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Interactions of Age, Ear, and Stimulus Complexity on Dichotic Digit Recognition

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Abstract

The effect that the aging process has on recognition performance was studied using a hierarchy of 1-pair, 2-pair, 3-pair, and 4-pair dichotic digits (1, 2, 3, 4, 5, 6, 8, 9, and 10, male speaker). Two groups of right-handed subjects were studied: 20 adults <30 years of age with normal hearing and 20 adults 60–75 years with mild-to-moderate hearing loss. Each of the multipaired sets contained the 72 possible 1-pair digit combinations in each presentation position with no digits repeated in a set. A three-way analysis of variance with repeated measures indicated three significant differences. First, as the complexity of the listening task increased from 1 pair to 2 pairs to 3 pairs to 4 pairs, recognition performance decreased systematically and significantly. The decreases in performance between the 1- and 4-paired conditions were larger for the left ear than for the right ear and were larger for the 60–75 years group than for the <30 years group. Second, performance on the materials presented to the right ear was significantly better than performance on the materials presented to the left ear. Third, recognition performance by the <30 years group was significantly better than recognition performance by the 60–75 years group. Recognition performance on the 1-pair condition was near maximum for both subject groups. Between the 1- and 4-paired conditions, recognition performance for materials presented to the left and right ears decreased 15.7 percent and 10.0 percent, respectively, in the <30 years group and decreased 29.3 percent and 15.7 percent, respectively, in the 60–75 years group.

Key Words: Auditory perceptual assessment, dichotic digits, word recognition

Since the introduction of dichotic digits by Broadbent (1954) and the subsequent refinement by Kimura (1961) and Bryden (1963), dichotic speech materials in one form or another have become a component of many of the auditory perceptual assessment test protocols. In addition to dichotic digits, dichotic consonant-vowel (CV) nonsense syllables were introduced 20 years ago (Berlin et al, 1973), followed more recently by dichotic sentence materials (Fifer et al, 1983). (A review of the dichotic literature is provided by Hugdahl [1988].)

Depending on the dichotic stimuli, right-handed subjects typically have better recognition/identification performance on materials presented to the right ear than on materials presented to the left ear. The magnitude of the so-called "right-ear advantage" is dependent upon the difficulty of the listening task, ranging from less than 10 percent with dichotic digit sets to around 15 percent with dichotic CV sets. The effect that the aging process has on recognition performance on dichotic materials is unclear. For example, with 3-paired dichotic digits and a biased response mode, Clark and Knowles (1973) reported that recognition performance on materials presented to the left ear declined as a function of age, whereas performance on materials presented to the right ear was constant as a function of age. On the dichotic CV task using an identification response, right-ear advantages around 12.5 percent were observed for both young (mean age = 23.6 years) and older (mean age = 66.6 years) groups (Gelfand et al, 1980). The older group, however, had normal pure-tone sensitivity that may reflect a subgroup of older individuals that are not typical of that age group. Using a 2-paired dichotic digit paradigm and a free-recall response, Martin and Cranford (1991) reported that combined right- and left-ear scores were 13 percent better (significant) with a young group of subjects

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(96.5%) than with an older group of subjects (82.9%); right-ear and left-ear scores were not reported. Jerger et al (1994) retrospectively examined dichotic sentence scores, in both free-report and directed-report modes, in 356 individuals ranging in age from 9 to 91 years. In both modes, the right-ear advantage, or left-ear disadvantage, increased systematically with age, from less than 2 percent in the youngest group to more than 30 percent in the oldest group.

The present study examined the effects that the aging process had on recognition performance of a hierarchical set of dichotic digits that ranged in complexity from easy (1-paired digits) to difficult (4-paired digits). The use of a hierarchical set of dichotic digits enables a range of recognition performances to be investigated that will be useful in differentiating the perceptual abilities of various subjects and subject groups. An inverse relation between stimulus complexity and recognition performance has been demonstrated. As the complexity of the listening task increases from easy to difficult, recognition performance decreases systematically (Bryden, 1963). Recognition performance on 1-paired digits should be near 100 percent correct for subjects with normal hearing (Noffsinger et al, 1994) and for subjects with peripheral hearing loss (Speaks et al, 1985). In comparison to the 1-paired digit data, the Bryden study suggests that, with 4-paired digits, a 20 percent decrease in recognition performance can be anticipated.

