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AUDITORY S-R COMPATIBILITY:

THE EFFECT OF AN IRRELEVANT CUE ON INFORMATION PROCESSING

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2 experiments demonstrated the existence of a strong population stereotype which affected the processing of verbal commands In a choice RT task, Ss pressed the right- or left-hand key in response to the words "right" or "left" which were presented to the right or left ear. RT was significantly faster when the content of the command corresponded to the ear stimulated than when it did not, i e, information processing was affected by a cue irrelevant to the task itself, the ear in which the command was heard Removing S's uncertainty regarding the ear to be stimulated resulted in significantly faster RT, and reduced but did not eliminate the effect of the irrelevant directional cue

A fundamental problem in man-machine system design is that of integrating display and control elements so that the information presented can be processed efficiently into appropriate control action. To facilitate information processing, the human engineer seeks to conform to population stereotypes; that is, he designs displays so that they give a "natural" indication of the correct response This occurs, for example, when the spatial arrangement of the display corresponds with that of the control (Fitts & Seeger, 1953; Garvey & Mitnick, 1955). Fitts and Seeger use the term S-R compatibility in referring to the extent to which the ensemble of stimulus and response combinations comprising the task results in a high rate of information transfer.

Up to now, the concepts of stereotype and compatibility have been applied almost exclusively in the realm of visual displays (Fitts, 1951; Loveless, 1962; McCormick, 1964). A notable exception is a study by Mudd (1963) which demonstrates that dimensions of pure tone (frequency, intensity, and interaural intensity difference) have a natural tendency to be associated with horizontal and vertical dimensions of space. Mudd's research has been concerned with reducing visual search time by providing *S* with additional relevant auditory cues (Mudd, 1965; Mudd & McCormick, 1960). The concern of the present study is with auditory S-R compatibility, that is, the role of irrelevant directional cues imbedded in the auditory display itself which interfere with information processing. Data to be presented indicate that the interpretation of a verbal directional command is affected by the ear in which the command is heard.

The major findings of the present study provide an excellent example of serendipity The original purpose of this study was to investigate the interaction between ear stimulated and handedness in an auditory reaction-time (RT) task. A number of recent studies indicate that the right ear is more efficient than the left in perceiving verbal materials under dichotic listening conditions, that is, simultaneous presentation of different stimuli to both ears (Broadbent & Gregory, 1964 Bryden, 1963; Kimura, 1961b, 1963). This greater right-ear effectiveness has not been interpreted to indicate right-ear superiority *as such* but rather the superiority of the ear opposite the dominant hemisphere for speech Kimura (1961a) found that, when speech was represented in the left hemisphere, the right ear was more efficient, but, when speech was represented in the right hemisphere, the left ear was more efficient. The aim of the present study was to extend these dichotic listening results to a monaural RT task. It was predicted that right-handed *S*s (presumed to be almost exclusively left-hemisphere dominant) would respond faster to a verbal command in their right ear than in their left, whereas left-handed *S*s (a majority presumed to be right-hemisphere dominant) would tend to respond faster to commands in the left ear.

EXPERIMENT I

Apparatus The apparatus provided a measure of choice RT to a series of monaural verbal commands which were presented to *S* through Grason-Stadler TDH-39 matched earphones Two telegraph keys were positioned 10 in apart on a table surface in front of *S* Instructions were to depress the right key as quickly as possible after hearing the word "right" and to depress the left key as quickly as possible after hearing the word "left" The *S* rested his forearms on the table surface and, upon the onset of a ready signal, placed his index fingers on the keys The ready signal was presented 2 sec prior to each command and consisted of the simultaneous onset of a warning light and a 1000-cps, 50-db binaural tone of 500-msec duration. A Hunter KlocKounter started when the command was presented and stopped when *S* pressed the key Depressing the key also signaled *E* as to which key had been pressed The instructions and verbal commands were recorded on tape and presented at 70 db by a Sony TC 500 Stereocorder There was a 6-sec interval between commands

Procedure and experimental design Each *S* responded to the same series of 132 prerecorded commands, each command consisting of the word "right" or the word "left" The commands were presented to either the right ear or the left ear in a predetermined random sequence The *S* had no way of knowing, prior to the presentation of each command, which ear would be stimulated or what the command would be The first eight trials were practice trials in which the "right" and "left" commands were presented twice to each ear in a random order For half of the *S*s in each Sex × Handedness subgroup the earphones were reversed in order to balance out any differences which may have existed between the two stimulus channels

Subjects. Two groups were used, one of 48 self-classified strongly right-handed *S*s and the other of 32 self-classified strongly left-handed *S*s The *S*s ranged in age from 18 to 28 (average age 19 7). There was an equal number of males and females in each handedness group The *S*s all passed a standard audiometric screening test in which pure tones of 500, 1000, and 2000 cps were presented to each ear separately No *S* had a hearing loss greater than 10 db at any one of the three frequencies tested Each *S* also responded to a short handedness-questionnaire indicating the hand he used to write, turn a screwdriver, throw a ball, hold a toothbrush, and swing a tennis racket All of the right-handed *S*s reported that they used their right hand exclusively for these activities while three left-handed *S*s reported using their right hand for one of the five activities queried

