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Auditory Illusions and Confusions

These failures of perception are studied because they isolate a clarify some fundamental processes that normally lead to accur of perception and appropriate interpretation of ambiguous sou

by Richard M. Warren and Roslyn P. Warren

For more than a century visual illusions have been of particular interest to students of perception. Although they are in effect misjudgments of the real world, they apparently reflect the operation of fundamental perceptual mechanisms, and they serve to isolate and clarify visual processes that are normally inaccessible to investigation. Auditory illusions, on the other hand, have received little scientific attention. Until recently the fleeting nature of auditory stimuli made it difficult to create, control and reproduce sound patterns as readily as visual ones. The tape recorder made it easy to manipulate sounds, and yet for a time there was little examination of auditory illusions, perhaps because there was no historical tradition to build on—no puzzles inherited from the experimental psychologists of the past century, as there were in the case of optical illusions. Some new investigations, however, have led to the discovery of illusions in hearing that help to explain the human ability to extract information from fleeting patterns of sound. These investigations have also led to the identification of confusions in hearing that help to explain some limitations of that ability.

Consider for a moment that you are at a convention banquet. While you are still finishing your dinner the after-dinner speeches begin. The clatter of dishes masks some of the speech sounds, as do occasional coughs from your neighbors and your own munching. Nonetheless, you may be able to understand what the speaker is saying by utilizing the information that reaches you during intervals that are relatively free of these interfering noises. In order to understand how speech perception functions in the presence of transient noises, we and Charles J. Obusek did some experiments last year in our laboratory at the University of Wisconsin at Milwaukee. First we recorded the sentence "The state governors met with their respective legislatures convening in the capital city." Then we carefully cut out of the tape recording of the sentence one phoneme, or speech sound: the first "s" in "legislatures." We also cut out enough of the preceding and following phonemes to remove any transitional cues to the identity of the missing speech sound. Finally, we spliced the recorded sound of a cough of the same duration into the tape to replace the deleted segment.

When this doctored sentence was played to listeners, we found that we had created an extremely compelling illusion: the missing speech sound was heard as clearly as were any of the phonemes that were physically present. We called this phenomenon "phonemic restoration." Even on hearing the sentence again, after having been told that a sound was missing, our subjects could not distinguish the illusory sound from the real one. One might expect that the missing phoneme could be identified by locating the position of the cough, but this strategy was of no help. The cough had no clear location in the sentence; it seemed to coexist with other speech sounds without interfering with their intelligibility. Phonemic restoration also occurred with other sounds, such as a buzz or tone, when these sounds were as loud as or louder than the loudest sound in the sentence. Moreover, phonemic restorations were not limited to single speech sounds. The entire syllable "gis" in "legislatures" was heard clearly when it was replaced by an extraneous sound of the same duration.

We did find a condition in which the missing sound was not restored. When a silent gap replaced the "s" in "legislatures," the gap could be located within the sentence and the missing sou tified. In visual terms, it was erasure of a letter in a printed te be detected, whereas an opa over the same symbol would illusory perception of the obliter ter, with the blot appearing as parent smear over another portic text [*see top illustration on page* 33]. Of course, in vision a blot localized readily, and even th elusive "proofreader's illusions" eliminated when the reader is tol vance just where the error in the curs. With phonemic restoration ever, knowledge of the nature extraneous sound and of the ide the missing phoneme does not clear perception of the missing even when the stimulus is playe listener as many times as he wish

The inability to localize an ext sound in a sentence was first rep 1960 by the British workers Pete foged and Donald E. Broadben they employed brief intrusive (clicks and short hisses) and to that no phoneme was obliterate nemic restorations did not arise. short, nonmasking extraneous were later used by a group at th sachusetts Institute of Technolo included Jerry A. Fodor, Merrill rett and Thomas Bever. They h ported that systematic errors in l the clicks are caused by various f of sentence structure, and they ha the errors to explore those features

Perceptual synthesis of the ph is accomplished on the basis bal context. In the case of the miss in "legislatures" the context prior absent sound suffices for identifi What about a sentence so const that the context necessary to iden obliterated sound does not com sions

