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From ear to brain

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ABSTRACT

In this paper Doreen Kimura gives a personal history of the "right-ear effect" in dichotic listening. The focus is on the early ground-breaking papers, describing how she did the first dichotic listening studies relating the effects to brain asymmetry. The paper also gives a description of the visual half-field technique for lateralized stimulus presentations in the visual domain, and a brief overview of asymmetry of touch and motor output.

1. The right-ear effect

The dichotic technique, simultaneous presentation of different sounds to the two ears – originally spoken digits from 1 to 10 was devised by Broadbent (1956) to study certain aspects of attention. In the late 1950s at McGill University, Woodburn (Woody) Heron of isolation studies fame, supervised my Master's thesis, on the effect of letter position on recognition. This thesis unwittingly foreshadowed later research on perceptual and brain asymmetry. When I started doctoral research with Brenda Milner at the Montreal Neurological Institute she was defining the functions of the left and right temporal lobes through study of the cognitive deficits in patients with temporal-lobe pathology. Woody suggested that the dichotic digits task would be very demanding of verbal processing and might therefore further help define some functions of the left temporal lobe.

Our first dichotic task was made on a reel-to-reel stereophonic tape recorder, and was far from high-tech. Since we knew the tape moved at 7½ in. per second, we marked with a felt pen on the tape a sequence of three points one second apart, for three successive dichotic pairs of digits, six digits in a set. There were 32 such sets. I first spoke all of the words for one ear into one channel via a microphone, using the pen marks as guide, then rewound the tape and recorded the other channel in the same way.

Our finished tape was not perfect, but the imperfections were apparently not a disadvantage. The simultaneity of the word pairs was not as exact as we wished, and there was some noise arising from the felt pen marks. But we did find that patients with left temporal-lobe pathology reported fewer digits correctly than did those with right temporal damage (Kimura, 1961a). The groups did not differ in simple digit span, suggesting that the competing messages added a critical load.

However, more intriguing to me was the finding that for all patient groups I tested, more words arriving at the right ear were correctly reported than words arriving at the left ear. I knew from animal research that the crossed pathways from the ear to auditory cortex predominate over the uncrossed, and in fact might occlude the uncrossed input where there was overlap (Rosenzweig, 1951; Tunturi, 1946). I concluded that the right-ear effect was due to the fact that in people also, the crossed auditory pathways were more effective than the uncrossed. This gave the right-ear input an advantage in accessing areas in the left hemisphere critical for speech perception (see Fig. 1).

I assumed this was a normal effect and should appear in a non-neurological population. Broadbent had not at that point compared left and right ear scores. When I asked about ear differences of a fellow student at McGill who was also using Broadbent's procedure and had tested a large number of normal subjects, he said he saw no differences. I there and then tested a small number of right-handed normal subjects and found a significant right-ear advantage (Kimura, 1961b). Because of our imperfect tape, I had reversed the earphones for half the subjects, so that left/right input was reversed. This ruled out possible influences of systematic asymmetry in the tape. Of course the effect has now been replicated many times, and with words other than digits.

The advantage of the crossed pathway had not previously been detected because speech is not usually presented in a way which promotes competition between ears. In everyday speech the same material arrives at the two ears; and rapidly alternating <u>monaural</u> presentation to left and right ears does not yield a right-ear superiority (Kimura, 1963b).

It should follow from the crossed-pathways hypothesis that if speech were represented in the <u>right</u> hemisphere, as happens in only a small number of people, the left-ear input would be advan-

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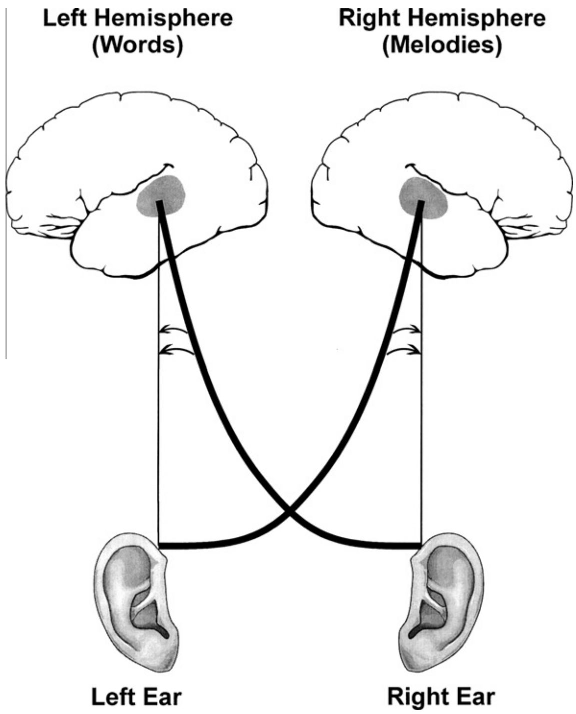