METHOD

Because of their availability as digital files, the digits (1, 2, 3, 4, 5, 6, 8, 9, and 10, spoken by a male) used on the *Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 1.0* compact disc (1992) were chosen as the materials. First, each of the nine files was edited so that the onset of the stimulus (the first voltage departure from baseline) coincided with the start of the data file. Second, a silent interval was concatenated to each stimulus data file to equalize the length of the files to 561 msec, which was the duration of the longest digit (9). Third, the files were interleaved to form the 72 possible combinations of the nine digit pairs with no digits repeated within a pair. These 72 digit pairs formed the 1-pair dichotic stimulus sets. Fourth, a 500-msec silent interval, which served as the interdigit interval for the multipair digit sets, was concatenated to the end of each 1-pair dichotic digit file. Finally, the 2-pair, 3-pair, and 4-pair files were constructed by concatenating as required two, three, and four of the interleaved 1-pair dichotic digit files. The following two rules were used in the compilation of each multipair digit list: (1) no digit was repeated in a stimulus set and (2) each of the 72 1-pair dichotic sets was used (randomly) once in each presentation position (e.g., with the 2-pair list, the "6–9" was used once as the first pair of a stimulus set and once as the second pair of a different stimulus set). The materials then were output from a 16-bit digital-to-analog converter (Antex, Model SX-10) and recorded on digital audio tape (DAT) (Sony, Model PCM 2500A,B) with 4-, 6-, 6-, and 8-sec interstimulus intervals for the 1-, 2-, 3-, and 4-pair stimuli, respectively. For each of the four stimulus lists, 10 practice stimulus sets (test items #63–72 in reverse order) preceded the 72 test items.

Two groups of 20 right-handed subjects served in the 1-hour protocol. Questioning established that all subjects wrote, threw, and ate with their right hands. The <30 years group (mean age = 21.0 years), who had hearing thresholds ≤20 dB HL (ANSI, 1989) at the octave intervals, was tested at the East Tennessee State University Hearing Clinic. At the University, the materials were presented from a DAT (Sony, Model 75ES) through an audiometer (Beltone, Model 2000) to TDH-50 earphones encased in P/N 510C017-1 cushions. The 60–75 years group (mean age = 63.4 years), who had mild-to-moderate high-frequency hearing losses (see Table 1 for the mean audiogram), was tested at the Auditory Research Laboratory in the VA Medical Center. At the VA, the materials were presented from a DAT (Sony, Model DTC-59ES) through an audiometer (Grason-Stadler, Model 10) to TDH-50P earphones encased in P/N 510C017-1 cushions.

For both subject groups, the materials were presented at 70 dB HL and the presentation order was always 1 pair to 4 pair, with the 10 practice items used with each set of materials. Presenting the 1-pair condition first accomplished two things. First, the subjects demonstrated that they could recognize correctly the stimulus items, thereby ensuring that peripheral hearing loss did not degrade recognition performance. Second, the subjects demonstrated that they could perform the dichotic listening task. The subjects were instructed to respond using a free-recall paradigm following each set of stimuli pairs (e.g., with the 3-pair condition, the responses were following presentation of the six stimuli). The verbal responses of the

Table 1 Mean Thresholds (dB HL)* and Standard Deviations for the 20 Subjects in the 60–75 Years Group

	Frequency (Hz)						
Ear	250	500	1000	2000	3000	4000	6000
Left	14.3 (8.8)	15.8 (8.4)	14.0 (8.6)	18.5 (13.9)	34.3 (16.4)	40.0 (20.9)	54.5 (19.8)
Right	16.5 (9.6)	19.0 (9.4)	17.3 (9.8)	19.0 (14.1)	29.8 (16.7)	38.0 (19.1)	52.0 (20.8)

*ANSI, 1989.

subjects were recorded (Marantz, Model PMD221) and scored by two audiologists.