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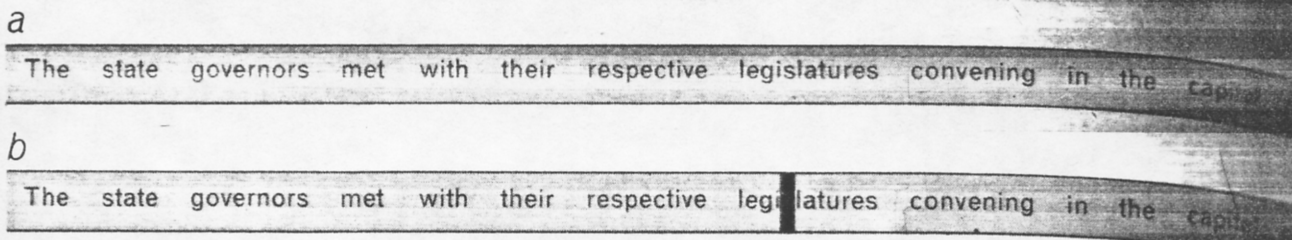

PHONEMIC RESTORATION is an illusion that shows the importance of context in determining what sound is heard. A sentence was recorded on tape (*a*). Then the first "s" in "legislatures" was excised and a cough of the same duration (*black* spliced in its place (*b*). When the altered sentence subjects, the missing "s" was heard clearly (*c*) and

later? With the symbol * representing a loud cough that replaces a speech sound, consider a spoken sentence beginning, "It was found that the *eel was on the ___." The context provided by the last word in the sentence should resolve the ambiguity and determine the appropriate phonemic restoration. Among the words that could complete the sentence are "axle," "shoe," "orange" and "table." Each implies a different speech sound for the preceding word