J Am Acad Audiol 5: 243–247 (1994)

Dichotic Listening to Musical Chords: Background and Preliminary Data

Douglas Noffsinger*
Charles D. Martinez*
Brad W. Friedrich†
Richard H. Wilson‡

Abstract

One test of dichotic listening utilizing nonverbal stimuli is included on the VA-CD *Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 1.0.* It is a test using three tone complexes that meet the definition of musical chords. The dichotic chords were included as a complement to the three dichotic speech procedures on the VA disc because musical chords may depend on right hemisphere brain function in a manner at least related to the way speech depends on left hemisphere organization/activity. Normative data were obtained from 120 normal-hearing listeners at nine testing centers in the United States. The three tone chords were presented dichotically under two onset time conditions, simultaneous and 90-msec onset time stagger, and three presentation levels, 70, 80, and 90 dB SPL. In general, subjects could identify the dichotically presented chords about 60 percent of the time in each ear. In addition, onset time relationships and presentation levels did not greatly affect accuracy. Overall, subject performance was similar to that noted by others and at levels that should allow lesion effects to be sought.

Key Words: Compact disc, dichotic listening, dichotic musical chords

Dichotic musical chords are included on the VA-CD *Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 1.0.* The dichotic chord test was included because it serves as a nonspeech complement to the dichotic digit, sentence, and CV speech tests on the disc (see Noffsinger et al, 1994a). Just as understanding dichotic speech materials is thought to depend on the integrity of the left temporal lobe, processing dichotic musical events is thought to be linked with the right brain hemisphere (see review in Noffsinger, 1985). Melodies (Kimura, 1964), chords (Gordon, 1970; Friedrich, 1975), and complex pitch perception (Sidtis and Gazzaniga, 1981; Sidtis, 1982), among others, have been linked to better left ear performance under dichotic listening conditions and directly or inferentially to right hemisphere brain function. The issue is not simple. Hummed melodies presented dichotically are better heard by the left ear (King and Kimura, 1972), but no ear preference is exhibited by normal listeners for nonmelodic hums and rhythms (Gordon, 1970; Spellacy, 1970; Van Lancker and Fromkin, 1973). Schweiger's look (1985) at the many effects of brain lesions on musicians included case studies of every possible combination of aphasia, amusia, musical skill, and musical ignorance, with no compelling evidence of what causes what.

In fact, little meaningful evidence exists about the value of using dichotic musical stimuli as a possible way to find central auditory system damage in the right hemisphere. Friedrich's 1975 study suggested that musical chords were viable stimuli with which to approach this question and that the left ear seemed better at recognizing such stimuli when dichotic presentation was employed. He noted "mirror-image" similarities between his findings and corollary findings in dichotic speech studies and that

*VA Medical Center, West Los Angeles, University of California, Los Angeles, California; †Northwestern University Medical School, Chicago, Illinois; and ‡VA Medical Center, Mountain Home, Tennessee, East Tennessee State University, Johnson City, Tennessee

Reprint requests: Douglas Noffsinger, Audiology/Speech Pathology (126), VA Medical Center, West Los Angeles, CA 90073

"...it seems reasonable to speculate on the basis of what is known about the specialization of man's cerebral hemispheres that the advantage [seen for the left ear reflects] a right hemisphere uniquely equipped to process the particular stimuli used in this study" (p. 6). The response task he picked for the musical chord task, a concatenation of dichotic and diotic stimuli similar to the method suggested by Gordon (1970), also proved effective. Finally, Friedrich suggested that, ultimately, only study of patients with prescribed lesions of the right hemisphere could answer many of these questions.

METHOD

Several experimental methods are covered earlier in the introductory article by Noffsinger et al (1994b) in this journal issue. These include digitization techniques, contents of each track on the VA-CD, general calibration stimuli available on the compact disc, overall picture of the strategies used in data collection, and details about the hearing sensitivity, ages, and handedness of the 120 young adults who comprised the subject pool. As is noted on instructions accompanying the disc, the chords peak slightly above 0 VU with reference to the calibration tone.

