Serial order effects in auditory discrimination by oddity and matching to sample*

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The oddity method and several matching-to-sample procedures were used for frequency and intensity discrimination by adult Ss. For all sequence tasks involving three choices, the Ss employed a decision strategy which resulted in a pattern of correctness that differed from the pattern of discriminability among the choice sounds. It was concluded that the use of signal detection theory for analysis of results had added an important dimension to the study, and it was recommended that this method of analysis be used in further attempts to relate sequential processes to various forms of verbal impairment.

Since Lashley (1950) posed the problem of serial order in behavior, a number of investigators have attempted to relate verbal disabilities of children and adults to difficulties in dealing with sequences (cf. Efron, 1963; Furth, 1964; Stark, 1967; Aten & Davis, 1968; Doehring, 1968). However, the exact processes by which selective responses to sequences are made have not been specified.

Gibson (1966) describes perception as an active self-guided search, where both spatial patterns and temporal sequences are perceived in a unitary manner by means of a system that is tuned to invariant information. He disavows traditional theories of perception and memory which assume that the observer apprehends a sequence of stimuli by passively receiving each sensation, temporarily storing it in the form of a memory trace, and then later retrieving the traces to construct a simultaneous composite. Gibson's theory provides an intuitively appealing explanation of complex perceptual phenomena. As Sherrick (1967) has suggested, however, the means for empirically verifying the theory are not obvious.

Signal detection theory (SDT) has been successfully applied to the investigation of certain types of sequential processes (Banks, 1970). Although the studies are largely interpreted according to the traditional theoretical constructs decreed by Gibson, SDT does provide a means of separating the contribution of active decision processes from

perceptual and memory factors in the analysis of responses to sequences. The majority of studies have involved short-term recognition memory for temporal sequences of verbal stimuli. Several types of serial position effects have been found, depending on the exact task requirements (Norman, 1966; Wickelgren, 1967; Murdock, 1968; Norman & Waugh, 1968). Nonverbal sequence effects have been considered by Wickelgren (1969), who proposed an associative strength theory of recognition memory for pitch that separates acquisition, storage, and retrieval processes (involving perception, memory, and decision factors, respectively) in the analysis of same-different and high-low responses to two-tone sequences.

In a previous study by the present writer (Doehring, 1969), it was found that 6- to 12-year-old children discriminated the odd sound among a sequence of three nonverbal sounds most accurately when the odd sound was last. This position effect was found for both simple and complex sounds and was associated with a uniform distribution of incorrect responses. It was hypothesized that successive same-different judgments of the first and second and the second and third sounds were made, with the easiest oddity decision occurring when the first and second sounds were judged the same. Further investigations of position effects for nonverbal auditory sequences seemed worthwhile in order to determine if such simple explanations would suffice for other effects that might be observed with systematic variation of the multiple-choice discrimination paradigm.

The purposes of the studies reported here were to determine if the third-position effect in auditory oddity discrimination would occur in adult Ss, and also to determine what, if any, position effects would occur

when adult Ss were required to indicate which of a series of sounds matched a sample sound that either preceded or followed the multiple-choice sequence. The situation in which the sample precedes the choice sounds, usually designated as matching to sample, will be identified here as S-AB (two-choice matching) or S-ABC (three-choice matching). The situation where the sample follows the multiple choices, often designated as an ABX procedure, is identified here as AB-S or ABC-S. In both cases, S is the sample sound and AB or ABC are multiple-choice sounds, one of which matches the sample. Five groups of Ss were tested to assess position effect in three- and four-choice oddity and in two- and three-choice matching, with both frequency and intensity discrimination required. Sounds were presented monaurally in an attempt to determine if there was ear asymmetry (Kimura, 1961) for these nonverbal tasks.

METHOD

Five groups of paid adult Ss were tested. All had limited or no experience in previous auditory experiments and had no more than 20-dB deviation from audiometric zero (ISO) in either ear and no more than 10-dB difference between ears for the test tone frequencies. All Ss except one in Group 1 and two in Group 2 were right-handed in both writing and throwing.

On the oddity tasks, the S was presented with a sequence of three or four pure tones, one of which was either higher or lower than the others in either frequency or intensity. The remaining sounds were of the same frequency and intensity. The S pressed one of three or four numbered pushbuttons to indicate his judgment of the serial position of the odd sound and was given immediate knowledge of the correct position.