RESULTS AND DISCUSSION

The mean performances by presentation position (1, 2, 3, and 4) for the left ear (open symbols) and right ear (filled symbols) are plotted in Figure 1 with the mean number of correct responses on the left ordinate and the corresponding percent correct recognition on the right ordinate. In the figure, data from the four stimulus conditions are depicted (1 pair—diamonds, 2 pair—circles, 3 pair—squares, and 4 pair—triangles) for the <30 years group (top panel) and the 60–75 years group (bottom panel). The corresponding descriptive statistics for the data in Figure 1 are listed in Tables 2 to 5. A three-way analysis of variance (ANOVA) (condition [4] by ear [2] by subject group [2]) with repeated measures was used to examine the data. For this analysis, the data across presentation positions were averaged for each subject for the 2-, 3-, and 4-pair conditions. The data in Figure 1 and Tables 2 to 5 and the results of the ANOVA indicated three significant main effects.[1] First (condition effects), as the dichotic task progressed from 1-pair stimuli to 4-pair stimuli there was a systematic and significant decrease in correct recognition performance ($F [3, 114] = 166.3$; $p = .0001$). Second (ear effects), recognition performance on the material presented to the right ear was significantly better than the recognition performance on the material presented to the left ear ($F [1, 38] = 24.5$; $p = .0001$). Third (group effects), the recognition performance by the <30 years group was significantly better than the recognition performance by the 60–75 years group ($F [1, 38] = 31.6$; $p = .0001$). These overall findings, three significant interactions from the ANOVA, and a discussion of response patterns are detailed in the subsequent sections.

[1]The .05 level is used as significant throughout this report.

Condition Effects

The recognition performances on the materials presented to the left and right ears were averaged for each of the paired conditions across the presentation positions and were tabulated for both of the subject groups. The mean percent correct data (and standard deviations) from this tabulation are listed in Table 6 and are illustrated in Figure 2. In the figure, the right-ear (circles and solid lines) and left-ear (triangles and dashed lines) data for the <30 years group (open symbols) and 60–75 years group (filled symbols) are depicted. The lines through the datum points are linear regressions fit to the data.[2] From the ANOVA described earlier, both the condition by subject interaction ($F [3,114] = 12.9$, $p = .0001$) and the ear by condition interaction ($F [3,114] = 12.1$, $p = .0001$) were significant. The results from the ANOVA and the data from both subject groups indicate that, as the complexity of the listening task increased from easy (1-pair) to difficult (4-pair), there was a corresponding significant decrease in recognition performance. For both subject groups, the percent correct recognition decreased more between the 1-pair and 4-pair conditions for the materials presented to the left ear than for the materials presented to the right ear. For the <30 years group, (1) the slope of the function for the left ear (−5.36%/pair) was nearly twice the slope of the function for the right ear (−3.50%/pair) (see Fig. 2); and (2) the decrease in recognition performance was 15.7 percent for the left ear between the 1-pair (99.2% correct) and the 4-pair

[2]The equations for the linear regressions are as follows:
(1) <30 years group, right ear
($y = 104.25 - 3.50x$ [$r^2 = 0.96$]),
(2) <30 years group, left ear
($y = 106.20 - 5.36x$ [$r^2 = 0.94$]),
(3) 60–75 years group, right ear
($y = 104.95 - 5.48x$ [$r^2 = 0.98$]), and
(4) 60–75 years group, left ear
($y = 108.85 - 10.16x$ [$r^2 = 0.98$]).