Fig. 1. Schematic representation of the two ears at the auditory cortex of each hemisphere.

taged. Fortunately at the time I was working with a patient population at the Montreal Neurological Institute whose early brain pathology increased the chance of speech being mediated by the right hemisphere. I had over time tested 13 patients who had speech in the right hemisphere, as determined by speech testing after sodium amytal injection separately into left and right sides of the brain. This group of patients, as predicted, showed a significant left-ear superiority in reporting the words.

Most of the latter patients were also left-handed, so the question of the contribution of handedness arose. However, left-handers with speech on the left showed a typical right-ear effect, and later work confirmed the negligible role in dichotic asymmetry of handedness *per se* (Kimura, 1983).

2. Nonverbal sounds

Identification of sounds that were not words, but involved use of the vocal chords, such as humming, coughing, or laughing (King & Kimura, 1972) did not show a right-ear superiority in normal persons, if anything the reverse. This suggested that the verbal nature of the sounds was critical for that effect.

It should follow that if one presented to typical left-speech dominant individuals, not words, but auditory material known to be predominantly processed by the right hemisphere, we should see better identification of such material from the left ear. I chose to test melodic patterns, since Milner (1962) had found that tonal patterns were among those Seashore Measures of Musical Talents (1960) that were impaired by right temporal pathology. I chose short snatches of melody from favorite baroque composers, and the Mozart horn concertos.

These melodies were then cut into 4-s samples and arranged in dichotic pairs having the same composer and instrumentation. In order for the subject to identify what s/he had heard, we then presented a sequence of four choices played binaurally, i.e., the same melody to the two ears. At the end of the four, the subject identified the two which had been dichotically presented, by choosing the two positions, e.g. "one and four" or "two and three", etc. The correct positions were counterbalanced over ears.

Melodies presented to the left ear were correctly identified more often than those presented to the right ear (Kimura, 1964). In the same group of normal subjects, words presented to the right ear were more often identified than those to the left, as before. The multiple-choice response requirement for melodies seems not to have been a critical factor in the left-ear superiority, since a similar procedure with words yielded a right-ear superiority (Broadbent & Gregory, 1964).

A left-ear superiority obtained also for environmental sounds, such as a dripping tap, car horn, toilet flushing and so on (Curry, 1967; Knox & Kimura, 1970); as well as for the vocal nonverbal sounds mentioned above (King & Kimura, 1972). It has also been found for identification of emotional tone of an utterance, e.g., happy, sad, as compared to its verbal content, the latter showing the typical right-ear superiority (Ley & Bryden, 1982).

So when ear asymmetries were found, they corresponded well with known or presumed functional brain asymmetries.

3. Vision

Similar methods were applied in other modalities. In vision, stimuli must be presented to left or right visual field, not eye (Kimura, 1966), because it is the visual field to the left or right of fixation that is represented in the opposite hemisphere (see Fig. 2).

Usually this is achieved by means of very brief presentation via a tachistoscope. With this device, stimuli were flashed to one field or the other for a fraction of a second, too brief to permit a new fixation, thus precluding direct access to the other field and hemisphere. In that situation, letters (processed by the left hemisphere), were more accurately identified in the right field, but this was not true of non-namable forms (Kimura, 1966), in rough parallel with the auditory modality.

Thus, nonverbal processes more dependent on the right hemisphere are facilitated when presented to the left visual field. While there are the expected parallels between established functions of the right hemisphere and a left-field perceptual advantage, lateralizing techniques have also added new information about functional brain asymmetry. They uncovered or confirmed as more right-hemisphere dependent: binocular disparity or stereoscopic fusion as a clue to depth perception (Durnford & Kimura, 1971), identification of line orientation, enumeration of dots (Kimura & Durnford, 1974), and localization of a point in space (Kimura, 1969).