fragment, respectively "wheel," "heel," "peel" and "meal." Preliminary studies by Gary Sherman in our laboratory have indicated that the listener does experience the appropriate phonemic restoration, apparently by storing the incomplete information until the necessary context is supplied so that the required phoneme can be synthesized. We are still investigating the influence of such factors as the duration of extraneous sounds in relation to the duration of the missing phoneme and the maximum temporal separation between the ambiguous word fragment and the resolving context that will still permit phonemic restoration.

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logical grounds by George
Rockefeller University. He
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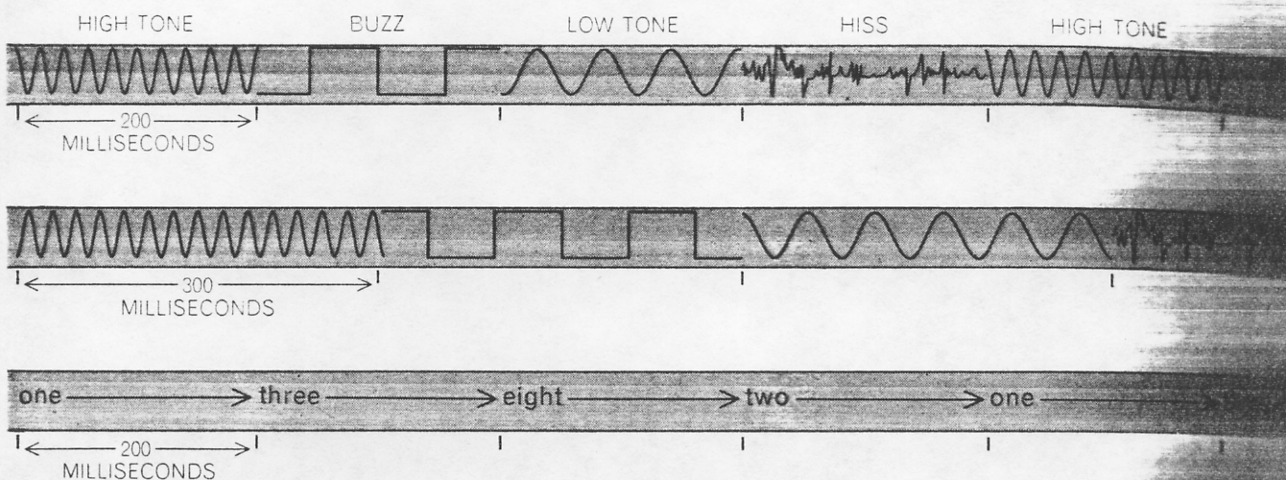
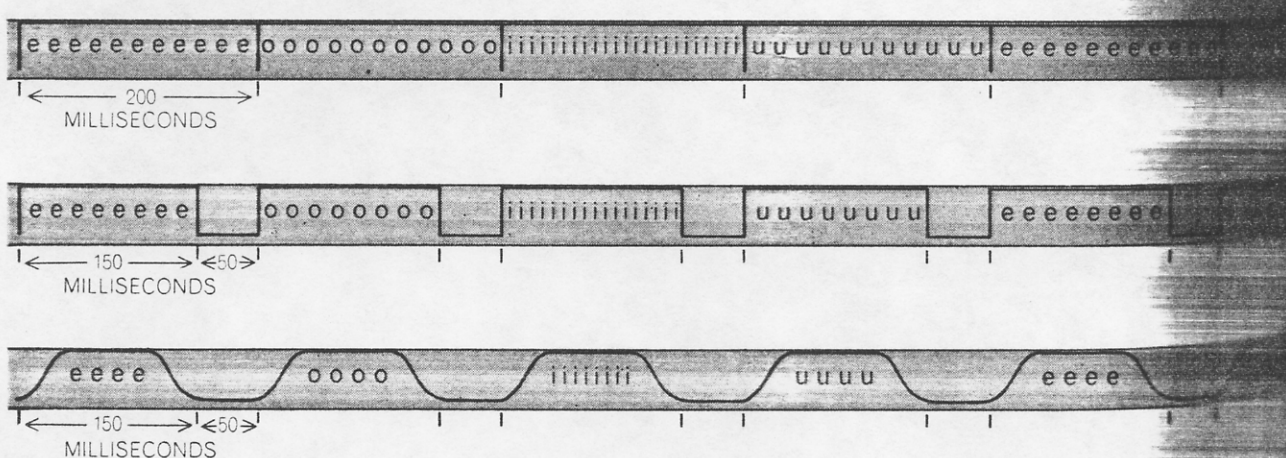
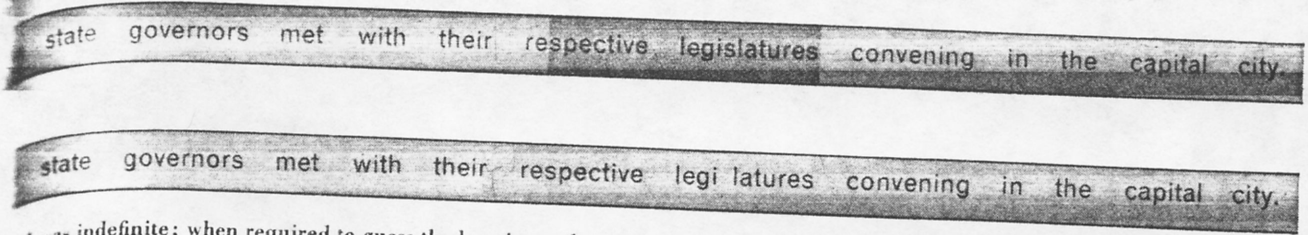