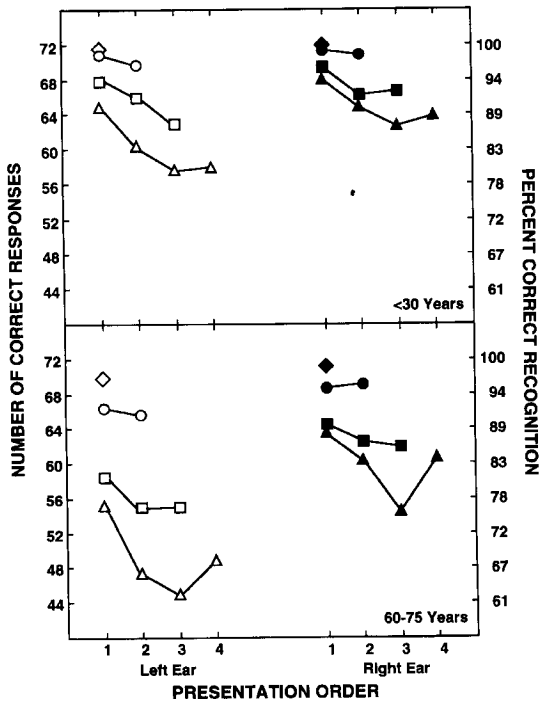

Figure 1 The mean number of correct responses (n = 72) (left ordinate) and the percent correct recognition (right ordinate) for the 1 pair (diamonds), 2 pair (circles), 3 pair (squares), and 4 pair (triangles) dichotic digits presented to two groups of 20 subjects (<30 years group—upper panel; 60–75 years group—lower panel).

(83.5% correct) conditions, whereas the same comparison for the right ear was 10 percent (see Table 6). Similar differences between performances on 1- and 4-pair dichotic digits (18% left ear and 13% right ear) were reported on 155 right-handed children using a selective listening task (Hiscock and Kinsbourne, 1980). Larger decreases in recognition performance were observed between the easy and difficult listening tasks with the 60 to 75 years group than with the <30 years group. With the 60–75 years group, the slope of the function for the left ear (−10.16%/pair) was nearly twice the slope of the function for the right ear (−5.48%/pair), with a 29.3 percent decrease in the left ear between the 1-pair (97.1% correct) and the 4-pair (67.8% correct) condition, and a 15.7 percent decrease in the right ear between the 1- and 4-pair conditions. Thus, in the current study, increasing the complexity of the listening task was more detrimental (1) to the recognition of the material presented to the left ear than to the recognition of the material presented to the right ear, and (2) to the 60–75 years group than to the <30 years group.

A final note of interest from the data in Figure 1 is the morphology of the functions for the

Table 2 Mean Percent Correct Recognition and Standard Deviation by Ear to 1-pair Dichotic Digits for the <30 Years and 60–75 Years Subject Groups

Statistic	*Left Ear*	*Right Ear*
<30 years group		
Mean	99.2	99.9
SD	1.1	0.4
60–75 years group		
Mean	97.1	98.9
SD	2.7	1.4

n = 20.

Table 3 Mean Percent Correct Recognition and Standard Deviation by Ear and by Presentation Position (1 and 2) to 2-pair Dichotic Digits for the <30 Years and 60–75 Years Subject Groups

Statistic	*Left Ear*		*Right Ear*	
	1	*2*	*1*	*2*
<30 years group				
Mean	98.3	96.7	98.9	98.3
SD	2.1	3.7	2.1	2.9
60–75 years group				
Mean	91.9	90.8	95.1	95.6
SD	7.3	7.0	3.4	4.1

n = 20.

Table 4 Mean Percent Correct Recognition and Standard Deviation by Ear and by Presentation Position (1, 2, and 3) to 3-pair Dichotic Digits for the <30 Years and 60–75 Years Subject Groups

Statistic	*Left Ear*			*Right Ear*		
	1	*2*	*3*	*1*	*2*	*3*
<30 years group						
Mean	94.2	91.5	87.4	96.3	92.0	92.6
SD	6.4	7.2	8.1	6.5	12.5	6.6
60–75 years group						
Mean	80.9	76.3	75.5	89.9	87.2	85.8
SD	12.7	14.2	15.9	10.1	8.3	11.4

n = 20.

Table 5 Mean Percent Correct Recognition and Standard Deviation by Ear and by Presentation Position (1, 2, 3, and 4) to 4-pair Dichotic Digits for the <30 Years and 60–75 Years Subject Groups

Statistic	Left Ear				Right Ear			
	1	2	3	4	1	2	3	4
<30 years group								
Mean	89.9	83.7	79.9	80.3	94.4	90.0	86.9	88.5
SD	12.1	14.0	13.8	10.0	10.3	10.7	10.6	8.9
60–75 years group								
Mean	76.5	65.6	62.4	66.8	88.8	84.2	76.1	83.8
SD	15.0	12.4	13.0	15.3	10.7	11.1	16.6	12.6

n = 20.