Studies on face perception have shown the dominance of the right hemisphere even without tachistoscopic viewing, in normal unrestricted vision. The side of the face contributing more to identification is the one in our left field, i.e., typically the right half of the face (Kolb, Milner, & Taylor, 1983; Kolb, Wilson, & Taylor, 1992; Yovel, Levy, Grabowecky, & Paller, 2003).

4. Touch

Studies in the tactile modality have been less consistent in reflecting the functions of the hemisphere opposite the palpating hand (Gibson & Bryden, 1983; Minami, Hay, Bryden, & Free, 1994). This is almost certainly related to the relatively long time (seconds, rather than fractions thereof) required for tactile perception via palpation, as compared to audition or vision. This permits information to be conveyed between hemispheres, and reduces perceptual asymmetry. In contrast, when commissural systems are absent, as in split-brain patients who lack transmission between hemispheres, the right hemisphere can be seen to be

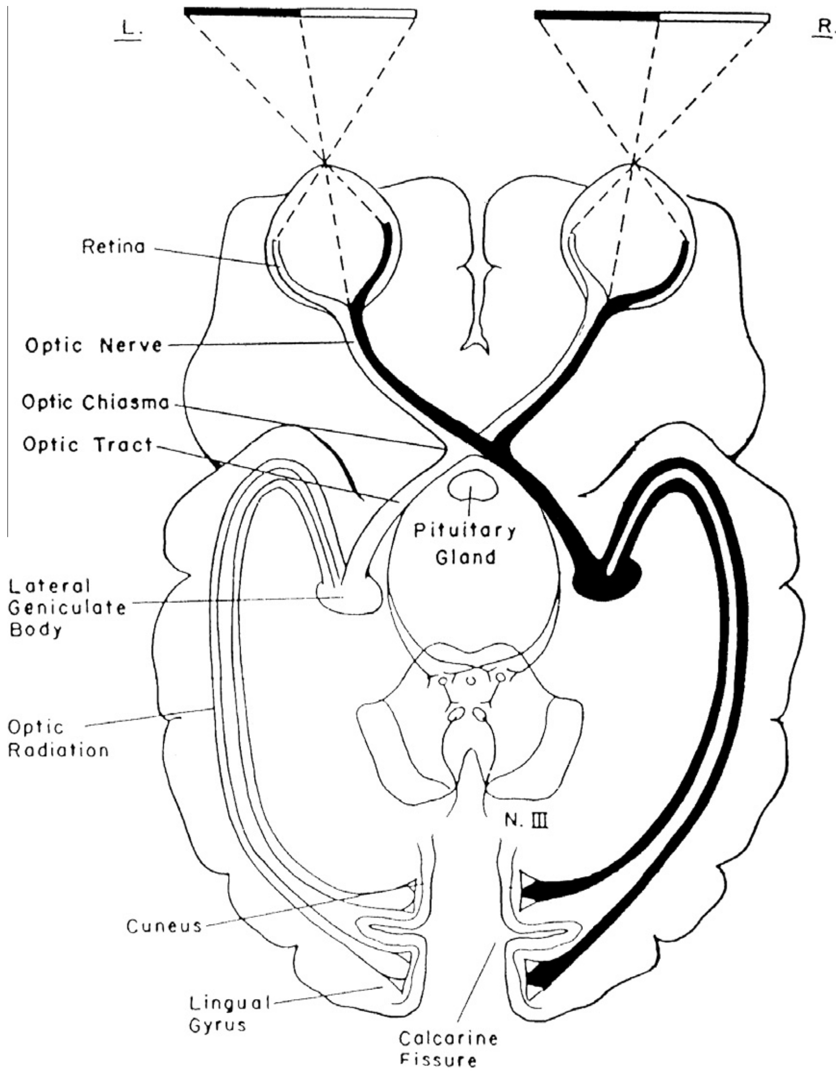

Fig. 2. Visual pathways from left and right visual fields to each hemisphere.

unequivocally predominant in identification and recall of two-dimensional unnamable tactile patterns (Milner & Taylor, 1972).

