BRAIN AND COGNITION 9, 48–56 (1989)

Duplex Perception: Some Initial Findings Concerning Its Neural Basis

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Duplex perception is the simultaneous perception of a speech syllable and of a nonspeech "chirp," and occurs when a single formant transition and the remainder (the "base") of a synthetic syllable are presented to different ears. The current study found a slight but nonsignificant advantage for correct labeling of the fused syllable when the chirp was presented to the left ear. This advantage was amplified in the performance of a "split-brain" subject. A subject with a left pontine lesion performed at chance level when the chirp was presented to her left ear. These findings suggest that some, if not complete, ipsilateral suppression does occur in the dichotic fusion procedure, and that identification of the fused syllable is maximal when the left hemisphere fully processes the linguistic characteristics of the base (through contralateral presentation), and at least minimally processes the frequency transition information of the chirp (through ipsilateral presentation).

The present study investigated the phenomenon of "duplex perception" in two neurologically impaired individuals, one with section of the corpus callosum, and one with a small extrinsic lesion to the left pontine area.

This research was supported in part by Haskins Laboratories, and by Dartmouth College. Supported in part by NICHD Grant HD 01994 to Haskins. We thank Doug Whalen and Bruno Repp for their advice in constructing the duplex perception tapes, Steven Winter for his assistance in testing the subjects, and Roderick Ashton for reading an earlier version of the paper. We are particularly grateful to L.L. and R.A., who generously agreed to participate in this study. This manuscript was prepared while Jacquelyn Cranney was a University of Queensland Postdoctoral Research Fellow. Carol A. Fowler is also with Haskins Laboratories. Requests for reprints should be addressed to Jacquelyn Cranney, who is now at the School of Psychology, University of New South Wales, P.O. Box 1, Kensington 2033, Australia.

00278-2626/89 $3.00

Duplex perception occurs when a synthetic stop consonant–vowel syllable is split in a certain way and presented dichotically (Rand, 1974). If an initial formant transition, which distinguishes one stop consonant from another (e.g., /da/ vs. /ga/), is removed from the rest of the syllable and played in isolation, subjects report hearing a nonspeech "chirp." When the rest of the syllable without the transition, the "base," is played in isolation, subjects report hearing a stop consonant–vowel syllable; however, the stop reported is not necessarily the one reported when the whole syllable is presented (e.g., either /da/ or /ga/). If the chirp is now presented to one ear and the base to the other ear, with the two stimuli timed as they would be in the whole syllable, subjects report a duplex percept. That is, in the ear in which the chirp was presented, they report hearing a nonspeech sound—the chirp; in the other ear, they report hearing the original syllable from which the two stimuli were derived.

One explanation given for this phenomenon is that the base and the chirp are fused to form the whole syllable which is heard in one ear, while the chirp alone is also heard separately in the other ear (Cutting, 1976; Liberman, Isenberg, & Rakerd, 1981). According to this account, the chirp is heard simultaneously as part of the fused speech syllable and as nonspeech (as it sounds in isolation). Liberman and his colleagues interpret the duplex phenomenon as supporting the existence of two distinct modes for perceiving sound: one auditory, for processing nonspeech sounds, and the other phonetic, for processing speech sounds (Liberman et al., 1981; Mann & Liberman, 1983; Repp, Milburn, & Ashkenas, 1983). Both modes seem to be engaged simultaneously in the duplex situation.

In contrast to the fusion process in duplex perception, the traditional dichotic listening procedure, as devised by Broadbent (1956) and Kimura (1961) presents incompatible and competing dichotic stimuli. Kimura (1961, 1967) was the first to note a slight but significant right ear advantage for the perception of dichotically presented verbal stimuli, and a left ear advantage for the perception of dichotically presented nonverbal stimuli. Kimura (1961, 1967) argued that ipsilateral projections to the cortex are partially occluded during dichotic presentation so that the most functional routes are from each ear to the contralateral hemisphere. She attributed the right ear advantage for verbal material to the superior connections from the right ear to the hemisphere specialized for processing speech and language.