4-pair mean recognition data, especially the data for the 60–75 years group. The "U-shaped" function is probably reflecting the "serial-position curve" described in the memory literature (Murdock, 1962; Bartz, 1968; Jahnke, 1968). The serial-position curve is characterized by a primacy effect and a recency effect that encompass the first presentation positions and the last presentation positions, respectively. With the current data, the decreasing performance over the initial presentation positions coincides with the primacy portion of the serial-position curve and the increased performance observed with the fourth presentation position coincides with the recency effect. The serial-position curve was not clearly defined with the 4-pair data from the <30 years group. One may speculate that the scores from the <30 years group were not sufficiently depressed to evoke the primacy and recency effects that are thought to underlie the U-shaped curve.

Ear Effects

As was indicated earlier, for both subject groups, recognition performance on the material presented to the right ear was significantly better than the recognition performance on the material presented to the left ear. The data in Table 6 and Figure 2 and the significant ear by group interaction from the ANOVA ($F\ [1,38] = 5.8$, $p = .021$) indicate that performance on materials presented to the right ears of the two subject groups was more similar than was performance on the materials presented to the

Table 6 Overall Mean Correct Recognition Scores in Percent (and Standard Deviations) by Dichotic Pair Condition and by Ear for the <30 Years and 60–75 Years Subject Groups

Condition	Right Ear	Left Ear	Difference
<30 years group			
1 pair	99.9 (0.4)	99.2 (1.1)	0.6 (1.0)
2 pair	98.6 (2.1)	97.5 (2.7)	1.1 (2.4)
3 pair	93.6 (7.8)	91.0 (5.9)	2.6 (9.1)
4 pair	89.9 (8.4)	83.5 (10.3)	6.5 (13.7)
60–75 years group			
1 pair	98.9 (1.4)	97.1 (2.7)	1.8 (2.7)
2 pair	95.3 (3.2)	91.3 (6.6)	4.0 (5.2)
3 pair	87.6 (9.0)	77.6 (12.1)	10.1 (14.0)
4 pair	83.2 (10.4)	67.8 (10.3)	15.4 (15.2)

n = 20.
The mean differences (RE–LE) are also listed.

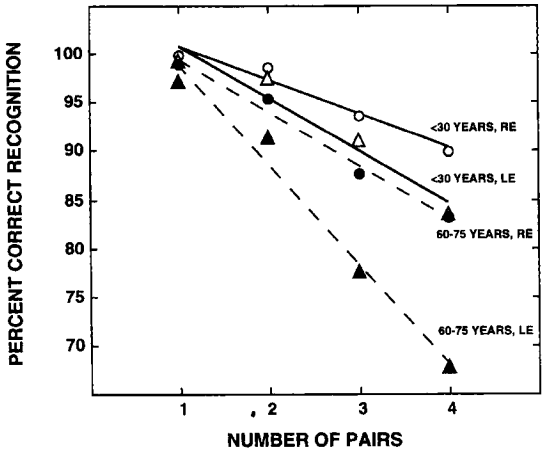

Figure 2 Mean percent correct recognition by ear (circles, right ear; triangles, left ear) and by subject group (open symbols and solid lines, <30 years group; closed symbols and dashed lines, 60–75 years group) as a function of the number of dichotic digit pairs (1 to 4).

left ears of the two subject groups. From Figure 2, the slopes of the functions for the right ears of the <30 years group and the 60–75 years group were −3.50 percent/pair and −5.48 percent/pair, respectively, whereas the slopes of the functions for the left ears of the two groups were −5.36 percent/pair and −10.16 percent/pair, respectively. Thus, for each of the paired conditions, the right-ear difference between the two subject groups was smaller than the left-ear difference. Further, there is a direct relation between the magnitude of the ear difference and complexity of the listening task. With the 1-pair condition, the mean data for the right ears of the two subject groups (see Table 6) were minimally different (1%); the same was true for the left-ear data (2%). By the 4-pair condition, the right ears of the two subject groups differed by 6.7 percent, whereas the left-ear difference between the two groups was 15.7 percent. Thus, performance by the 60–75 years group on materials presented to the right ear was more resilient to degradation than was performance on materials presented to the left ear. As the pure-tone thresholds of the 60–75 years group were symmetrical (see Table 1), the difference in recognition performances on the materials presented to the ears of the subjects in the 60–75 years group cannot be attributable to hearing loss. One may speculate that this ear differential, which increases with complexity of the listening task, is the result of decreased neural processes and neural efficiency in the 60–75 years group that had more effect on inputs to the left auditory periphery and right cortical mechanism than on inputs to the right auditory periphery and left cortical mechanism.