The sinusoids used to create the chords were digitally generated at a sampling rate of 20,000 Hz using in-house software. The frequencies chosen were those used by Friedrich (1975). The computer files containing the sinusoids were added to produce the three-tone chords listed in Table 1. The dichotic stimuli were formed by interleaving two of the chords so that alternating data bits would be presented in separate channels. The chords were combined so that the onsets of the two chords were simultaneous or that onset of the chord on the left channel trailed its counterpart of the right channel by 90 msec (i.e., the two time-lag conditions were created by sending the CD channel outputs to different earphones). This allowed three onset conditions: simultaneous, 90-msec left ear lag, 90-msec right ear lag.

Two of the stereo tracks on the VA-CD contain 30 possible pairings of six dichotic musical chords, which are illustrated in Figure 1. Following an initial 500-msec dichotic pair of chords and a 1-sec pause, there are four sequential 500-msec chords that are diotic (i.e., the same chords in each ear). The interstimulus interval between the four diotic chords is 500 msec. The listener's task was to pick the two chords from the sequence of four that made up the initial dichotic pair. Responses were marked on a printed form, and two responses were required for each trial.

Table 1 Frequency Composition (and Chord Number) of Musical Chords Used in the Dichotic Chords Test

Chord Number	*Pure-Tone Composition (Hz)*
1	512.0 - 640.0 - 768.0
2	550.0 - 682.7 - 825.0
3	576.0 - 733.3 - 880.0
4	618.7 - 768.0 - 896.0
5	640.0 - 825.0 - 990.0
6	682.7 - 880.0 -1024.0

Triad chords were used: each consists of a base tone and tones a third and a fifth above that. The major chords (C-major, C#-major, etc.) on a just intonation scale between 512 and 1024 Hz were chosen (Olson, 1952; Apel, 1960). The target chords were never the same in the two ears, and the subjects were given practice in listening to them before the VA-CD trials began. As mentioned earlier, trials involving chords with simultaneous onsets and with time-staggered onsets were conducted.

The musical chords were presented through a speech audiometer at 50, 60, and 70 dB hearing-level control dial settings (i.e., at 70, 80, and 90 dB SPL [ANSI, 1989]). Three groups of 40 of the normal listeners each heard one onset condition at the three different presentation levels.

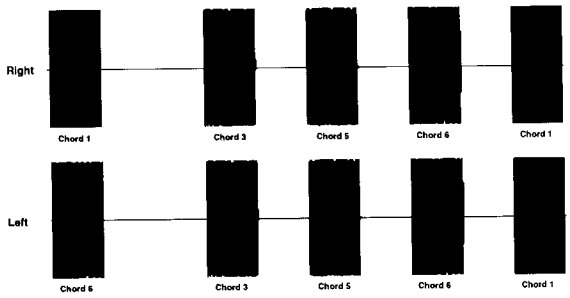

Figure 1 An example of the dichotic musical chord paradigm. Amplitude (Y) by time (X) displays of the digital waveforms of a dichotic pair of 500-msec chords, followed by a 1-sec interstimulus interval, and then four 500-msec diotic chords separated by interstimulus intervals of 500 msec. Two of the diotic chords constituted the original dichotic pair. Further descriptions of the chords are in Table 1.

RESULTS

Table 2 and Figures 2 to 5 present the results of the compact disc trials. Mean right ear and left ear scores and standard deviations for three onset conditions and three presentation levels are portrayed. Sample sizes numbered 40 subjects (80 ears) for each dichotic condition (n = 120).

In Figure 2, data are shown for the condition in which the onset of the chord to the left ear lagged in time, by 90 msec, compared to the onset of the chord to the right ear. Lag-time onset trials were included in the normative studies to get an idea of how normal listeners responded to tasks that were easier than simultaneous-onset ones and because Friedrich (1975) suggested that a lag effect like that seen in dichotic CV studies might also apply for dichotic chords. For this lag condition, clinically insignificant ear differences (see SD) of 5 percent or less are seen across presentation levels.

Similar findings are seen in Figure 3 for the 90-msec right ear lag conditions. Ear differences did not exceed 4 percent for presentation levels of 70, 80, and 90 dB SPL.