The right ear advantage for verbal material is amplified in individuals whose corpus callosum has been sectioned (e.g., Milner, Taylor, & Sperry, 1968; Musiek & Wilson, 1979). "Split-brain" subjects display "left-ear suppression": very few if any dichotically presented left ear stimuli are reported, despite an ability to fully identify monaurally presented left ear stimuli. This finding was explained in terms of suppression of ipsilateral auditory input in the dichotic situation (Milner et al., 1968), the phenomenon being "unmasked" in the split-brain case where there is no opportunity for callosal transfer of otherwise suppressed information (Sparks & Geschwind, 1968). In the neurologically intact individual, then, suppressed ipsilateral auditory information will eventually reach the hemisphere through callosal transfer. In the split-brain subject, that transfer cannot occur. In addition, when the task requires verbal processing, the language-dominant left hemisphere out-performs the right hemisphere.

Procedures giving rise to fusion of dichotically presented stimuli (Cutting, 1976) involve presentation of independent but highly compatible stimuli. The question then arises as to whether the same processes of stimulus competition, ipsilateral suppression, and hemispheric specialization, operative in the perception of the separate stimuli in the traditional dichotic task, will be operative also in the perception of the fused syllable in duplex perception. A related issue concerns the neural level at which fusion occurs. There are at least three possibilities: (1) If there is no ipsilateral suppression, and the fusion occurs subcortically, then both hemispheres will receive the fused syllable and the chirp, so that both hemispheres are able to produce a duplex perception response. (2) If there is no suppression, and if the fusion occurs at the cortical level, then both hemispheres will receive the base and the chirp, so that both hemispheres are able to produce a duplex perception response. In this case, however, the left hemisphere (LH) may be superior to the right hemisphere (RH) in processing the phonetic information, so that a lateralization effect may be evident. (3) If there is ipsilateral suppression, then each hemisphere will receive the contralaterally presented information directly and the ipsilaterally presented information indirectly through callosal transfer. Again, a lateralization effect may be evident. This case will be distinguished, however, by the lack of fusion in the commissurotomized patient, where callosal transfer, and hence fusion, is prevented.

Studdert-Kennedy and Shankweiler (1970) have argued that RH lexical capacity is restricted to auditory, without phonetic, analysis. If duplex perception is a phonetic, rather than an auditory event, as Liberman (1982) has argued, then it follows that only the LH is capable of displaying duplex perception. Zaidel (1983) reported informal observations that several split-brain patients displayed duplex perception when the stimuli were presented to either ear. This finding rules out the notion of complete ipsilateral suppression in duplex perception. Zaidel (1983) argued that the finding need not be interpreted in terms of a RH phonetic processing capability; rather, the fusion of the two ear signals occurs at a subcortical level and so does not require RH phonetic processing. In addition, he argued that the paradigm does not create ipsilateral suppression and so allows access of both ears to both hemispheres. Zaidel (1983) does not mention differential performance by the two hemispheres; thus his explanation in terms of subcortical fusion is a viable one.

The current study attempts to replicate Zaidel's (1983) informal observations and compares the performance of a split-brain individual to that of an individual with a subcortical lesion. A second purpose of the study was to look at the possibility of lateralization in duplex perception, in both normal and the brain-impaired individuals, in order to elucidate the nature of the neural basis of duplex perception.

METHOD

Subjects. Thirty-four (19 female and 15 male) first-year psychology students at Dartmouth College volunteered for the experiment in return for course credit. Three females and one male were dropped from the final analysis because they failed the hearing test or were left-handed. The age of the remaining subjects ranged from 19 to 28 years ($M = 20.5$, $SD = 3.3$). No subjects were experienced in speech perception experiments.

A female (33 years old) with an extrinsic lesion to the left pontine area, R.A., and a male (22 years old) with a complete commissurotomy, L.L., were also tested.

R.A. suffered a severe brain injury as a result of a car accident when she was 30 years old. After the accident, she remained in a coma for 10 days. Subsequent neurologic exams indicated that she had right-sided central facial paresis, that the left pupil was slightly larger than the right, that there was weakness and paresthesia in the left arm and leg, and that she had several orthopedic injuries to the right side. CAT scan and skull X rays were normal. Neurologic diagnosis was a contusion to the left mid-to-upper pons.

