AUDITORY FIGURAL AFTER-EFFECTS

by

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INTRODUCTION

In 1933, Gibson (6) reported that a curved line tends to look less curved after long inspection, and that a straight line subsequently shown in the same location looks curved in the opposite direction. Soon afterwards, he (7,8) reported exactly analogous effects for bent and tilted lines. He referred to the gradual change a curved, bent, or tilted line undergoes during inspection as "adaptation", and to the effect upon a subsequently presented straight line as a "negative after-effect".

Gibson held that "adaptation" is to be attributed to the existence of popularly accepted norms. Thus, if a line is curved, adaptation causes it to straighten because of our concept of straightness. A line that is almost vertical tends to become more vertical in order to approach our concept of verticality, and a line that is almost horizontal tends to become more horizontal because it is seen as approaching the horizontal. The "negative after-effect", according to the theory, occurs because the inspection figure has, to a degree, become a norm and the test figure is perceived relative to that norm.

Gibson (6) also demonstrated that an analogy exists between visual and kinesthetic perception. Each of his subjects reported that running his hand over a slightly convex surface resulted in the surface appearing to become progressively less convex with time, and that a subsequently presented straight edge felt definitely concave[1].

Other investigators (1), working during this time but after Gibson's first paper, confirmed his discoveries. Later, a new theoretical explanation of Gibson's findings was proposed by Köhler and Wallach (14). Briefly stated, this theory maintains that prolonged inspection of a figure with a well-defined border will alter the distribution of energy in the cerebral cortex in such a manner as to cause a distorted perception of subsequent figures exciting the area. The modification which the cortex undergoes when an inspection figure is fixated for an extended length of time is termed "satiation", and the term "figural after-effects" refers to the changes or distortions in the perception of a test figure. Figural after-effects, therefore, are caused by the satiated condition of the visual cortex[2].

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[1] Other forms of kinesthetic perception have also yielded figural after-effects, as for example, running the thumb and forefinger of one hand over the edges of strips of varying widths (12). Another form, demonstrated by Nachimas (18), shows that kinesthetic after-effects can be induced by the subjective comparison of the stationary position (relative to the body) of the two hands.

[2] In more technical terms, the Kohler-Wallach theory assumes that inspection of any visual object is associated with electrical currents in the visual sector of the nervous system. The cortex is regarded as a volume conductor through which these figure currents flow, polarizing all cell surfaces through which they pass. Continued flow of these currents creates an electrotonic state. Electrotonus is defined as a polarization plus a change in polarizability of cells. It is brought about by the figure current and is the physiological basis of satiation.

Satiation is regarded as a state of increased resistance due to the electrotonic condition created by the figure currents. When currents spread through a medium which does not have the same resistance throughout, these currents will follow the path of least resistance. Consequently, the effect of electrotonus established by a figure current is to deflect subsequent figure currents into less satiated areas. These current distortions may persist for some time.

Figural after-effects include a displacement of the test figure, plus a tendency to see it as less bright and farther ways than it objectively is. Hammer (9) found a recognizable displacement after only a five-second inspection period.

The satiational theory has been the subject of much controversy since its original presentation. Fisichelli (3) lends support to it. Working with Lissajous figures, he feels that the satiation principle of reversibility provides an explanation for the way in which increased stimulation increases the reversal rate of these figures.

On the other hand, Prentice and Beardslee (21) question Kohler and Wallach's claim that the satiation theory can account for all the effects observed by Gibson. They maintain that the theory fails to explain Gibson's adaptation effect, and that adaptation and figural after-effects must be related phenomena and explainable by a common theory. In order to test their convictions, Prentice and Beardslee conducted an experiment in which all possibilities of figural after-effects were obviated. Their results indicate that prolonged inspection of lines tilted 10 degrees from the vertical or horizontal show an adaptation[3] of about two degrees. They feel that these results provide additional evidence for Gibson's "adaptation" effect.