5. Motor output

Some asymmetric motor output of the hands has been found to reflect the involvement of the left hemisphere during speaking. Speaking is accompanied by what are often called "gestures", free movements of the hand and arm musculature that do not touch anything (Kimura, 1973a). They occur almost exclusively during speaking, rarely during a silent verbal task, nor during a vocal non-verbal task such as humming.

These free movements are asymmetric during speech, occurring primarily in the right hand/arm. In right-handers this is especially true for subjects with speech on the left as determined by a dichotic words task (Kimura, 1973a), but for left-handers the relationship of hand movement asymmetry to dichotic asymmetry is less marked (Kimura, 1973b). That is, even in left-handers with higher right-ear scores, suggesting speech representation in the left-hemisphere (admittedly a small sample), free movements during speaking do not differ between hands/arms.

These findings are consistent with data from left-handers with unilateral brain pathology which suggest that hemispheric lateralization for speech may be different from that for manual praxic functions. This is unlike the situation for right-handers in whom both manual and speech functions largely depend on the left hemisphere (Kimura, 1993, pp. 133–137). Thus, manual and speech functions appear more dissociable in left-handers than in right-handers. Further clarification of this mechanism might well provide clues to the nature of hand preference.

Although in left-speech-dominant right-handers free movements during speech occur primarily on the right, there appears to be no alteration in the degree of asymmetry related to speaking topic. Thus, describing a spatial layout, for example, did not reduce the relative strength of rightward asymmetry (Lavergne and Kimura, 1987). The act of speaking, rather than its content, was the major determinant.

However, in a silent problem-solving task, the hand employed may reflect the hemisphere primarily activated in its solution (Hampson & Kimura, 1984). In a situation in which the manipulanda were always 25 one-inch cubes, there was a rightward shift (that is, to the left hemisphere) from a neutral baseline for verbal tasks, and a leftward shift (to the right hemisphere) for nonverbal tasks some of which involved mental rotation.

6. Asymmetry methodology

The paper reporting the right-ear effect was cited so often it became a "Citation Classic" (This week's Citation Classic, 1979). This and related methods for studying the functional asymmetry between the left and right hemispheres became very popular because they permitted neuropsychologists to study significant aspects of brain function without invading the brain, and without reliance on medical settings. They became an important *addition* to the traditional neurological methods of investigation.

However, as with any methodology, it has limitations. We have noted that in the tactile modality it is difficult to limit input to one hemisphere, hence we don't see a reliable left-hand advantage even though the right hemisphere is known to be predominant in tactile spatial pattern identification and memory (Milner & Taylor, 1972). The absence of perceptual or motor asymmetry therefore need not necessarily be interpreted as an absence of, or lesser cerebral asymmetry for, any particular function.

It might also be expected that perceptual asymmetries would be more likely to appear if the functional asymmetries are synaptically close to sensory receiving areas. The farther or more dispersed a function is in the hemisphere, the less likely it would be to yield a perceptual asymmetry. This need not be true for motor functions.

Brain imaging methods such as fMRI and PET scans are other currently popular techniques used to identify neural systems involved in various cognitive functions, and which have their limitations. Chief of these limitations is the practice of "subtraction", subtracting a supposed baseline or control pattern, usually a simpler task, from that seen for the function of interest. A good example might be the subtraction of brain activity for simple identification of a complex figure, from the brain activity for identification of a rotated form of the figure.

Despite these cautions, brain imaging has made useful contributions, when applied judiciously, to our understanding of brain mechanisms in cognition.

The perceptual and motor asymmetry methods described in this paper have rounded out and refined our view of hemispheric asymmetry, as in basic visuospatial functions of the right hemisphere in point localization and binocular fusion. They also provide another means of following the development of brain function. For example, the right-ear superiority is strongly evident in both sexes by age four (Kimura, 1963a), and might occur earlier. This suggests that the left hemisphere is prepotent for speech very early in life, despite the brain's known flexibility in re-organizing speech after left-hemisphere pathology later in life.

A fairly recent application of asymmetry techniques has been to the study of changes in functional hemispheric asymmetry during natural fluctuations in sex hormones (Mead & Hampson, 1996; Saucier & Kimura, 1998). Such application has the potential for integrating the interaction of hormones, type of skill, and the brain systems involved, in human cognitive function.

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