Neuropsychologia, 1983, 21, pp. 289-293

NOTE

THE OCTAVE ILLUSION IN RELATION TO HANDEDNESS AND FAMILIAL HANDEDNESS BACKGROUND

DIANA DEUTSCH

Center for Human Information Processing, University of California at San Diego, La Jolla, CA 92093, U.S.A.

Abstract—The octave illusion is produced by a dichotic sequence of tones that alternate in frequency between 400 and 800 Hz, such that when the right ear receives 400 Hz the left ear receives 800 Hz; and vice versa. Most listeners obtain the illusion of a single high tone in one ear alternating with a single low tone in the other ear. Further, most right-handers hear the high tone on the right and low tone on the left. The present study examined localization patterns in this illusion as a function of handedness and also of familial handedness background. The effect of handedness was highly significant: the tendency to hear the high tone on the right and the low tone on the left was lower among mixed handers and left-handers than among right-handers. The effect of familial handedness background was also highly significant: the tendency to hear the high tone on the right and the low tone on the left was lower among those with a sinistral familial background than among those with a purely dextral familial background. These findings are discussed in relation to the hypothesis that perception of the illusion serves as a reflection of the direction of cerebral dominance in most individuals.

INTRODUCTION

There is strong evidence that patterns of cerebral dominance are related both to handedness and also to familial handedness background. A number of studies have shown that the overwhelming majority of right-handers have speech represented in the left cerebral hemisphere; however, this is true of only about two-thirds of nonright-handers. Further, right-handers tend to have a clear-cut dominance of the left hemisphere for speech; however, a substantial proportion of nonright-handers have some speech representation in both cerebral hemispheres [12, 13, 18, 22].

That left-handedness may be familial has also been demonstrated in a number of studies [1, 2, 15]. Evidence that a sinistral familial background may be associated with different patterns of cerebral dominance than a purely dextral familial background comes from investigations involving both brain-damaged and normal populations. Right-handers with left-handed relatives have a greater probability of recovery from aphasia [18, 27] and also a greater probability of crossed aphasia [11] than right-handers without left-handed relatives. In normal populations, right-handers with a sinistral familial background have been found to show reduced superiority for the right VHF for visually presented verbal materials, compared with right-handers with a purely dextral familial background [16, 21, 22]. Further, it has been reported that, while nonfamilial left-handers show a right sided superiority on dichotic listening and tachistoscopic recognition tasks, familial left-handers show a nonsignificant tendency toward a left-sided superiority [30]. In a study of tactile perception of direction it was found that, for both right-handers and nonright-handers, a sinistral familial background was associated with a reduced superiority of the left hand [29]. Concurrent verbalization on a dowel rod balancing task has been reported to produce interference with either hand in nonfamilial left-handers, but more interference with the left hand in familial left-handers [14]. There is considerable evidence, therefore, that a sinistral familial background is associated with a tendency away from patterns of cerebral dominance that are typical of right-handers with a purely dextral familial background. This reduction is manifest across handedness populations.

The present study was undertaken to examine the effect of familial handedness background on perception of the octave illusion [5]. This illusion, which has pronounced handedness correlates [4, 5, 19], was originally produced by DEUTSCH [5] in the following way. A sequence of sine wave tones was presented, whose frequencies alternated between 400 and 800 Hz. The identical sequence was presented to both ears simultaneously; however, when the right ear received the high tone the left ear received the low tone, and vice versa. With this configuration, the illusory percept most commonly obtained was that of a single high tone in one ear alternating with a single low tone in the other ear [4, 5, 6, 19]. This illusion was later shown to be based on two factors: (a) the perception of the frequencies presented to one ear (those presented to the other ear being suppressed), and (b) the localization of each tone to the ear receiving the higher frequency signal, regardless of whether the higher or the lower frequency was in fact perceived [6 – 10]. Among right-handers who obtained this percept, there was a highly significant tendency to hear the high tone on the right and the low tone on the left, reflecting perception of the frequencies presented to the right ear. However this was not true of left-handers [5]. This localization tendency among right-handers has been replicated by McCLURKIN and HALL [19].

Although the above illusion was the one most commonly obtained in the study of DEUTSCH [5], different illusory percepts were obtained by other subjects. Some heard a single tone that alternated from ear to ear, whose pitch either remained constant or changed only slightly with a change in the perceived location of the tone. Other subjects obtained a variety of complex percepts, and the proportion of these was higher in the left-handed than in the right-handed population (see also CRAIG [4]). DEUTSCH [9] hypothesized that this pattern of results reflects the greater cerebral equipotentiality among left-handers, which leads to weaker and less consistent patterns of inhibition between the dominant and nondominant pathways.