Approximately 3 weeks after the accident, the patient complained of a hearing difficulty on the left side. A month later, she developed a left-side spastic hemiparesis and increased hemisensory loss thought to be due to cervical root compression. Later, however, the patient began to improve on all fronts, but she still complained of a mild hearing loss that was difficult for her to describe in detail. Extensive audiological testing at 7 months after the accident demonstrated that the subject had normal pure-tone thresholds and speech discrimination ability bilaterally; however, auditory brain stem responses and acoustic reflexes were abnormal for the left ear, indicative of brain stem dysfunction (Musiek, 1982).

From an early age, L.L. had suffered from severe epileptic seizures. At age 20 years, he underwent the first of a two-stage commissurotomy, where the anterior half of the corpus callosum was sectioned. One year later, he underwent the second stage of the operation where the posterior half of the corpus callosum was sectioned. Following the second stage operation, the number of epileptic episodes was decreased, but L.L. developed a debilitating motor control deficit, in which his left hand often made independent movements not under his conscious, verbal control. At the time of testing, 7 months following the second stage operation, L.L. was still suffering from the motor problem and had also been quite depressed. Nevertheless, he was a cooperative subject.

Stimuli. The stimuli were two three-format synthetic syllables created on the Haskins Laboratories parallel resonance synthesizer, and represented /da/ and /ga/.[1] All syllables were 250 msec in duration and had linear 50-msec initial transitions in all three formants, followed by a 200-msec steady state. The first formant rose from 279 to 765 Hz, the second formant fell from 1650 to 1230 Hz, and the third formant, which alone distinguished the two syllables, started at either 3000 Hz, /da/, or 2333 Hz, /ga/, and went to 2527 Hz.

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[1] A more detailed specification of the stimulus characteristics, as well as the exact order of stimulus presentation in each set, can be obtained by writing to Jacquelyn Cranney or Carol Fowler.

The chirps consisted of the 50-msec transition of the third formant in isolation; the "base" consisted of a syllable without that distinctive transition, that is, with no energy in the third formant region during the first 50 msec. Consequently, there were two different chirps but only one base.[2] The stimuli were presented dichotically at 65 dB SPL to neurologically intact subjects, and 65 dB HL to the brain-lesioned subjects.

The experimental tape comprised a practice sequence of 24 repetitions of the base in conjunction with one of the two transitions. The base was presented an equal number of times to the right and left ears. The practice sequence was followed by a test sequence with four sets of 30 stimuli each. Within each set, there were (a) four sets of five dichotic stimuli in which the base was presented to one ear, and the /da/ or /ga/ chirp to the other ear; the ear hearing the chirp (left or right) was crossed with the chirp (/da/, /ga/) to make up the four sets; (b) two sets of three monaural stimuli with the base to the left ear in one set and to the right ear in the other set; (c) four diotic base stimuli. These stimuli types were presented in a different random order in each set, with an interstimulus interval of 3 sec.

The stimuli were presented to the normal subjects through TDH39 earphones, and to the neurologically impaired subjects through TDH49 earphones.

Procedure. Neurologically intact subjects were tested individually in a quiet room. First, they were given a brief screening test of their hearing to determine that their thresholds were within the normal range between 250 through 8000 Hz. The subjects were then told that they would be listening to the synthesized production of the syllables, "da" and "ga," and that their task was to identify which syllable they heard by pointing with both hands to one of two cards placed in front of them. Two cards, one with a printed "da," the other with a printed "ga," were situated in front of the subject. The left–right position of the cards was changed between subjects. Subjects were told to pay special attention to the differences between the two stimuli. After listening to the practice sequence without identifying them overtly, the subjects practiced responding to one set of 30 test items (Practice), then the ear position of the headphones was changed. Subjects listened again to the 24 practice items, then responded to four sets of 30 test items (Tests 1–4). Again, the ear position of the headphones was changed, and the same procedure of listening to the practice items then responding to the four sets of test items (Tests 5–8) was employed.

Subjects L.L. and R.A. were tested individually in an IAC double-walled sound-attenuated chamber (ambient noise level below 25 dBA). Both subjects were first tested for their hearing sensitivity. L.L. displayed a slight hearing deficit. Hence, these two subjects were tested at 65 dB HL. Because L.L. had difficulty keeping his left hand under control, he responded verbally. In addition L.L. responded during the "just listen" sequences, so that these sets were counted as the practice set and Test 5, respectively. These were the only departures from the normal procedure.