Heinemann and Marill (10) repeated the Prentice-Beardslee experiments. Their results indicate that what appears to have been adaptation in the Prentice-Beardslee experiments was nothing more than

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[3] Prentice and Beardslee use the term "normalization" instead of "adaptation".

the tendency of the tilted-line figures to align themselves with the borders of the cardboard on which they were drawn. They conclude that there is no evidence for an adaptation effect in Gibson's sense. Fox (4), however, feels that adaptation and satiation are factors both involved in figural after-effects.

Weitz and Post (28) conducted a stereoscopic study of figural after-effects which appears to contradict the Köhler-Wallach theory. Using two squares, one over the other, as the test figure, the bottom square was perceived to be brighter, clearer, larger, and closer than the top square despite the fact that it was the lower one which pervaded an area previously occupied by an inspection figure (an enclosing circle, in this particular case). They also found that prolonged fixation of the test figure without a preceding inspection resulted in having the lower square appear as brighter, clearer, larger, and closer. Walthall (27) also found this to be true. Weitz and Post state, that if the satiation theory is tenable, there should be no differential effect on the test figures if no inspection figure is first presented. The authors conclude that, since these results "were not only unexpected from Köhler's work but were contradictory to his theory" (28, p.64), some other explanation is needed. The observed results are tentatively explained by Weitz and Post in terms of past visual experience. They point out that if two objects, one behind the other, are viewed from above they will be seen as one above the other. The lower object will be the closer.

Kendon Smith (23) presents several objections to the satiation theory. He maintains that the theory is unable to account for figural after-effects in modalities other than vision. He also sees no reason to believe that a particular region was especially satiated in curvature when Gibson's (6) subjects, using prisms to distort objectively straight lines into curved ones, found that upon removal of these lens the straight lines in the environment assumed a contrary curvature. With respect to the existence of figural after-effects in the third dimension of visual space, which Köhler and Emery (13) demonstrated in monocular vision, Smith finds it difficult to understand "how a certain 'distance' can be satiated since there is no known correlate in the monocular visual system for the distance from which a stimulus emanates" (23, p.284). Finally, after-effects essentially similar to figural after-effects are obtained in the waterfall illusion and Plateau spiral. Smith states that "in none of these situations is there any selective adaptation which provides a basis even for static displacements in the test-field, let alone for the obvious dynamic after-effects which are commonly observed" (23, p.284).

A new interpretation of figural after-effects was presented in 1952 by Osgood and Heyer (20). This theory, referred to as the "statistical theory", is unlike the Köhler-Wallach model in that it is based upon neurophysiological principles concerning a nervous system composed of single neurons with precise connections. It is their thesis that figural after-effects "are due to differential adaptation within the projection system, produced by the prolonged inspection of contours" (20, p.98). Osgood and Heyer feel that all of the phenomena accounted for by the satiational theory are equally well covered by the statistical theory.

Immediately following the presentation of the statistical theory of figural after-effects, Kendon Smith (24) presented exactly the same objections to the theory that he had previously raised against the satiational theory (23) (see page 4). In addition to these objections, Smith argued that according to the statistical theory test contours should not move toward inspection contours, a phenomenon which he claims does occur.

In response to Smith, Osgood (19) maintains that the test contours do not move toward inspection contours[4]. He also objects to Smith's claim that neither the satiational nor the statistical theory would explain after-effects in sense modalities other than vision. In reply to the criticism that neither theory explains the waterfall and Plateau spiral after-effects, Osgood says that this is requiring too much of a theory. He feels that no single theory should be required to explain all phenomena of perception. Osgood adds that since the illusions referred to involve continuous movement of contours in the field they may involve mechanisms beyond those concerned with figural after-effects.

The Köhler-Wallach theory appears to be in even more serious difficulty in view of recent findings obtained with more direct methods of investigation. Lashley, Chow and Semmes (16) devised an experiment designed to disturb the cortical fields by short-circuiting DC potentials.