The above handedness correlates lead to the conjecture that perception of the octave illusion may serve as a reflection of patterns of cerebral dominance. If this were so, then we might also expect to find a significant effect of familial handedness background on how the illusion is perceived. The present study was concerned with correlating localization patterns in the illusion with this factor. It was predicted that a sinistral familial background would be associated with a reduced tendency to hear the high tone on the right and the low tone on the left; and that this reduction would hold across handedness populations.

METHOD

Stimuli

The stimulus pattern consisted of a sequence of sine wave tones at equal amplitude, each 250 msec in duration, with no gaps between tones. The frequencies of the tones alternated between 400 and 800 Hz. The tones had no rise-fall times. There were no voltage jumps at the frequency transitions, neither did the voltage slope change sign at the transitions; this was so as to minimize transients. The sequence was generated on two channels simultaneously; however, when one channel received the 400 Hz tone the other channel received the 800 Hz tone. The duration of the entire sequence was 20 sec.

Apparatus

The tones were generated by two Wavetek function generators (Model No. 155) controlled by a PDP 11/03 computer, and they were recorded on a Revox tape recorder. The sequence was played to subjects through high quality earphones (Grason-Stradler Model No. TDH-49; calibrated and matched) at an amplitude of 70 dB SPL.

Procedure

The subjects were individually tested. They were told that they would hear a repeating sequence of tones, and were asked to indicate on a forced choice questionnaire which description best fit their percept. Four choices were given:

(A) A high tone on the right alternating with a low tone on the left.
(B) A high tone on the left alternating with a low tone on the right.
(C) A tone switching from ear to ear with no change in pitch.
(D) None of the above (explain).

The order of choices A and B was strictly counterbalanced, as was the positioning of the earphones. The subjects were cautioned to wait until the end of the sequence before making their judgments. Before leaving, the subjects completed a 10-item handedness questionnaire (taken from VARNEY and BENTON [29]) which also contained questions concerning the handedness of the subjects' parents and siblings.

Subjects

The subjects were 250 undergraduates (105 male and 145 female) at the University of California, San Diego, who were paid for their participation. All had normal audiograms.

The subjects were divided into three handedness populations according to the following criteria: those who responded "Right" to at least 8 out 10 questions on the handedness questionnaire were categorized as right-handed. Those who responded "Left" to at least 8 out of 10 questions were categorized as left-handed. The remainder were categorized as mixed handed. Each of these three populations was further divided into the following three categories: those who responded that at least one parent was left or mixed handed ("left or mixed handed parent"); those who responded that at least one sibling (but not a parent) was left or mixed handed ("left or mixed handed sibling"); and those without left or mixed handed parents or siblings ("dextral"). Further, subjects were categorized as musically trained if they had had at least three years of training on a musical instrument: the remainder were categorized as musically untrained.

RESULTS AND DISCUSSION

Eighty-nine percent of the subjects responded either that they heard a high tone on the right alternating with a low tone on the left, or that they heard a high tone on the left alternating with a low tone on the right.[*] The localization patterns for these subjects are displayed for each population separately on Table 1. It can be seen that the tendency to hear the high tone on the right and the low tone on the left was lower for the mixed and the left-handed groups than for the right-handed groups. The overall effect of handedness was found to be highly significant ($\chi^2 = 17.63$, $df = 2$, $P < 0.001$). Highly significant effects were also found when comparison was made between the right-handed and mixed-handed groups alone ($\chi^2 = 8.13$,

Table 1. Percentages of subjects reporting the high tone on the right in the octave illusion, tabulated by handedness and familial handedness background

	Dextral	Left or mixed-handed parent	Left or mixed-handed sibling
Right-handed	87.2% ($N = 86$)	64.0 % ($N = 25$)	79.3 % ($N = 29$)
Mixed-handed	67.7% ($N = 31$)	44.4% ($N = 9$)	58.3% ($N = 12$)
Left-handed	55.6% ($N = 9$)	50.0% ($N = 16$)	33.3% ($N = 6$)

[*] Of the remaining subjects, those who responded that they heard a single pitch that alternated from ear to ear comprised 13 right-handers, 2 mixed-handers and 1 left-hander. Those who responded "None of the above (explain)" all described complex percepts. These comprised 2 right-handers, 4 mixed-handers and 4 left-handers. Thus, although the numbers involved were small, a high proportion of those reporting complex percepts were nonright-handers. This is as reported in previous studies [4, 5].

df = 1, *P* < 0.01), and between the right-handed and left-handed groups alone (χ^2 = 15.00, *df* = 1, *P* < 0.001). The difference between the mixed-handed and left-handed groups did not reach statistical significance.