Results Median RTs were computed for each *S* for each of the four experimental conditions, that is, "right" and "left" commands in the right and in the left ear Trials on which anticipations or incorrect responses occurred (about 1% of the trials) were omitted

Table 1 summarizes the mean RT under each treatment condition for each Sex × Handedness subgroup Analysis of variance revealed no differences as a function of the main effects of ear stimulated, command, or handedness group There was, however, a significant difference between the sex groups—$F(1/76) = 5.02$, $p < .05$—with males responding faster than females (391 versus 426 msec)

The predicted Ear Stimulated × Handedness interaction was not significant—$F(1/76) = 1.95$, although, as Table 1 indicates, the differences were in

TABLE 1

REACTION TIME TO VERBAL COMMANDS AS A FUNCTION OF EAR STIMULATED, HANDEDNESS, AND SEX

Group	Ear stimulated	Males			Females			*M* ear stimulated
		Command			Command			
		"Right"	"Left"	*M*	"Right"	"Left"	*M*	
Right handers	Right ear	363	413	388	400	441	421	404
	Left ear	411	375	393	445	406	426	409
	M	387	394	391	423	424	423	407
Left handers	Right ear	377	406	391	426	434	430	411
	Left ear	427	352	390	458	400	429	409
	M	402	379	390	442	417	429	410
M of handedness groups combined		393	388	391	430	421	426	

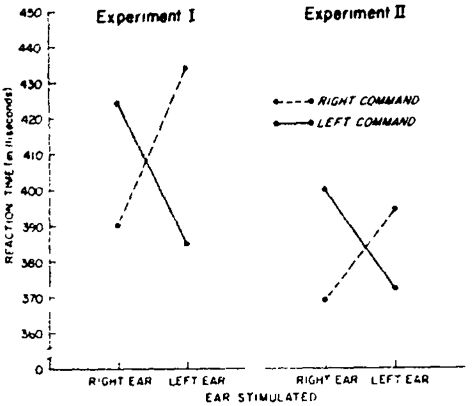

FIG. 1 Effect of ear stimulated on RT to verbal directional commands

the expected direction with right-handers tending to respond faster to right-ear stimulation and left-handers showing the opposite tendency A chi-square analysis indicated that a significant proportion of the right-handed group (32/48) responded faster on the right-ear trials than on the left-ear trials ($\chi^2 = 4\ 68$, $p < 05$) There was no tendency, however, among left-handed *Ss* to favor the left ear (15 were faster on the left-ear trials, 15 were faster on the right, and there were 2 ties), so the handedness groups did not differ significantly in the relative proportion of *Ss* showing right-ear superiority ($\chi^2 = 2\ 34$; $p > .10$) The analysis of variance revealed a significant Command $\times$ Handedness interaction—$F(1/76) = 11\ 82$, $p < 01$—which reflects the fact that right-handers tended to respond faster to the "right" command (i e, with their right hand), and left-handers tended to respond faster to the "left" command (i e, with their left hand)

By far the most conspicuous result was the significant Command $\times$ Ear Stimulated interaction—$F(1/76) = 226\ 50$, $p < 001$ The left half of Figure 1 pictures this effect It will be noted that RT was markedly faster when the "right" command was heard in the right ear than when it was heard in the left ear (390 versus 434 msec) Similarly, RT to the "left" command was faster when it was heard in the left ear than when it was heard in the right ear (385 versus 424 msec)

EXPERIMENT II

The purpose of this experiment was to determine whether the irrelevant cue noted in Experiment I (i e, ear stimulated) would continue to affect RT if *S* knew which ear would be stimulated prior to presentation of the command It was conjectured that, as a result of removing *S*'s uncertainty as to the source of the command, the variance contributed by this irrelevant cue would be eliminated and the hypothesized interaction between ear stimulated and handedness might then be detected.

Apparatus, procedure, and experimental design The apparatus was the same as that used in Experiment I The procedure, however, differed in that trials were presented in blocks rather than in the random ear order employed previously. Each *S* performed on two blocks of trials, one block in which the commands were presented to his right ear and the other block in which the commands were presented to his left ear. Instructions prior to each block of trials stressed the fact that *S* would hear the commands in his right ear *only* or in his left ear *only* as the case may be. Each block consisted of 62 test trials appearing at 5-sec. intervals in which the word "right and the word "left' appeared an equal number of times in a predetermined random sequence Each block was preceded by four practice trials consisting of two "right" commands and two "left" commands The instructions and verbal commands were prerecorded and presented at 70 db

The design was an extension of a Type VI (Lindquist, 1953) with two between- and two within-*S* dimensions Half of the 16 *Ss* in each Sex $\times$ Handedness subgroup performed the right-ear trials first while the other half performed the left-ear trials first By simply reversing the headset, the same random series of commands was used for both right- and left-ear blocks of trials

Subjects The *Ss* were 64 University of Iowa undergraduate volunteers between the ages of 18 and 29 (average age 20 0) Two groups were used one consisted of 32 strongly right-handed *Ss* and the other of 32 strongly left-handed *Ss*. There were 16 men and 16 women in each group