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[4] Smith (25) later provides experimental evidence for this phenomenon.

This was accomplished by inserting gold pins and strips of gold foil in the occipital lobes of two monkeys. There were no changes in the monkeys' subsequent visual performances on a number of discrimination problems. Jaffe (11), using human subjects who had cerebral lesions, obtained results which also weaken the Köhler-Wallach theory. Investigating kinesthetic after-effects rather than visual, he found no significant differences between the performances of normal and brain injured animals. Since Köhler and Wallach assume that (a) perceptual activity depends on the appearance of direct currents in the corresponding cortical fields, and (b) the distribution of these currents in the field are directly related to the shape, localization and duration of the resulting percepts, the results of Lashley et al., and Jaffe are in contradiction to the satiational theory as it stands.

Relatively little work has been done on figural after-effects in the auditory sense. Two important studies, however, have been conducted: Deutsch (2) investigated figural after-effects in pitch, and Krauskopf (15) has worked with figural after-effects in auditory space. Deutsch measured the difference limen for a 1000 cps tone in eight subjects. He then subjected the other ear to a prolonged tone with the same frequency, and remeasured the difference limen for the first ear. He found that the difference limen was increased 47 percent. Six control subjects did not vary in difference limen from one test to another. He feels that his results provide evidence for the existence of auditory figural after-effects.

Krauskoph (15) maintains that figural after-effects will alter the apparent spatial position of a sound source, and concludes that the evidence strongly suggests that the Kohler-Wallach model is a general schema applicable to spatialized perceptual systems.

STATEMENT OF PROBLEM

As can be seen in the INTRODUCTION, figural after-effects have been observed in both the visual and the kinesthetic senses and have been suggested for the auditory sense. The visual figural after-effects studied have been concerned primarily with the effects of a spatial pattern. That is, the studies have investigated the effect of exposure of the eye by a stationary spatial pattern over a period of time. In kinesthesis, however, the patterns have been primarily temporal in the fact that the subject has been asked to run his hand over a curved or slanted surface and then to describe the apparent characteristics of a flat surface. Analogies for both of these types of patterning should be possible in the auditory sense. That is, an unvarying sound should be equivalent to the constant visual stimulation, and a tone varying temporally in pitch or intensity should be equivalent to the usual kinesthetic situation.

On this basis, then, one might expect to obtain after-effects from the auditory sense as well as from the visual and kinesthetic senses. The effects should be obtained from both temporal sound patterning and from an unvarying sound presented over a period of time. Deutsch (2) (see page 7) gave some evidence for the existence of auditory figural after-effects from an unchanging sound source. The present study was performed for the purpose of determining whether a tone of constant amplitude and constant frequency (a test tone) appears to vary in any way as the result of the presentation of an immediately preceding tone of constant amplitude but of varied frequency (an inspection tone).

PROCEDURE

The fifty-six subjects employed in this study were junior, senior, and graduate students at the University of Arizona. They were divided into three groups: 26 served as subjects in Experiment I, 10 in Experiment II, and 20 in Experiment III. No subject was aware of the problem being studied, but a few subjects were familiar with visual figural after-effects.

In Experiment I, Series A tones were used. This series, as described in the APPARATUS section, consisted of four pairs of sounds and of 4 single sounds. For one half of the subjects the paired sounds were presented first, and for the remaining one-half of the subjects the single sounds were presented first. The single sounds were given to supply a control situation for the paired sounds. A five-minute interval was allowed between the presentation of each band on the disc. There was a 15-second interval between the two members of the pair.

The subjects, a maximum of five at one time, were seated, provided with paper and pencil, and given the following instructions:

> "You will hear a series of tones, the first half of which will be grouped into pairs.[5] Listen carefully to the characteristics of each tone, and describe the second tone only of each pair. Describe this tone carefully but concisely, and not in relation to the preceding tone but independently of it. For the single, unpaired tones

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[5] Or second half, depending upon the order of presentation.

write as careful a description of each as you can. A five-minute rest interval will follow each unit during which you may write down your impressions. To your right is an earphone. Hold it to one ear and use the same ear throughout the experiment. Cover your other ear with your free hand while the tones are being presented."