On the matching tasks, the S was presented with a sequence of three or four pure tones, one of which was the sample and occurred either at the beginning (S-AB and S-ABC matching) or the end (AB-S and ABC-S matching) of the series. The remaining sounds differed from each other in either frequency or intensity, and one of them (either the higher or the lower in two-choice matching, or the higher, middle, or lower in the three-choice matching) was the same as the sample sound. The S pressed one of two or three numbered pushbuttons to indicate his judgment of the serial position of the sound that matched the sample, and was given immediate knowledge of the correct position.

The experimental conditions for each group are summarized in Table 1.

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Table 1
Summary of Experimental Conditions for the Five Groups. Each S served under all conditions for his group.

Group	N	Task	Total Trials	Trials Per Position	Trials Per Series	Number of Series				Total
						Frequency Discrimination		Intensity Discrimination		
						R Ear	L Ear	R Ear	L Ear	
1	6	3-Choice Oddity	1,512	504	36	14	14	7	7	42
2	6	3-Choice Oddity	480	160	30	4	4	4	4	16
		S-AB Matching	480	240	30	4	4	4	4	16
		AB-S Matching	480	240	30	4	4	4	4	16
3	6	3-Choice Oddity	288	96	36	2	2	2	2	8
		S-ABC Matching	288	96	36	2	2	2	2	8
		ABC-S Matching	288	96	36	2	2	2	2	8
4	6	3-Choice Oddity	144	48	36	2	(Binaural Presentation)	2		4
		S-ABC Matching	144	48	36	2		2	4	
		ABC-S Matching	144	48	36	2		2	4	
5	8	4-Choice Oddity	288	72	24	3	3	3	3	12

Each S served under all conditions for his group. Each series of test trials was preceded by a set of practice trials. Within each series, only one ear was tested (except for Group 5, where all sounds were given binaurally), with one task for one type of discrimination at one level of difference between tones. The odd or matching sound was presented at each of the two or three different frequency or intensity values and in each of the two, three, or four serial positions on an equal number of trials, but the position and the value of the odd or matching sound was otherwise randomized.

Test stimuli were sequences of pure tones 1 sec in duration, with onset and decay times of 25 msec and interstimulus intervals of 1 sec. The tones were centered at 1,000 or 2,000 Hz in frequency and at 80 dB SPL in intensity. A Uher 22 Special tape deck was used for recording and playing back the tonal sequences at 3¾ ips. Either one or two pure-tone oscillators with associated electronic switches, attenuators, and pulse generators were used in conjunction with a semiautomatic switching system for recording. The two levels of test tone required for Group 1 were generated by setting the two oscillators at different frequencies or different intensities. For the remaining groups, a single beat-frequency oscillator was used with a clutch-operated synchronous motor that rotated the one-cycle increment control for frequency change and a stepping switch that added the necessary attenuation for intensity change. The latter arrangement eliminated the need for constant readjustment of oscillators during recordings. A vacuum tube voltmeter was used to monitor the output level during playback. The S listened through matched TDH 39 earphones. On each trial, the pressing

of any pushbutton lighted the pushbutton in the correct position, giving immediate knowledge of correctness. Responses were not permitted until all sounds in a sequence had been presented. There were no other restrictions on response time, but S usually responded within 2 sec after the last sound, resulting in an intertrial interval of about 4 sec. The various stimulus and response contingencies were controlled by a solid-state programming system.

All series for a given type of discrimination with a given task (e.g., frequency discrimination at 2,000 Hz by three-choice oddity) were given consecutively, beginning with the largest difference between tones presented to the two ears in successive series, and with the next smaller difference between tones presented in each subsequent pairs of series. The order of ears, tasks, and types of discrimination was counterbalanced among the Ss of each group.

Differences between choice sounds employed for each group are shown in Table 2. On oddity tasks the odd sound was either higher or lower than the remaining sounds by the amounts shown. In two-choice matching, the

matching sound differed from the nonmatching sound by the amounts shown. In three-choice matching, the center tone differed from the higher and lower tones by the amounts shown, and any of the three tones might match the sample. For Group 1 the difference levels were chosen to produce a wide range of difficulty, and the levels for the remaining groups were intended to be moderately difficult.