For simultaneous onset conditions portrayed in Figure 4, ear differences were 3 percent or less, and as was the case for all dichotic musical chord trials, all mean scores were between 60 and 70 percent accurate at all listening levels.

Figure 5 shows ear scores collapsed across the various onset time conditions. In general, subjects could identify correctly about 6 of each 10 chords presented dichotically to the two ears. Overall, the left ear (64%) did slightly better than the right ear (63%), especially when it lagged in time, but these effects were unremarkable.

DISCUSSION

A useful gauge in judging normal performance on any procedure is the mapping of confidence areas. For the dichotic musical chords, 92 percent of all ears scored 50 percent or better at 70, 80, and 90 dB SPL. The 90th percentile was at 50.9 percent. Said differently, scores below 50 percent accurate leave a clinician the reasonable conclusion that such performance is worse than expected in a population of young adults with no hearing complaints, the sort tested in this study.

Another way to look at data from the dichotic musical chords test is to examine ear differences, regardless of the absolute scores. Across presentation levels, 90 percent of the normal subjects had differences in performance between ears of 23 percent or less (interear differ-

Table 2 Performance (% Accurate) by Normal Listeners on Dichotic Musical Chords under Various Listening Conditions

	Presentation Level (dB SPL)					
	70		*80*		*90*	
	RE	*LE*	*RE*	*LE*	*RE*	*LE*
Left Ear Lag Condition (90 msec)						
Mean	64	64	60	65	61	65
SD	10	12	12	11	10	9
Minimum score	33	40	33	30	30	43
Maximum score	80	90	87	87	77	80
Right Ear Lag Condition (90 msec)						
Mean	61	61	63	62	67	63
SD	10	9	11	12	9	12
Minimum score	40	37	37	40	40	37
Maximum score	77	87	90	87	87	87
Simultaneous Condition						
Mean	63	64	64	67	66	69
SD	12	11	11	14	10	11
Minimum score	37	43	37	27	47	40
Maximum score	87	87	93	93	90	93

n = 40 persons (80 ears) for each condition.
RE = right ear, LE = left ear.

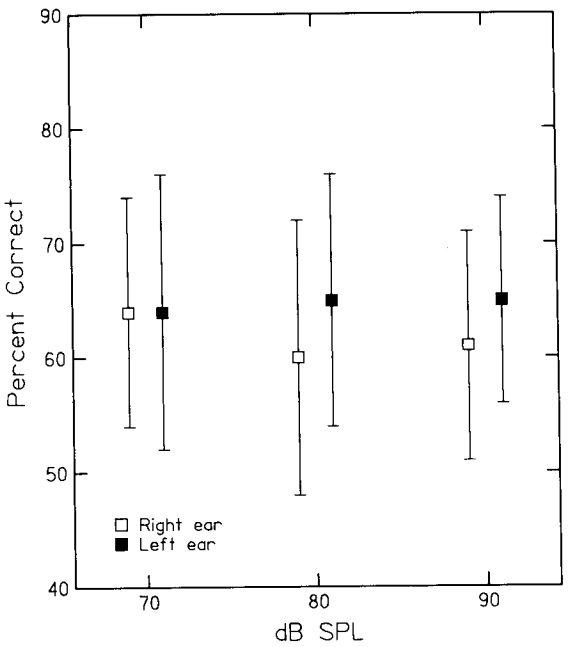

Figure 2 Mean performance (% correct) with one standard deviation for the right ear (open squares) and left ear (closed squares) of 40 subjects at each of three presentation levels (n = 120). The dichotic condition featured a 90-msec lag in onset of the left ear musical chord.