RESULTS

The mean percentage correct labeling of fused syllables by the neurologically intact subjects in the Practice and Test sets is presented in Table 1. Analysis of variance revealed that, across all four sets of data (Practice, Test 1, Tests 1–4, Tests 5–8), there was a slight but nonsignificant advantage when the chirp was presented to the left ear. A practice effect

[2] The total physical energy of the chirps and of the base were matched, so that interpretation of lateralization effects would not be confounded by intensity differences. Although the chirp intensity is less than the base in natural speech, its higher intensity in this situation did not have a deleterious effect on fusion.

TABLE 1
MEAN PERCENTAGE CORRECT FUSIONS WHEN THE CHIRP WAS PRESENTED TO THE LEFT OR RIGHT EAR, AND THAT DATA COMBINED

Stimulus set	Left	Right	Combined
Practice	78.7 (16.3)	76.7 (18.8)	77.7 (15.4)
Test 1	82.0 (18.1)	79.3 (20.7)	80.7 (18.3)
Tests 1–4	86.4 (15.7)	85.6 (16.5)	85.9 (15.6)
Tests 5–8	92.5 (8.6)	91.6 (10.0)	91.8 (8.3)

Note. Numbers in parentheses are standard deviations.

was evident between Tests 1–4 and Tests 5–8, $F(1, 29) = 5.9$, $p < .05$, but not between the Practice set and Test 1.

Analyses comparing performance by males and females yielded a significant difference in the last data set only, Tests 5–8, where females made more correct identifications than males, $F(1, 28) = 4.5$, $p < .05$, independent of ear of chirp presentation. For all four data sets, overall performance was significantly better than the chance level of 50% (Practice: $t(29) = 12.6$, $p < .05$; Tests 5–8: $t(29) = 27.7$, $p < .05$).

The percentage correct labeling of fused syllables by L.L. and R.A. is presented in Table 2. For L.L., across all four sets of data, there is a clear advantage when the chirp is presented to the left ear. As indicated by the results of the binomial Z tests (see Table 2), performance during the test sets was significantly higher than chance, and this was primarily attributable to performance when the chirp was presented to the left ear. Unlike the neurologically intact subjects, L.L.'s performance appeared to decrease slightly with practice, although it was within one standard deviation of the neurologically intact subjects' mean performance except on the last set of tests. This decrement in performance over time can be related to an apparent decrement in motivation over the testing period.

For R.A., across all four sets of data there is a clear deficit when the

TABLE 2
PERCENTAGE CORRECT FUSIONS WHEN THE CHIRP WAS PRESENTED TO THE LEFT OR RIGHT EAR, AND THAT DATA COMBINED, FOR SUBJECTS L.L. AND R.A.

Stimulus set	L.L.			R.A.		
	Left	Right	Combined	Left	Right	Combined
Practice	66.7	58.3	62.5	10.0	50.0	30.0
Test 1	90.0*	55.6	72.8*	70.0	80.0	75.0*
Tests 1–4	79.5*	64.1	71.8*	55.0	80.0*	67.5*
Tests 5–8	75.0*	61.8	68.4*	52.5	75.0*	65.0*

Note. Binomial Z tests were computed for all data points.
* $p < .05$.

chirp was presented to the left ear. Following below-chance performance during the practice set, R.A. showed reasonably stable performance in the test sets. Her performance was within one standard deviation of the neurologically intact subjects on Test 1, but not on the remaining sets of data. As indicated by the results of the binomial Z tests, performance during the test sets was significantly higher than chance, and this was primarily attributable to performance when the chirp was presented to the right ear. Following the tests, R.A. reported that the stimuli sounded strange but she was able to develop a strategy for responding.

Labeling of the base when it was presented without the chirp (monaurally to left or right ear, and diotically—to both ears) was also examined. With the normal subjects, there were no differences in labeling of the base when it was presented to the left or to the right ear, and in each case, there was an equal probability of the base being labeled /da/ or /ga/. When the base was presented diotically, however, some differences occurred. Subjects were more likely to label the base /ga/ than /da/ during the Practice set ($t(29) = 2.9$, $p < .05$), during Test 1 ($t(9) = 2.1$, $p < .05$), and during Tests 5–8 ($t(29) = 2.9$, $p < .05$). The perceived intensity of the dichotically presented base was higher than that of the monaurally presented base; initial pilot studies had indicated that labeling of the base varies with perceived intensity.