The Ss were tested in a soundproof room with tape recorder and programming equipment outside. Appropriate instructions were given before beginning each new procedure. Tests were given in daily sessions about 45 min in length.

RESULTS

Percent correct discriminations as a function of positions, ears, amount of difference between sounds, and interactions of these variables were assessed by separate analyses of variance for each type of discrimination and each task within each group, a total of 23 analyses. Significance levels were evaluated by the conservative procedure recommended by Winer (1962) for

Table 2
Levels of Frequency and Intensity Difference Employed for Oddity and Matching Tasks.
The center frequency was always 2,000 Hz except as noted for Group 1,
and the center intensity was always 80 dB SPL.

Group	Type of Discrimination	Difference Levels
1	Frequency (1,000 Hz)	20, 15, 10, 7, 5, 3, 1 Hz
	Frequency	40, 30, 20, 14, 10, 6, 3 Hz
	Intensity	4.0, 2.6, 1.8, 1.4, 1.0, 0.6, 0.2 dB
2	Frequency	15, 10, 6, 2, Hz
	Intensity	2.0, 1.4, 0.8, 0.2 dB
3	Frequency	15, 10 Hz
	Intensity	2.0, 1.4 dB
4	Frequency	15, 10 Hz
	Intensity	2.0, 1.4 dB
5	Frequency	25, 15, 10 Hz
	Intensity	4.0, 2.0, 1.4 dB

Table 3
Percent Correct Responses to Each Position, With Significance Levels Indicated

Group	Task	Type of Discrimination	1	2	3	4	Significance Level of F Ratio
1	3-Choice Oddity	Frequency (1 KH)	78	74	68		
		Frequency	67	61	61		
		Intensity	73	66	68		
2	3-Choice Oddity	Frequency	47	48	53		
		Intensity	45	52	54		
	S-AB Matching	Frequency	69	59			
		Intensity	60	58			
	AB-S Matching	Frequency	67	59			
		Intensity	65	60			
3	3-Choice Oddity	Frequency	52	48	41		
		Intensity	65	69	56		
	S-ABC Matching	Frequency	43	59	42		.05
		Intensity	60	70	53		.05
	ABC-S Matching	Frequency	38	48	56		.05
		Intensity	40	66	73		.01
4	3-Choice Oddity	Frequency	60	65	57		
		Intensity	66	72	65		
	S-ABC Matching	Frequency	65	67	49		
		Intensity	72	78	54		.05
	ABC-S Matching	Frequency	38	51	69		
		Intensity	42	67	84		.05
5	4-Choice Oddity	Frequency	64	60	67	64	
		Intensity	66	64	63	66	

repeated measurements of the same Ss.

Correctness decreased significantly with decreases in the difference between sounds in 16 of the 23 analyses. Only for the largest differences used for Group 1 was mean accuracy greater than 80%, and only for the smallest differences used for Groups 1 and 2 did accuracy approach chance levels. Differences between ears were very small and inconsistent for all groups tested monaurally, and none approached significance.

Percent correct responses to each position are given in Table 3, with significance levels of the F ratios indicated. There were no significant differences among positions for any of the oddity discriminations, with virtually no indication of the higher third-position accuracy observed in children. For both two-choice matching tasks, accuracy was greatest when the matching sound was first, but none of the differences was significant.

There was a large increase in the accuracy of ABC-S matching from the first to the second and from the second to the third sound. This effect was significant in three of the four comparisons for Groups 3 and 4. In three-choice S-ABC matching, however, accuracy was greatest when the matching sound was in the middle and least when it was last. These differences were significant in three of the four comparisons for Groups 3 and 4.

Only 3 of the 71 interactions in the 23 analyses were significant: Positions by Ears in oddity intensity

discrimination for Group 2 and Ears by Difference levels in S-AB frequency discrimination for Group 2, both at the .05 level. Since neither involved a significant main effect for positions, they will not be considered further.