The apparatus and the experimental procedure followed in Experiment II were identical to those of Experiment I with one exception: the intensity of the tones presented was reduced.

Series B tones were used for Experiment III. The series consisted of 2 pairs of sounds and of 2 single sounds. The order of presentation for one-half the subjects was the reverse of the presentation order for the other one-half. There was a five-second interval between the paired sounds. A five-minute interval was allowed between each of the bands. A control situation for the paired sounds was provided for by the single sounds.

The procedure in Experiment III was similar to that of Experiments I and II except that the subject was asked to mark a questionnaire during the five-minute interval rather than to write a general description of the tone. This questionnaire consisted of a form on which each subject was instructed to indicate the perceived increase, decrease, or lack of variation in both pitch and intensity of the test tones. As in the former experiments, the maximum number of subjects at any one time was five.

APPARATUS

The apparatus used in the experimental situation consisted of two recorded phonographic discs (Series A and B), a phonograph player (RVA Victor table model), and five monotic earphones (Utah-Chicago ANB-H-1).

The tones for Series A were recorded on a ten-inch, 33 1/3 rpm microgroove disc. The inspection tone, which was given first in each pair, was 15 seconds in duration. It consisted of a constant amplitude wave with a frequency rising from 1000 cps to 1100 cps and then descending again to 1000 cps (if represented graphically, frequency plotted against time, a Gaussian shaped curve results). The test tones, which followed each inspection tone, were of unvarying frequency and intensity but differed in frequency level from one another. The intensity of all test tones was the same as the intensity of the inspection tone.

Side 1 of Series A disc was composed as follows:

		Time Interval	
Band No.	15 sec.	15 sec.	15 sec.
1	Inspection tone	(silence)	900 cps test tone
2	Inspection tone	(silence)	1000 cps test tone
3	Inspection tone	(silence)	1100 cps test tone
4	Inspection tone	(silence)	1200 cps test tone
5	(silence)	(silence)	900 cps test tone
6	(silence)	(silence)	1000 cps test tone
7	(silence)	(silence)	1100 cps test tone
8	(silence)	(silence)	1200 cps test tone

The bands comprising side 2 of Series A were exactly as those on side 1 except that their sequence was in the reverse order, i.e., Band 8 first, Band 7 second, etc.

The tones for Series B were recorded on a 10-inch, 78 rpm microgroove disc with four bands per side. The inspection tone for this series was of constant amplitude with the frequency rising from 1000 cps to 1100 cps in a linear fashion over a ten second period. The test tones were of unvarying frequency and intensity but at different frequency levels. The intensity of the test tones was the same as that of the inspection tone.

Side 1 of Series B disc was as follows:

		Time Duration	
Band No.	10 sec.	5 sec.	10 sec.
1	Inspection tone	(silence)	1000 cps test tone
2	Inspection tone	(silence)	1100 cps test tone
3	(silence)	(silence)	1000 cps test tone
4	(silence)	(silence)	1100 cps test tone

Side 2 of Series B consisted of the same bands but reversed in order of presentation.

The original sound source from which the disc recordings were made was an audio-generator (Huitt-Backard). The variations in frequency were produced by manually turning the control knob on the instrument, and the excursion rate was timed with a conventional stop watch. To insure that all tone waves of the same frequency would be identical, as for example, the inspection tone for each series, the tone waves from the audio-generator were first recorded on tape (modified Magnecorder).

These tones were then transcribed onto a disc recorder (Presto 8DG) in their proper sequence and whenever called for. The number of bands in Series B made it possible to make the recording at 78 rpm instead of 33 1/3 rpm as in Series A. This was desirable for at higher speeds minute fluctuation in turntable speed is not nearly as noticeable as at lower speeds.