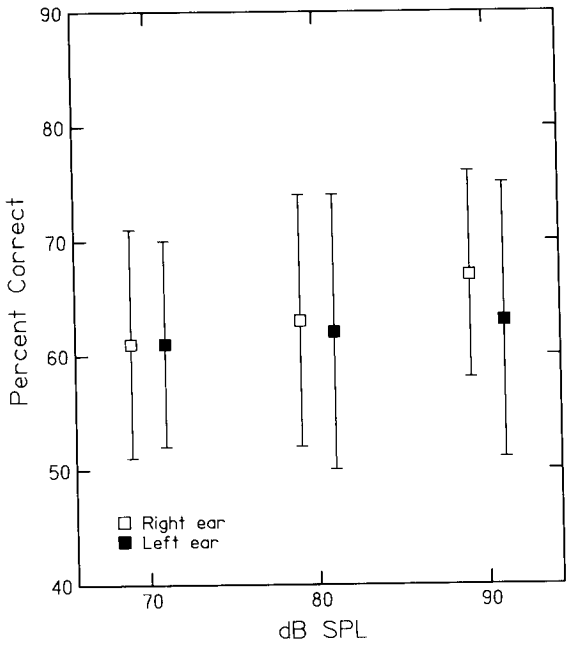

Figure 4 Mean performance (% correct) with one standard deviation for the right ear (open squares) and left ear (closed squares) of 40 subjects at each of three presentation levels (n = 120). The dichotic condition featured a simultaneous onset of the chords to the two ears.

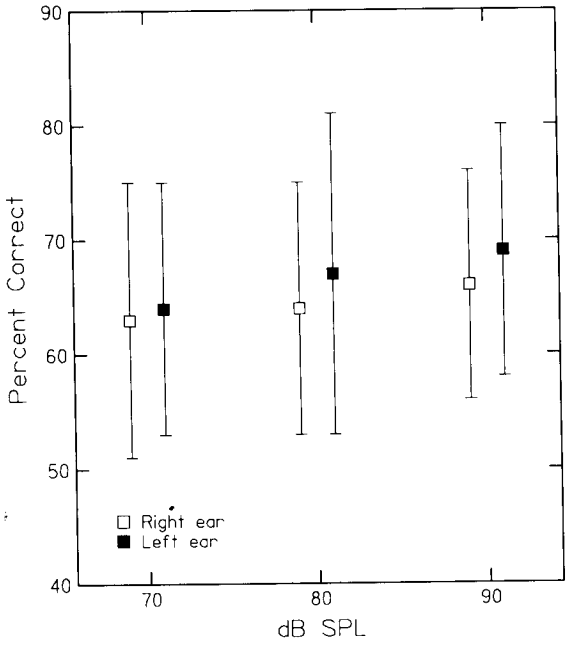

Figure 3 Mean performance (% correct) with one standard deviation for the right ear (open squares) and left ear (closed squares) of 40 subjects at each of three presentation levels (n = 120). The dichotic condition featured a 90-msec lag in onset of the right ear musical chord.

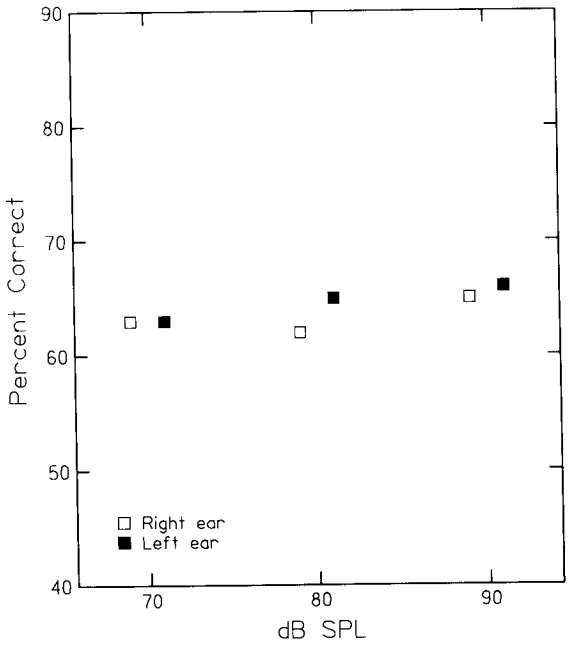

Figure 5 Mean performance (% correct) for the right ear (open squares) and left ear (closed squares) of 40 subjects at each of three presentation levels (n = 120). The data are collapsed across the onset-time conditions in Figures 2–4.

ences of seven chords correct) for both 90-msec lag conditions and 27 percent or less (interear differences of eight chords correct) for the simultaneous condition. These indices may be a useful guide to making decisions about when one ear's score is meaningfully different from the other ear's score.