TEMPORAL CONFUSION was observed when a high tone, a buzz, a low tone and a hiss (represented here schematically), each lasting 200 milliseconds, were presented repeatedly (*top*). not report the sequence of the sounds properly



FOUR VOWEL SOUNDS were used in another experiment on temporal confusion. When the vowel sounds of "beet," "boot," "bit" and "but" were presented at a sustained level their sequence could not be determined (*top*).

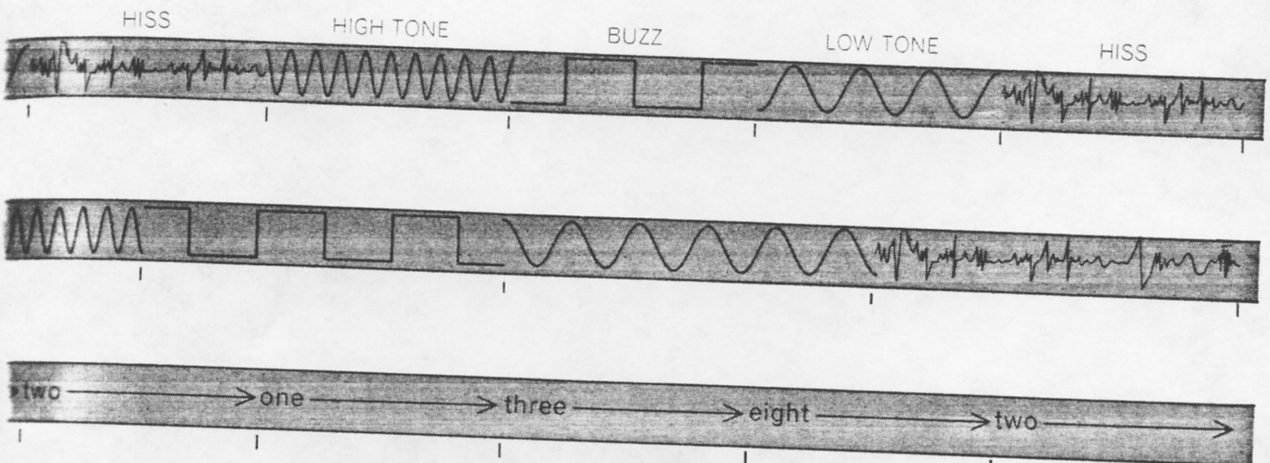


gh was indefinite; when required to guess the location, sub- erally missed the correct position by several phonemes, as d (*gray area*). When a silent gap, rather than a cough, re- placed the "s," the gap could be located and the missing sound could be identified (*d*). This illustration, like those that follow, is necessarily an approximate representation of an auditory effect.

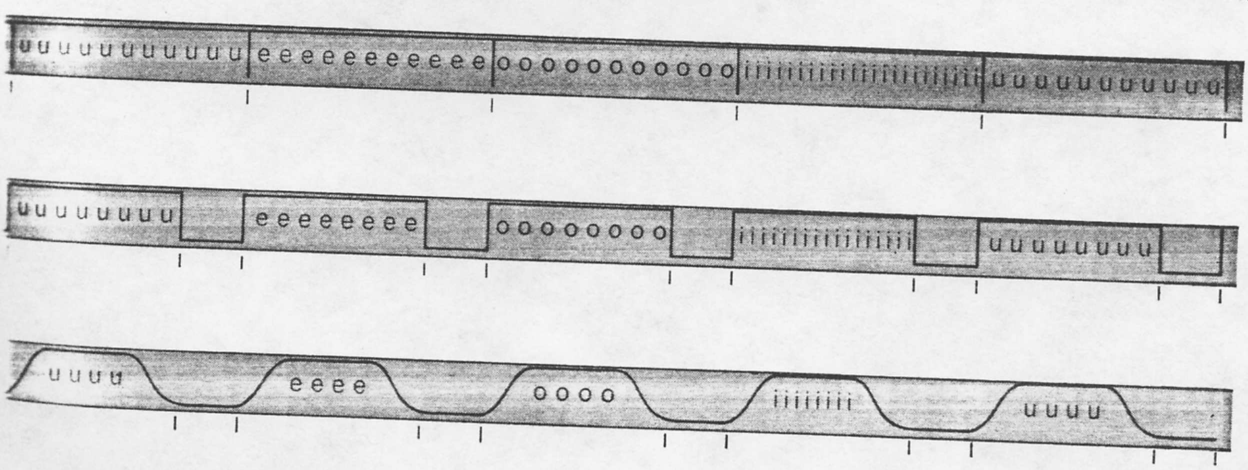
formation is associated with rrection. In the 1890's William nd Noble Harter noted that high- d telegraphers listening to Morse d not transcribe the auditory sig- constituted a word until some words after the signals were d subsequent portions of the could not provide helpful con- n the case of stock quotations or ons in cipher, the telegraphers their strategy and followed ge much more closely in time. h companies charged higher rates for sending such messages precisely because they lacked redundant context, were therefore much more difficult to re- ceive and had to be transmitted more slowly.

This telegrapher's technique illus- trates a surprising relation that one en- counters again and again in perception: The development of an extremely com- plex procedure for data processing is necessary to achieve the deceptive im- pression of an "easy" perceptual task. From time to time other workers have noted the delay between language input and motor response. In 1925 William Book observed the similarity between typewriting and code transcription, re- porting that in the case of an expert typist "attention was pushed ahead of the hands as far as possible (usually four or five words)."

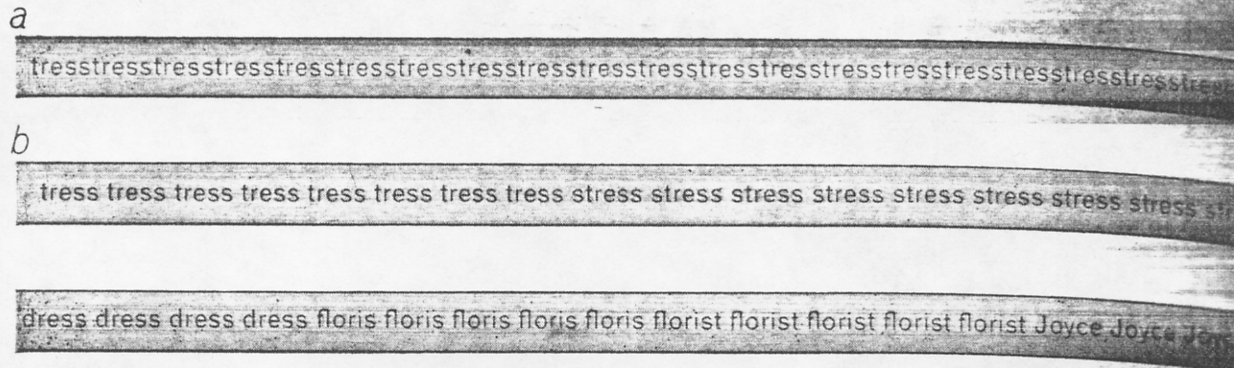
Inability to locate the position of ex- traneous sounds in sentences repre- sents a failure in the detection of tem- poral order. It might be thought that this temporal confusion results from a conflict between verbal and nonverbal