RESULTS

A. Experiment I

The results of Experiment I were analyzed to determine whether any apparent variations in pitch and in intensity were produced by the existence of an inspection tone. The study was designed primarily to determine variations in apparent pitch. However, probably due at least partially to attention shifts, the subjects reported variations in the apparent intensity of the sound. It was felt that an analysis of these variations should be included in this study. The results of the subjects receiving the tones in one sequential order were combined with the results of the subjects receiving the same tones in the reversed order. The tabulations are presented in TABLES I and II.

TABLE I shows the number of subjects who heard a rising pitch, a falling pitch, no variation in pitch, a rising followed by a falling pitch, a falling followed by a rising pitch, and unpatterned fluctuations. The table is divided to show the data for both the experimental and control groups.

As can be seen in TABLE III, none of the differences in perception of pitch between the experimental and control situations are significant beyond the 39.5% level of confidence when twelve-fold Chi-square values are computed. Calculation of four-fold values based upon the report of a falling followed by a rising pitch (the expected

TABLE I

THE NUMBER OF SUBJECTS WHO HEARD VARIATIONS IN THE APPARENT PITCHES OF THE TEST TONES

Group	Tone Unit	Increase	Decrease	Steady	Inc.-Dec.	Dec.-Inc.	Fluctuations
Experimental	I-tone & 900 cps T-tone	0	0	23	0	0	3
	I-tone & 1000 cps T-tone	0	0	18	0	1	7
	I-tone & 1100 cps T-tone	1	3	14	0	1	7
	I-tone & 1200 cps T-tone	0	0	21	0	0	5
Control	900 cps T-tone	1	1	18	0	2	4
	1000 cps T-tone	2	1	17	0	0	6
	1100 cps T-tone	3	0	14	0	0	9
	1200 cps T-tone	0	1	20	1	0	4

TABLE II

THE NUMBER OF SUBJECTS WHO HEARD VARIATIONS IN THE APPARENT INTENSITIES OF THE TEST TONES

Group	Tone Unit	Increase	Decrease	Steady	Inc.-Dec.	Dec.- Inc.	Fluctuations
Experimental	I-tone & 900 cps T-tone	5	0	19	0	0	2
	I-tone & 1000 cps T-tone	5	0	19	0	0	2
	I-tone & 1100 cps T-tone	3	1	18	1	0	3
	I-tone & 1200 cps T-tone	7	1	16	0	0	2
Control	900 cps T-tone	10	0	16	0	0	0
	1000 cps T-tone	1	3	21	0	0	1
	1100 cps T-tone	6	2	14	0	1	3
	1200 cps T-tone	6	0	19	1	0	0

TABLE III

CHI-SQUARE VALUES FOR THE DIFFERENCE IN OBSERVED PITCH BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

Frequency Level	Chi-square (5df)	Level of Confidence
900 cps	4.753	45.3%
1000 cps	4.106	53.6%
1100 cps	5.250	39.5%
1200 cps	2.136	82.8%

shift) as against all other reports would, as can be seen in TABLE I, result in even lower indications of significant variations between experimental and control groups than do the twelve-fold calculations.

TABLE II shows the apparent shifts in intensity found for both the experimental and control groups and TABLE IV shows that these shifts in apparent loudness are not significantly more frequent for the experimental than for the control groups.

B. Experiment II

The data from Experiment II were analyzed in the same manner as the data from Experiment I with very similar results. TABLE V shows the number of subjects who heard various changes and absence of change in the pitches of the test tones. Computing twelve-fold Chi-square values for the tabulated figures in TABLE V, one finds, as can be seen in TABLE VII, that none of the perceived differences in pitch between the experimental and control situations are significant beyond the 80.8% level of confidence.