Concerning the effect of familial handedness history, it was found that the tendency to hear the high tone on the right and the low tone on the left was lower for those with a sinistral familial background than for those with a purely dextral familial background (χ^2 = 10.89, *df* = 2, *P* < 0.01). Because of a possible confounding effect of family size with presence of a left-handed sibling, further analyses were performed, comparing only the dextral groups with the groups having a left-handed or mixed-handed parent. Again, the effect of handedness was highly significant (χ^2 = 12.31, *df* = 2, *P*<0.01), as was the effect of familial handedness background (χ^2 = 10.53, *df* = 1, *P* < 0.01). Further, the two familial sinistrality groups did not differ significantly from each other (χ^2 = 1.47, *df* = 1, *P* > 0.05). No sex differences were found, neither were there any effects of musical training.

It will be recalled that the typical right-handed percept of the illusion, i.e. that of a high tone on the right alternating with a low tone on the left, is based on two factors: (a) the perception of the frequencies presented to the right ear, those presented to the left ear being suppressed; and (b) the localization of each tone at the ear receiving the higher frequency signal, regardless of whether the higher or the lower frequency is in fact perceived [6-10]. When we consider the first factor, we find that the direction of ear superiority is the same as that obtained in dichotic listening to verbal materials [3, 17, 26]. Further, the proportion of right-handers showing a right ear superiority in the present study compares favorably with the proportions generally obtained in studies employing verbal materials [28]. This in turn leads to the conjecture that a test utilizing the octave illusion might serve as a useful indicator of the direction of cerebral dominance in most individuals. This conjecture is strengthened by the present finding of strong correlates in the expected direction, not only with handedness, but also with familial handedness background. It should be noted, however, that localization patterns in this illusion are sometimes unstable, particularly among left-handers [5, 6, 9]. Thus although the data based on single trials presented here are useful in demonstrating group effects, data averaged over multiple trials are likely to be more reliable in drawing inferences about individuals. Validation of this conjecture would, of course, require clinical investigation.

It is at present unclear why the octave illusion produces such strong handedness correlates indicating processing by the dominant hemisphere. However, two points may here be made. One factor of importance to the illusion is that the alternating tones be presented in rapid, repetitive sequence. The strength of the illusion has been found to build with repetitive presentation, and to build more rapidly as repetition rate increases [7-9]. Another factor of importance is that the two ears should receive the same frequencies in succession [8, 9]. The illusion therefore appears to be based in part on a sequential, frequency-specific inhibition of a nondominant pathway by a dominant pathway. (For detailed review of this issue, see DEUTSCH [9].)

Finally we may enquire as to the anatomical locus of the inhibition responsible for the suppression of the frequencies presented to the nondominant ear. Transmission of information from ear to ipsilateral hemisphere involves two pathways. First, a direct route follows the ipsilateral auditory pathway. Second, an indirect route follows the contralateral auditory pathway to the opposite hemisphere, and then travels to the ipsilateral hemisphere via the corpus callosum. From the evidence and arguments presented by SPARKS and GESCHWIND [24]. MILNER, TAYLOR and SPERRY [23] and SPARKS, GOODGLASS and NICKEL [25], it would seem most likely that interactions involving the callosal pathway are responsible; however, this question can only be settled by clinical investigation.[*†]

[*] This work was supported by United States Public Health Service Grant MH-21001.

[†] Requests for reprints should be sent to Diana Deutsch, Department of Psychology, C-009, University of California at San Diego, La Jolla, CA 92093, U.S.A.