The ideas behind putting a version of the Friedrich task on the VA-CD were to provide the clinical investigator with a means of looking at nonverbal dichotic listening, to provide a task and response structure that were workable, and to demonstrate that the task allowed normal listeners enough success that abnormality could be recognized when it occurred. It also was thought useful to have on the VA-CD a nonspeech task that might allow search for ear advantages/hemispheric organization in normal listeners and lesion effects in suspected abnormal ones. The musical chord task satisfies these goals.

Normal listeners are challenged by this task. Nobody in the trials reported here ever got all the chords delivered to one ear correct under any listening condition. This is unlike the situation for dichotic CVs discussed by Noffsinger et al (1994a) elsewhere in this journal issue, where subjects sometimes got almost everything right in a particular trial, or for dichotic digits and sentences where subjects usually got everything correct. Listeners also complained about the difficulty of the chords task, reporting that they felt little confidence in their two forced responses.

The forced-response paradigm is often critical in dichotic listening. Subjects allowed to give only responses of which they are confident present entirely different pictures than those painted in this report. Their left ears look very potent in chord identification. The mirror-image phenomenon is true for dichotic nonsense syllables. If subjects report only responses in which they have confidence, then the right ear advantage is much larger than it is when two responses per dichotic presentation are required. Possible reasons for these behaviors are not relevant here, but it is important to emphasize that performance scores for dichotic materials on the VA-CD reported in this series of articles apply only to situations where the subject/patient must respond twice to a presentation, even if she/he thinks it is a guess.

Acknowledgment. Gratitude is extended to Norma Antonanzas, M.A. and Amy Schaefer, M.A. for their help.

The other three authors acknowledge the critical role Brad Friedrich played in this line of inquiry. Brad is very much missed by his many friends.

REFERENCES

American National Standards Institute. (1989). *Specifications for Audiometers.* (ANSI S3.6-1989). New York: ANSI.

Apel W. (1960). *Harvard Dictionary of Music.* Cambridge: Harvard University Press.

Friedrich B. (1975). *Perception of Dichotic Simultaneous and Time-Staggered Synthetic Musical Chords.* Unpublished dissertation, Northwestern University, Evanston, Illinois.

Gordon H. (1970). Hemispheric asymmetries in the perception of musical chords. *Cortex* 6:387–398.

Kimura D. (1964). Left-right differences in the perception of melodies. *Q J Exp Psychol* 16:355–358.

King F, Kimura D. (1972). Left-ear superiority in dichotic perception of vocal, non-verbal sounds. *J Psychol (Canada)* 26:111–116.

Noffsinger D. (1985). Dichotic-listening techniques in the study of hemispheric asymmetries. In: Benson DF, Zaidel E, eds. *The Dual Brain.* New York: Guilford, 127–141.

Noffsinger D, Martinez C, Wilson R. (1994a). Dichotic listening to speech: background and preliminary data for digits, sentences, and nonsense syllables. *J Am Acad Audiol* 5:248–254.

Noffsinger D, Wilson R, Musiek F. (1994b). Department of Veterans Affairs compact disc (VA-CD) recording for auditory perceptual assessment: background and introduction. *J Am Acad Audiol* 5:231–235.

Olson H. (1952). *Musical Engineering.* New York: McGraw-Hill, 38–58.

Schweiger A. (1985). Harmony of the spheres and the hemispheres: the arts and hemispheric specialization. In: Benson DF, Zaidel E, eds. *The Dual Brain.* New York: Guilford, 359–374.

Sidtis J. (1982). Predicting brain organization from dichotic listening performance: cortical and subcortical functional asymmetries contribute to perceptual asymmetries. *Brain Lang* 17:287–300.

Sidtis J, Gazzaniga M. (1981). Complex pitch perception after colossal section: further evidence for a right hemisphere mechanism. *J Acoust Soc Am* 69:S119.

Spellacy F. (1970). Lateral preference in the identification of patterned stimuli. *J Acoust Soc Am* 47:574–584.

Van Lancker D, Fromkin V. (1973). Hemispheric specialization for pitch and "tone": evidence from Thai. *J Phonetics* 1:101–109.