The frequency of apparent shifts in the intensity of the test tones is shown in TABLE VI. As indicated in TABLE VIII, there is no significant difference in the number of shifts between the experimental control groups.

C. Experiment III

The questionnaires used in Experiment III were analyzed and the results of the subjects receiving the tones in one sequential order were combined with the results of the subjects receiving the same tones in the reversed order. The sum totals were entered in TABLE IX which

TABLE IV

CHI-SQUARE VALUES FOR THE DIFFERENCE IN OBSERVED INTENSITY BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

Frequency Level	Chi-square (5df)	Level of Confidence
900 cps	3.924	56.3%
1000 cps	6.100	29.7%
1100 cps	3.833	57.7%
1200 cps	4.334	50.3%

TABLE V

THE NUMBER OF SUBJECTS FOR EACH OF THE TONE UNITS WHO HEARD VARIATIONS IN THE APPARENT PITCHES OF THE TEST TONES

Group	Tone Unit	Increase	Decrease	Steady	Inc.-Dec.	Dec.-Inc.	Fluctuations
Experimental	I-tone & 900 cps T-tone	2	0	8	0	0	0
	I-tone & 1000 cps T-tone	0	0	7	0	0	3
	I-tone & 1100 cps T-tone	1	0	6	0	1	2
	I-tone & 1200 cps T-tone	2	0	7	0	0	1
Control	900 cps T-tone	2	1	6	1	0	0
	1000 cps T-tone	1	0	8	0	0	1
	1100 cps T-tone	1	0	7	0	0	2
	1200 cps T-tone	0	0	9	0	0	1

TABLE VI

THE NUMBER OF SUBJECTS WHO HEARD VARIATIONS IN THE APPARENT INTENSITIES OF THE TEST TONES

Group	Tone Unit	Increase	Decrease	Steady	Inc.-Dec.	Dec.-Inc.	Fluctuations
Experimental	I-tone & 900 cps T-tone	1	0	8	0	0	1
	I-tone & 1000 cps T-tone	1	0	9	0	0	0
	I-tone & 1100 cps T-tone	1	1	6	1	0	1
	I-tone & 1200 cps T-tone	1	0	9	0	0	0
Control	900 cps T-tone	4	0	5	0	0	1
	1000 cps T-tone	1	0	8	0	1	0
	1100 cps T-tone	4	0	5	0	0	1
	1200 cps T-tone	3	0	6	0	0	1

TABLE VII

CHI-SQUARE VALUES FOR THE DIFFERENCE IN OBSERVED PITCH BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

Frequency Level	Chi-square (5df)	Level of Confidence
900 cps	2.286	80.8%
1000 cps	2.067	83.8%
1100 cps	1.077	95 - 100%
1200 cps	2.250	81.3%

TABLE VIII

CHI-SQUARE VALUES FOR THE DIFFERENCE IN OBSERVED INTENSITY BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

Frequency Level	Chi-square (5df)	Level of Confidence
900 cps	2.492	77.7%
1000 cps	1.059	95 - 100%
1100 cps	3.891	56.8%
1200 cps	2.600	76.1%

TABLE IX

THE NUMBER OF SUBJECTS WHO HEARD VARIATIONS IN THE APPARENT PITCHES AND INTENSITIES OF THE TEST TONES

Group	Tone Unit	PITCH			INTENSITY		
		Increase	Decrease	Steady	Increase	Decrease	Steady
Experimental	I-tone & 1000 cps T-tone	1	1	20	7	1	14
	I-tone & 1100 cps T-tone	4	3	15	8	1	13
Control	1000 cps T-tone	1	0	21	5	1	16
	1100 cps T-tone	2	3	17	5	1	16

shows the number of subjects who heard a rising pitch, a falling pitch, or no variation in pitch. TABLE IX also shows the number of subjects who heard variations in the apparent intensity of the test tones. The table is divided to include the data for both the experimental and control groups.