All *Ss* were given a standard audiometric screening test, and none had a hearing loss greater than 10 db at any one of three "speech" frequencies 500, 1000, and 2000 cps The *Ss* then completed the same handedness-questionnaire that was used in Experiment I All of the right-handed *Ss* and 26 left-handed *Ss* reported using their preferred hand exclusively for the 5 activities queried, whereas 6 left-handed *Ss* reported using their right hand or either hand for 1 or 2 of the tasks

Results Median RTs were computed for each *S* under the four experimental conditions, that is "right" and "left" monaural commands in the right and left ear Analysis of variance provided no evidence of the predicted Ear Stimulated $\times$ Handedness interaction There were also no differences due to the main effects of ear stimulated, command, or handedness group The Command $\times$ Handedness interaction, which was significant in Experiment I, was not replicated Males tended to respond faster than females (372 versus 396 msec.), but the difference failed to reach an acceptable level of significance—$F(1/60) = 2\ 64$, $p > 10$ The difference between right- and left-ear trials was different for males than for females—$F(1/60) = 5\ 98$; $p < .05$

As in Experiment I, the major source of variance was the Command × Ear Stimulated interaction—$F(1/60) = 83.46$; $p < .001$—which is pictured in the right half of Figure 1. It will be noted that the compatible reactions, that is, "right" in the right ear and "left" in the left ear, were significantly faster than the incompatible reactions, that is, "right" in the left ear and "left" in the right ear. Mean RT for the two compatible conditions was 371 msec versus 397 msec. for the two incompatible conditions.

Comparison of Experiments I and II. Figure 1 facilitates a comparison of the results of the two experiments. To reiterate, the major difference in procedure between the two was that, in the latter experiment, instructions were used to remove *S*'s uncertainty regarding the ear in which the command would appear. In the former experiment, on the other hand, *S* did not know prior to hearing the command which ear would be stimulated. An overall analysis of the combined data from the two experiments indicated that *S*s responded significantly faster in Experiment II than in Experiment I (384 versus 408 msec.)—$F(1/140) = 5.07$; $p < .05$. Figure 1 indicates that while both compatible and incompatible reactions were faster under the conditions of Experiment II, there was a relatively greater speedup of the incompatible reactions. This latter effect was reflected in a significant Command × Ear Stimulated Experiment interaction—$F(1/140) = 14.97$; $p < .001$. In the random ear order presentation employed in Experiment I, the average difference between compatible and incompatible reactions was 42 msec. This difference was reduced to 26 msec in Experiment II where *S*s were told in advance which ear would be stimulated.

DISCUSSION

Results clearly indicated that speed of processing verbal commands (i.e., the words "right" and "left") was affected by a cue irrelevant to the task itself, that is, the ear in which the command was heard. RT was significantly faster when the content of the command corresponded to the ear stimulated (i.e., "right" in the right ear or "left" in left ear) than when it did not (i.e., "right" in left ear and "left" in right ear). These results suggest the existence of a strong natural tendency to associate right-ear stimulation with a right-hand response and left-ear stimulation with a left-hand response. When the verbal command called for a response which corresponded to this population stereotype, *S*s responded rapidly. However, when conflict existed between the symbolic cue (content of command) and the irrelevant directional cue (ear stimulated), a marked delay in responding occurred. It was as if *S*s had to inhibit the stereotypic directional response before reacting to the symbolic content of the command.

The data underline the potency of the stereotype in question. The irrelevant cue was particularly influential in Experiment I where *S*s were uncertain as to which ear would be stimulated. Removing this uncertainty in Experiment II significantly reduced but by no means eliminated the effect.

Questions still remain as to the generality of the findings. Is the stereotype specific to a bimanual task such as the one employed in the present study where *S* responds with the body member on the same or the opposite side as the ear stimulated? Or would the same irrelevant cue operate in a unimanual task where, for example, *S* moves a lever to the right or left from the midline of his body in response to verbal commands?

Auditory displays have not been widely used for providing directional information in man-machine systems (McCormick, 1964). "Flybar" (Chapanis, Garner, & Morgan, 1947, ch. 9) represented an early attempt to provide pilots with spatial information by means of complex auditory signals. Present results suggest that additional basic studies are urgently needed. One potentially promising avenue for research would involve attempting to increase the speed of processing directional information from an auditory display by *utilizing* the cue provided by the ear stimulated. One wonders whether *S*s would respond faster to a combination of directional and symbolic cues ("right" command in the right ear or "left" in the left ear) than to directional or symbolic cues alone.

Other results bear mentioning because of their relation to previous research. The finding that men responded significantly faster than women supports the oft-noted tendency for male superiority on RT tasks (Teichner, 1954; Woodworth & Schlosberg, 1955). The tendency for the right-handed group to respond faster to right-ear stimulation is consistent with recent findings of ear preference in auditory perception (Borkowski, Spreen, & Stutz, 1965; Bryden, 1963; Dirks, 1964) and supports the view that *S*s tend to tune in with their right ear when they are uncertain as to which ear will be stimulated.

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