DISCUSSION

The current study found a slight but nonsignificant advantage for correct labeling of fused syllables when the chirp was presented to the left ear. This advantage was amplified in the performance of the split-brain subject, whereas the subject with a left-sided brain stem lesion displayed a deficit when the chirp was presented to her left ear.

Although the chirp-to-left-ear advantage is only suggestive at this point, it is interesting to speculate about underlying processes. If no ipsilateral suppression occurred, and each hemisphere received equal amounts of information from each ear, then it should not have mattered whether the chirp was presented to the left or to the right ear. It could be argued, then, that suppression of ipsilateral auditory information did occur to a certain degree, so that the chirp-to-left-ear labeling advantage was the result of one or both of the following processes: (a) presentation of the chirp to the left ear resulted in initial processing by the right hemisphere, which may have processed more effectively the frequency characteristics of the nonverbal chirp stimulus, thus contributing to a more categorical perception of the fused stimuli, and (b) presentation of the base to the right ear resulted in initial processing by the left hemisphere, which may have processed more effectively the linguistic characteristics of the base, thus contributing to a more categorical perception of the fused stimuli. The finding that the left ear advantage was amplified in the performance of the split-brain patient supports this notion. In this case, the effect of suppression was more evident, as there was no compensatory process of callosal transfer of the otherwise suppressed ipsilateral information.

The performance of the split-brain subject also indicates that transfer of information across the corpus callosum was not necessary to the fusion process, as his labeling of fused syllables was within the normal range of performance. This finding corroborates the informal observations of Zaidel (1983). Two points are worth noting, however. First, performance by L.L. when the chirp was presented to the right ear was not significantly different from chance. Whether this effect is replicable in other split-brain individuals, and whether it may be an artifact associated with the verbal response mode used, will be determined by further investigation. Second, our results do suggest, contrary to Zaidel's (1983) argument, that some ipsilateral supression does occur in the duplex perception paradigm. It seems likely, then, that the contralateral and the somewhat suppressed ipsilateral stimuli enter the cerebral hemispheres where they are finally fused into an integrated percept, which itself varies in quality according to a number of factors, including amount of suppression and the functional specialization of the hemisphere.

This conclusion is supported to a certain extent by the results with R.A., who showed a chirp-to-left-ear deficit. If a certain amount of suppression occurred, then the left pontine lesion likely interfered with a strong contralateral signal and a weak ipsilateral signal. This effect was evident only when the contralateral signal was the base, suggesting that although the LH may receive a weak base signal through callosal transfer, it was not enough to compensate for the degraded or nonexistent contralateral base information.

The relative contribution of the chirp in the left ear and base in the right ear to duplex perception could be assessed in future studies by examining the identification and discriminability of the nonverbal chirp percept, as well as of the syllable percept (Mann & Liberman, 1983), with a range of neurologically impaired subjects. For instance, chirp and syllable identification ability could be compared in left- and right-hemisphere-lesioned subjects. Given that very little information from the chirp is necessary to produce duplex perception (B.H. Repp, personal communication, January 1984), it is possible that RH-lesioned individuals will display a performance deficit on the chirp identification task (presumably a nonverbal RH). In contrast, these subjects will perform normally on the syllable identification task, providing the chirp is presented to the left ear. In this situation, sufficient frequency transition information from the degraded contralateral or suppressed ipsilateral chirp will reach the left hemisphere to combine with the fully processed base stimulus. Such findings would suggest that left hemisphere processing of the base stimulus is the primary factor in producing the chirp-to-left-ear advantage in the neurologically intact and the split-brain subjects in this study.

In future studies, a more direct measure of the fusion process in each hemisphere, irrespective of whether it receives contralateral or ipsilateral chirp information, could be derived. Such information should indicate the relative efficiency of each hemisphere in processing the stimuli, and should differentiate among the proposed explanations of the chirp-to-left-ear advantage. This measure could be derived by systematically varying the response hand, or by using the tachistoscopic response method employed by Zaidel (1983).

In summary, the current study has provided some initial findings on the possible neural basis of duplex perception and has demonstrated the potential of the dichotic fusion procedure for generating data relevant to discovering the neural basis of the complex interactions of dichotically presented acoustic stimuli.

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