The results were pooled over frequency and intensity discrimination for further analysis in terms of SDT, in an attempt to assess separately perception, memory, and decision factors in positional responding. Hit rate for each position, which corresponded to the percent correct measure used in the previous analyses, was the proportion of trials on which an odd or matching sound in that position was correctly detected. False-alarm (FA) rate for each position was the number of incorrect responses to that position divided by the total number of incorrect responses that were possible at that position, where incorrect responses were considered possible on all trials except those for which the position was correct. The relative discriminability of each position was expressed in terms of the d' measure obtained from the tables prepared by Elliott (1964), and reflected both the hit and FA rates. A similar procedure was used by Murdock (1968) in his analysis of serial effects in short-term memory.

Hit rate, FA rate, and d' were calculated for the combined frequency and intensity discrimination results at each position for each S on each task. The number of trials per calculation varied from 48 to 504 (Table 1). No further information regarding position effects in S-AB and AB-S matching

could be obtained from these additional calculations, since FA rate for one position must vary inversely with hit rate for the other position on any two-choice task, resulting in equal d' values for the two positions. Mean hit rates, FA rates, and d' for all Ss performing each of the other tasks are shown in Table 4. It can be seen that discriminability varies directly with hit rate and inversely with FA rate. For example, discriminability increases with increases in the proportion correct where rate of incorrect responses remains constant, but any increases in FA rate tend to decrease discriminability. Analyses of variance for position effects were carried out for the hit rate and d' measures. Where significant position effects were found, the significance of differences between each pair of positions was assessed by the Newman-Keuls test (Winer, 1962).

With pooled results for Groups 1 to 4 on the three-choice oddity task, the difference among positions for hit rate remained small and nonsignificant. However, the high FA rate for Position 2 and low FA rate for Position 3 resulted in a significant position effect for the d' measure at the .01 level, where Position 2 was significantly less discriminable than either Position 1 or Position 3 ($p < .01$) and Position 3 was more discriminable than Position 1 ($p < .05$). In four-choice oddity, the discriminability was also lowered at the two middle positions as a result of higher FA rates at these positions, but there were no significant position effects.

Table 4
Mean Proportion Correct (Hit Rate), Proportion Incorrect (FA Rate), and Discriminability (d') for Each Position on the Oddity and 3-Choice Matching Tasks, With Results Pooled for Frequency and Intensity Discrimination

Task	Groups	N		Serial Position			
				1	2	3	4
Oddity	1-4	24	Hit Rate	.60	.60	.57	
			FA Rate	.20	.24	.17	
			d'	1.14	1.02	1.19	
Oddity	5	8	Hit Rate	.65	.62	.65	.65
			FA Rate	.11	.14	.12	.11
			d'	1.65	1.44	1.59	1.69
S-ABC	3 and 4	12	Hit Rate	.60	.69	.50	
			FA Rate	.18	.25	.18	
			d'	1.20	1.20	.94	
ABC-S	3 and 4	12	Hit Rate	.39	.58	.70	
			FA Rate	.15	.25	.27	
			d'	.83	.91	1.22	

For S-ABC matching by Groups 3 and 4, the hit rates for Positions 1 and 3 were significantly lower than the rate for Position 2 ($p < .01$), and Position 1 was significantly higher than Position 3 ($p < .01$). However, the higher FA rate for Position 2 resulted in an equal d' for Positions 1 and 2, with Position 3 remaining the least discriminable ($p < .01$).

For ABC-S matching by Groups 3 and 4, the hit rate increased significantly from Position 1 to Position 2 ($p < .01$) and from Position 2 to Position 3 ($p < .05$). The FA rates showed a similar increase, with the result that Position 3 was more discriminable than Positions 1 and 2 ($p < .01$), for which d' did not differ significantly.

DISCUSSION

The adult Ss in the present study were uniformly correct in their oddity choices for each position, but there was a difference among positions in the discriminability (d') of the odd sound when the rate of incorrect responses (FAs) at each position was taken into consideration. For both types of three-choice matching there were significant differences in discriminability among positions, accompanied by an asymmetrical pattern of incorrect responses that was associated with alteration of the pattern of correctness. Thus, for each of the sequence tasks involving three choices, the Ss employed a decision strategy that altered the pattern of correctness over positions with reference to the underlying pattern of discriminability presumably imposed by perception and memory factors.