Response Patterns

The response patterns, that is, the order of report or the order in which the subjects responded to each stimulus set, were analyzed for each subject and are listed in Table 7. Because of the uncertainty created by two or more errors in a response to a stimulus set, only the response patterns with one error or less were evaluated. For the 1-pair and 2-pair conditions, all of the response patterns were tabulated. For the 3-pair and 4-pair conditions, however, only the four most systematic response patterns were analyzed. The 1-pair data indicate that 60 percent of the initial responses were to the stimuli presented to the right ear, whereas 40 percent of the initial responses were to stimuli presented to the left ear. Although not listed in Table 7, this same 60 percent/40 percent pattern was observed with the first responses to each of the multipair stimuli.

The analysis of the response patterns with the 2-, 3-, and 4-pair conditions listed in Table 7 revealed that no response pattern dominated. With the 2-pair condition, the response patterns ranged from 28.8 percent for the RLRL pattern (<30 years group) to 7.8 percent for the LRLR pattern (60–75 years group). With the 3- and 4-pair conditions, the response patterns are substantially varied with the most frequent response pattern (12.4% to 22.9%) involving RRRLLL and RRRRLLLL, respectively, for the two conditions. Finally, from Table 7, it is perhaps noteworthy with the 2-, 3-, and 4-pair conditions that the 60–75 years subjects tended to group their responses by ear more than did the <30 years subjects. For example, with the 2-pair condition, the 60–75 years subjects responded with the RRLL or LLRR pattern about 50 percent of the time, whereas the <30 years subjects used the RRLL or LLRR pattern only about 22 percent of the time. Similarly, with the 3-pair condition, the 60–75 years subjects responded

Table 7 Percentage Order of Report by Response Pattern for the Four Paired Conditions and Two Subject Groups

Pair/Pattern	*<30 Years*	*60–75 Years*
1 pair		
RL	61.5	58.3
LR	38.2	41.7
2 pair		
RRLL	13.0	25.3
LLRR	9.3	26.6
RLRL	28.8	14.3
LRLR	14.2	7.8
RLLR	17.1	11.6
LRRL	17.4	13.3
3 pair		
RRRLLL	12.4	22.9
LLLRRR	9.0	16.9
RLRLRL	11.3	4.4
LRLRLR	5.3	2.8
4 pair		
RRRRLLLL	15.0	19.6
LLLLRRRR	4.5	10.3
RLRLRLRL	2.4	1.9
LRLRLRLR	1.5	0.1

The 1-pair and 2-pair conditions have all response pair patterns, whereas the 3-pair and 4-pair conditions have only the most systematic response patterns listed.

with a RRRLLL or LLLRRR pattern about 40 percent of the time, whereas the <30 years subjects responded with the RRRLLL or LLLRRR pattern about 21 percent of the time. These findings indicate that the response strategies of the two groups differ, with the 60–75 years subjects more focused than the <30 years subjects on sequential responses to the input channels (i.e., responses to all of one input channel and then responses to all of the second input channel).

SUMMARY

The data from this study, based on a hierarchy of 1-pair, 2-pair, 3-pair, and 4-pair dichotic digits, indicate the following for right-handed subjects:

1. Recognition performance on materials presented to the right ear is better than recognition performance on materials presented to the left ear.
2. Recognition performance by the <30 years group was better than recognition performance by the 60–75 years group.
3. Recognition performance decreases systematically as the complexity of the task increases from easy (1-pair) to difficult (4-pairs) on materials presented to either ear. With both subject groups, however, the decrease in performance with increased complexity was more on the materials presented to the left ear than on materials presented to the right ear.
4. Recognition performance by the <30 years group and the 60–75 years group on materials presented to the right ears was much more similar than was recognition performance on materials presented to the left ears. Thus, the right-ear advantage exhibited by the 60–75 years group was larger than the right-ear advantage exhibited by the <30 years group.

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