REFERENCES

1. ANNETT, M. Handedness in families. *Ann. Hum. Genet.* **37,** 93-105, 1973.
2. ANNETT, M. Handedness in the children of two left-handed parents. *Br. J. Psychol.* **65,** 129-131, 1974.
3. BERLIN, C. I. Hemispheric asymmetry in auditory tasks. In *Lateralization in the Nervous System*, S. HARNARD, R. W. DOTY, L. GOLDSTEIN, J. JAYNES, and G. KRAUTHAMER, (Editors), pp. 303-323. Academic Press, New York, 1977.
4. CRAIG, J. D. The effect of musical training and cerebral asymmetries on perception of an auditory illusion. *Cortex* **15,** 671-677, 1979.
5. DEUTSCH, D. An auditory illusion. *Nature, Lond.* **251**, 307-309, 1974.
6. DEUTSCH, D. Musical illusions. *Sci. Am.* **233**, 92-104, 1975.
7. DEUTSCH, D. Lateralization by frequency for repeating sequences of dichotic 400- and 800-Hz tones. *J. acoust. Soc. Am.* **63,** 184-186, 1978.
8. DEUTSCH, D. Ear dominance and sequential interactions. *J. acoust. Soc. Am.* **67,** 220-228, 1980.
9. DEUTSCH, D. The octave illusion and auditory perceptual integration. In *Hearing Research and Theory*, J. V. TOBIAS and E. D. SCHUBERT (Editors), Vol. I, pp. 99-142. Academic Press, New York, 1981.
10. DEUTSCH, D. and ROLL, P. L. Separate "what" and "where" decision mechanisms in processing a dichotic tonal sequence. *J. Exp. Psychol.: Human Perception and Performance* **2,** 23-29, 1976.
11. ETTLINGER, G., JACKSON, C. V. and ZANGWILL, O. L. Cerebral dominance in sinistrals. *Brain* **79,** 569-588, 1956.
12. GOODGLASS, H. and QUADFASEL, F. A. Language laterality in left-handed aphasics. *Brain* **77,** 521-543, 1954.
13. HÉCAEN, H. and AJURIAGUERRA, J. de, *Left-Handedness*. Grune and Stratton, New York, 1964.
14. HICKS, R. E. Intrahemispheric response competition between vocal and unimanual performance in normal adult human males. *J. comp. Physiol. Psychol.* **89,** 50-60, 1975.
15. HICKS, R. E. and KINSBOURNE, M. Human handedness: a partial cross-fostering study. *Science*, *N. Y.* **192,** 908-910, 1976.
16. HINES, D. and SATZ, P. Superiority of right visual half-fields in right-handers for recall of digits presented at varying rates. *Neuropsychologia* **9,** 21-25, 1971.
17. KIMURA, D. Cerebral dominance and the perception of verbal stimuli. *Can. J. Psychol.* **15,** 156-165, 1961.
18. LURIA, A. B. *Traumatic Aphasia.* Mouton, The Hague, 1969.
19. MCCLURKIN, R. H. and HALL, J. W. Pitch and timbre in a two-tone dichotic auditory illusion. *J. acoust. Soc. Am.* **69,** 592-594, 1981.
20. MCKEEVER, W. F. and GILL, K. M. Visual half-field differences in masking effects for sequential letter stimuli in the right- and left-handed. *Neuropsychologia* **10,** 111-117, 1972.
21. MCKEEVER, W. F., VAN DEVENTER, D. A. and SUBERTI, M. Avowed, assessed and familial handedness and differential hemispheric processing of brief sequential and non-sequential visual stimuli. *Neuropsychologia* **11,** 235-238, 1973.
22. MILNER, B., BRANCH, C. and RASMUSSEN, T. Evidence for bilateral speech respresentation in some non-right-handers. *Trans. Am. Neurol. Ass.* **91,** 306-308, 1966.
23. MILNER, B., TAYLOR, L. and SPERRY, R. W. Lateralized suppression of dichotically presented digits after commissural section in man. *Science, N. Y.* **161,** 184-186, 1968.
24. SPARKS, R. and GESCHWIND, N. Dichotic listening in a man after section of neocortical commissures. *Cortex* **4**, 3-19, 1968.
25. SPARKS, R., GOODGLASS, H. and NICKEL, B. Ipsilateral versus contralateral extinction in dichotic listening resulting from hemisphere lesions. *Cortex* **6**, 249-260, 1970.
26. STUDDERT-KENNEDY, M. and SHANKWEILER, D. Hemispheric specialization for speech perception. *J. acoust. Soc. Am.* **48,** 579-594, 1970.
27. SUBIRANA, A. The prognosis in aphasia in relation to cerebral dominance and handedness. *Brain* **81,** 415-425, 1958.
28. TENG, E. L. Dichotic ear difference is a poor index for the functional asymmetry between the cerebral hemispheres. *Neuropsychologia* **19,** 235-240, 1981.
29. VARNEY, N. R. and BENTON, A. L. Tactile perception of direction in relation to handedness and familial handedness. *Neuropsychologia* **13,** 449-454, 1975.
30. ZURIF, E. B. and BRYDEN, M. P. Familial handedness and left-right differences in auditory and visual perception. *Neuropsychologia* **7,** 179-188, 1969.