In the previous study of oddity discrimination by children (Doehring, 1969), the most correct responses were made to the third position and the pattern of accuracy directly reflected discriminability, since there was a uniform pattern of incorrect

responses. The adult Ss in the present study also found the odd sound most easily discriminable in the third position, but the most striking effect was the relatively poor discriminability at the second position. The adults may have successfully employed a strategy of uniform positional correctness by adopting a different criterion value (designated as beta in SDT) for the oddity decision at each position, resulting in an FA rate that varied sufficiently from position to position to counteract differences in discriminability. The underlying differences in discriminability can be most easily explained as a primacy effect for Position 1 and a stronger recency effect for Position 3. Murdock (1968) also found a strong recency effect and a relatively weak primacy effect in his study of recognition memory. Further research is needed to account for the apparent difference in decision strategies and memory processes of adults and children.

In S-ABC matching, the occurrence of the sample before the choice sounds seems to have prevented a recency effect, since the sound heard last was least discriminable. Nor was there a primacy effect for the first as compared with the second sound. This suggests that the S withheld any decision that the first sound matched the sample until he had heard the second sound. In this sense, there could be a recency effect for the second that was as strong as a primacy effect for the first sound. The Ss did not employ a decision strategy that resulted in uniform positional correctness for S-ABC matching. The high FA rate for the second position may have represented an attempt to compensate for a mistaken assumption that the second position was less discriminable than the first, and the low rate of response to the final sound may have occurred because of the difficulty of matching it to a sample

separated by two intervening sounds and a relatively long time interval.

A different process seems to have been involved in ABC-S matching. There was a very strong recency effect when the third sound was not only the last to occur but was also closest to the sample. However, the temporal and positional remoteness of the first sound did not make it significantly less discriminable than the second sound, perhaps because of a primacy effect. The decision strategy in ABC-S matching was quite different from those used in oddity discrimination and S-ABC matching. The FA rate varied directly with discriminability, resulting in an enhanced trend for increased correctness from first to third position. The Ss could have found this task the most difficult and abandoned all efforts to maintain uniform positional accuracy in an attempt to maximize overall accuracy. Even with this apparent optimization strategy, the overall accuracy for ABC-S was still only 55%, as compared with 60% for S-ABC.

The variations of relative discriminability among positions for the three tasks can be explained without too much ambiguity in terms of serial position effects, but no single explanation can account for the variety of decision strategies that seem to have been employed. According to the explanations that have been suggested, the Ss successfully applied a strategy to combat primacy and recency effects in oddity discrimination, employed somewhat the same strategy inappropriately in S-ABC matching, and seemed to attempt a strategy for maximizing overall accuracy in ABC-S matching. Further variation of the sequential paradigm should provide some clarification of the roles of decision and memory factors. In oddity tasks it would be interesting to determine the effect of decreased uncertainty by using only one direction of change for the odd sound relative to the other sounds. In the matching paradigm, the effects of increasing the number of choices and using an intermediate sample (e.g., A-S-BC or AB-S-C matching) should be assessed. Increasing interstimulus intervals for both tasks should provide information regarding not only the role of decay processes in primary memory, but also the possible operation of secondary memory factors in longer term storage. Further study of oddity and matching skills in children is needed in order to specify the manner in which memory and decision factors change with age.

The absence of ear differences permitted no inferences regarding possible hemispheric specialization for frequency and intensity discrimination

by oddity and matching. Another study will be carried out using test tones of lower intensity, a condition previously shown to produce ear asymmetry in monaural intensity discrimination by an incremental method (Swisher, Dudley, & Doebling, 1969).

The use of SDT added an important dimension to the analysis of sequence effects in the present study, and should also be of great value in any further attempts to relate sequential processes to various forms of verbal impairment. The investigation of increasingly complex auditory sequencing tasks may lead to greater understanding of man's superlative ability to comprehend spoken language. SDT may not be the most appropriate theoretical model. Even though it meets some of Gibson's objections to traditional theories of perception by explicitly postulating an active S who imposes a preconceived strategy on the perceptual event and may, in this sense, be tuning himself to some form of invariance, the class of experimental paradigms that can be analyzed by SDT may require perception, memory, and decision processes that are trivial and irrelevant with respect to verbal perception. It is probably best to interpret findings regarding temporal sequencing abilities in a broad theoretical framework, including not only SDT and perceptual theories of the type proposed by J. Gibson (1966) and E. Gibson (1969), but also theories of

speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967) and short-term memory (Bower, 1967).

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