As shown in TABLE X, none of the differences in the perceived pitch between the experimental and control situations are significant beyond the 60.8% level of confidence when six-fold Chi-square values are computed. TABLE X shows that differences in the perception of apparent intensity are not significantly more frequent for the experimental than for the control groups.

TABLE X

CHI-SQUARE VALUES FOR THE DIFFERENCE IN OBSERVED PITCH AND INTENSITY BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

Variable	Frequency Level	Chi-square (2df)	Level of Confidence
Pitch	1000 cps	1.024	60.8%
	1100 cps	0.792	67.7%
Intensity	1000 cps	0.466	79.3%
	1100 cps	1.004	61.4%

DISCUSSION AND CONCLUSIONS

If we assume that (a) the phenomena of figural after-effects are general characteristics of the sensory systems and that (b) the objective characteristics of the sound patterns employed in this study are analogous to the temporal configurations employed in past investigations with kinesthesis, it would appear that the present study should have yielded figural after-effects in audition. This expectation was not realized.

Analysis of results for Experiment I, which utilized rising and falling inspection tones at a high intensity level, yields no difference beyond the 39.5 percent level of confidence between the numbers of reported shifts in the perceived pitch of the test tone for the experimental and control groups. A similar analysis of apparent shifts in intensity of the test tones reveals that they did not occur significantly more frequently for the experimental than for the control groups.

In Experiment II, the differences in apparent shifts for both pitch and intensity are also far from significant. In this experiment, the same inspection and test tones as in Experiment I were presented, but at a lower intensity level.

Similarly, the results of Experiment III, with simple rising but not falling inspection tones, reveal only insignificant differences between the experimental and control groups.

On the basis of these experimental results, the main conclusion to be derived is that a tone of constant intensity and frequency does not appear to vary in any manner as the result of the presentation of an immediately preceding short-duration tone of constant intensity but of varied frequency. The observed variations can be attributed to no more than chance. Although visual figural after-effects are always due to simultaneously presented cortical spatial patterns, kinesthetic after-effects have been obtained using temporal patterns which would appear to be analogous to the temporal auditory patterns used in this study.

It appears unlikely that the failure to obtain figural after-effects is due to the lack of cortical localization of different sound frequencies although this is a possible basis for the failure. Tunturi (26) has demonstrated that under proper conditions cortical projection of various frequencies is extremely sharp. He was able to show in dogs that frequency shifted .1 octave for each .2 millimeter antero-posterior, cortical displacement. This fact would lead one to expect figural after-effects in audition if either the satiational theory or the statistical theory of figural after-effects is correct. However, Tunturi found that the sharpness of auditory localization depends upon the intensity of the stimulus. The more intense the stimulus the greater the spread of excitation. Similarly Galambos and Davis (5) have shown that, at all levels of the neural pathway for audition, fibers are specialized for certain frequencies. This differential sensitivity is relatively sharp for threshold intensities but broadens a great deal as intensity is increased. In view of these facts, it appears that the distinctly suprathreshold intensities employed in this study would not lend themselves to sharp cortical representation, and thus might not yield sufficient differential satiation to produce figural after-effects. A pattern which is to vaguely or diffusely projected will not afford a clear-cut differential between an area which is active and one that is not. However, the meeting of this possible objection is complicated by the probability that threshold intensities would produce very little satiation.

Since the absolute threshold as well as the difference limen is not constant for all tones within the audible frequency range, it is conceivable that presentation of frequencies to which the ear's sensitivity is relatively low could decrease the efficacy of the tones in producing after-effects. In this particular study, however, this possibility was obviated by utilizing tones falling between 900 and 1200 cps. As Shower and Bidulph (22) have shown, these tones fall safely within the range of maximum sensitivity and minimum difference thresholds.

