detection model (Luce, 1963) the resulting d' is given by

$$d_2'=2^{\frac{1}{2}}d'. \tag{14}$$

These values are given in Sec. v of the Table and are again too low. This analysis assumes that the noises on the channel were uncorrelated. If they were in fact correlated, the predicted values for d' in the two channel situation would be even lower.

One possible way of obtaining d''s as high as those implied by Brown and Hopkins would be if the noise on the two channels were effectively correlated negatively, though such a concept is rather peculiar in a bisensory situation. A second possibility is that a relatively high level of internal noise enters the system after the convergence of the two channels. If σ_e^2 and σ_i^2 are the variances of the contributions of the external and internal noise sources, respectively, then, if the contribution of the signal to the hypothetical variable X upon which decisions are made is m, the distributions of X will be given by the following expressions, assuming that both signal and noise on the two channels were perfectly correlated.

$$\text{visual or auditory alone: } X=N(m,\ \sigma_e^2+\sigma_i^2), \tag{15}$$

$$\text{visual and auditory together: } X=N(2m,\ 2\sigma_e^2+\sigma_i^2). \tag{16}$$

The values of d' will be given by

$$d_1'^2=m^2/(\sigma_e^2+\sigma_i^2), \tag{17}$$

$$d_2'^2=4m^2/(2\sigma_e^2+\sigma_i^2). \tag{18}$$

Therefore, the ratio of the variances, k, is given by

$$k=\sigma_i^2/\sigma_e^2=2(d_2'^2-2d_1'^2)/(4d_1'^2-d_2'^2). \tag{19}$$

Using the values of d' computed in Secs. i and ii of Table I, the ratio k for the three values of $P'(D)$ would be 3.93, 2.15, and 1.33, respectively, k being greatest for the lowest value of $P'(D)$, that is, for the lowest S/N ratio.

Swets, Shipley, McKey, and Green (1959) estimate k from repeated observations of the same signal and noise segment, obtaining values that were equal to or less than unity for external noise levels of 35 and 17 dB 0.0002 dyn/cm², with S/N ratios of 12.5 and 13 dB, respectively, finding no consistent differences in k between the two conditions for their three observers. Brown and Hopkins used a noise level (for the auditory channel) of 39.7 dB, with S/N ratios of approximately 18, 20, and 22 dB for $P'(D)$'s of 0.2, 0.4, and 0.6, respectively. Thus one might conclude that their observers had a higher internal noise level than those of Swets *et al.* The values of k computed above vary with signal level, implying that internal noise goes down as the signal level rises. This is in contrast with what Swets *et al.* term the apparent correlation of internal noise with external noise. If the "internal noise" is a consequence of instability of the criterion, then the results may be accounted for by the plausible assumption that such instability is an inverse function of the S/N ratio.

To conclude, Brown and Hopkins have presented data for the two-channel situation that indicates that their subjects performed better than would be predicted from various independence models. This is artifactual. (It has been implicit in the discussion that by "independence" is meant that categorical decisions are made on the individual channels before the channels are combined. This appears to be the sense in which Brown and Hopkins use the term.)

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