On the other hand, several factors in the experimental make-up can be pointed out which could be responsible for the failure to demonstrate auditory figural after-effects. In the first place, a single presentation of the inspection tone may not be enough to establish cortical activity of sufficient strength in order to affect subsequent test tones. This is very likely in view of the procedure used by Gibson with kinesthesis. In his experiment, which is the best analogy to the present study, he had his subjects run their fingers over the inspection contours many times before the presentation of the straight test contour. The importance of firmly established initial visual patterns is evidenced by the finding that the amount of displacement is proportional, within limits, to the length of inspection period (9). Correction, then, of this possible weakness in the present study might be to repeat the inspection tone several times before presenting the test tone. However, the difficulty with such a shift in method might be the formation of a complex rather than a repetitive simple pattern.

Finally, Hammer (9) has found that the length of time between the presentation of the inspection and test patterns is of critical importance. She demonstrated that for an inspection period of 60 seconds, displacement was maximal with immediate presentation of the test figure and reached zero in 90 seconds. If this fact applies equally well to auditory phenomenon, the inter-stimulus interval employed in this study may not have been ideal. However, if the interval were exceedingly short no distinction would be made between the inspection and test tones.

SUMMARY

In 1933, Gibson (6) discovered a visual phenomenon which since then has been termed figural after-effects. This phenomenon is described as a perceptual distortion of a figure as the result of the past stimulation. At the same time, analogous after-effects were found to exist in kinesthesis (6). Subsequent to these discoveries, other investigators confirmed the existence of this and other effects and paved the way for an elaborate theoretical explanation of the phenomena by Köhler and Wallach (14). This theory, which is termed the satiational theory, maintains that polarized cortical tissue through which figure currents have passed will affect subsequent figure currents which happen to pervade the same region. The theory has received support by some investigators (3), and has been questioned by others both on neurophysiological grounds (15, 16, 11) and on the basis of apparent contradiction to Gestalt principles (17). Despite these explanatory controversies the fact remains that figural after-effects exist, and that they are probably not peculiar to one or a few sense modalities but are characteristic of the sensory projection system in general.

The present study was done in order to present evidence, either for or against, the existence of figural after-effects in audition. Pitch was the principal dimension investigated, although shifts in apparent intensity were analyzed as well.

Three separate experiments were conducted with a total of 52

subjects participating. The procedure employed consisted in the presentation of an inspection tone of moderate to high intensity followed by a test tone which was to be described by the subject. Experiment I and II differed from each other only with respect to the intensity of the sounds. The inspection tones were of a rising followed by falling frequency. In Experiment III, a new inspection tone pattern was utilized, the inspection tones consisting simply of rising frequency tones. The test tones for all experiments were essentially the same; namely, a steady tone unvarying in frequency and intensity. In Experiment I and II, the subjects were asked to describe their impressions of the test tones. In Experiment III, the subjects were instructed to mark a questionnaire.

The data yielded negative results in all three experiments. Shifts in the perceived pitch and loudness of the test tones were not significantly more frequent for the experimental than for the control groups. The conclusion, therefore, was that the tones of constant intensity and frequency were not affected in any way as the result of an immediately preceding tone of constant intensity but of varied frequency.

Neurophysiological evidence for the existence of precise cortical representation of different frequencies suggests that auditory figural after-effects are not unlikely, providing satiation or fatiguing of cortical areas can be accomplished. However, a dilemma is presented by the fact that the sharpness of cortical localization is limited to threshold levels of intensity; levels which would probably produce insufficient satiation for figural after-effects.

Consideration of other apparently important factors creates questions which cannot be answered without further experimentation. Among these is the question of whether a single presentation of an inspection tone produces sufficient cortical satiation to make figural after-effects possible. It may be impossible to check this hypothesis since repetition of the experimental tone may create a complex pattern rather than a repetitive simple pattern. Again, the question of the interval between stimuli deserves consideration in view of the fact that, in vision at least, the degree of displacement of the test pattern varies inversely with the time between presentations. This creates a problem; exceedingly short intervals would not permit a distinction between the test and inspection tones.

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