rbally or by ordering four cards, each representing a n sounds lasted 300 milliseconds, subjects could order them with cards (*middle*). When spoken digits were substituted for sounds, it was easy for subjects to report their order (*bottom*).



ch sound and replacing it with silence (*middle*) al- the subjects to determine the sequence. The se- quence was readily determined when vowels were given normal qualities of gradual onset and decay, suggested by curves (*bottom*).



VERBAL TRANSFORMATION EFFECT is noted when subjects listen to a distinct recording of a single word repeated on a loop of tape (*a*). One might expect a kind of reversal effect, ulus "tress" perceived sometimes as "rest." Instead

modes of perception. Recent observations in our laboratory have indicated, however, that inability to detect sequence is not restricted to verbal-nonverbal interactions. In 1968, during an experiment on loudness, we noted to our surprise that listeners could not tell the order of three successive sounds repeated over and over without pauses. The sounds—a hiss, a tone and a buzz—each lasted a fifth of a second (200 milliseconds) and were recorded on a tape that was then spliced to form a loop. The duration of each sound was quite long compared with the 70- to 80-millisecond average for a phoneme in speech and was well within the temporal range used in music for the successive notes of melodies; the hiss, tone and buzz could each be heard clearly. Yet it was impossible to tell the order of the sounds. The pattern swirled by, the temporal structure tantalizingly just beyond one's grasp.

It might be thought that a little advance planning would make the task easy. It should be possible, for example, to concentrate on one of the sounds (say the hiss) and then decide whether the sound that follows it is a tone or a buzz; this single decision would fix the third sound in the remaining slot and solve the problem. In practice, however, the single decision cannot be made with accuracy. Out of 50 listeners we found that only 22 named the order correctly—slightly fewer than the 50 percent correct answers that would be expected by chance alone.

This seemed at first to contradict the findings of earlier studies. Results reported by Ira Hirsh of the St. Louis Central Institute for the Deaf and by others had indicated that temporal resolution of such sounds as tones, hisses and buzzes should be possible down to a separation of about 20 milliseconds—even less time than is required for accurate temporal ordering of the sounds forming speech or music. These values, however, had been based on pairs of sounds. The subjects listened to a single pair (such as a tone and a hiss) and reported their order. It was possible, we reasoned, that subjects could say which sound came first and which last not by actually perceiving the temporal order as such but by detecting which of the sounds occurred at either the onset or the termination of the stimulus pair. In 1959 Broadbent and Ladefoged had suggested that the ability of their subjects to order pairs of sounds might be based on the "quality" of the pair as a whole. Could that "quality" be determined by which sound was present at the onset and/or the termination of the brief pair?

With threshold judgments of this kind, when subjects are working at the limit of their ability, introspection as to how they make their decisions is particularly difficult; they simply cannot say. To determine what criteria are actually being used one must rely on experiments. We returned to our recycled 200-millisecond stimuli (hiss, tone, buzz) that could not be ordered, but this time we inserted a three-second interval of silence between successive presentations of the three-sound sequence. Most listeners could now identify the first and last items in the series correctly, somewhat more accurately in the case of the last sound. This supported our suspicion that "sequence perception" with pairs of sounds represents a special case and is really perception of onset and termination.

In order to examine further the perception of temporal order in the absence of onset and termination cues, we employed a variety of repeated four-item sequences. The chance of guessing the order correctly, starting with whichever sound one chooses, is one in six. With a sequence consisting of a high tone (a frequency of 1,000 hertz, or 1,000 cycles per second), a buzz (40-hertz square wave), a low tone (796 hertz) and a hiss (2,000-hertz octave band of noise), each lasting 200 milliseconds, correct responses were only at the level of chance. It was necessary to increase the duration of each item to between al
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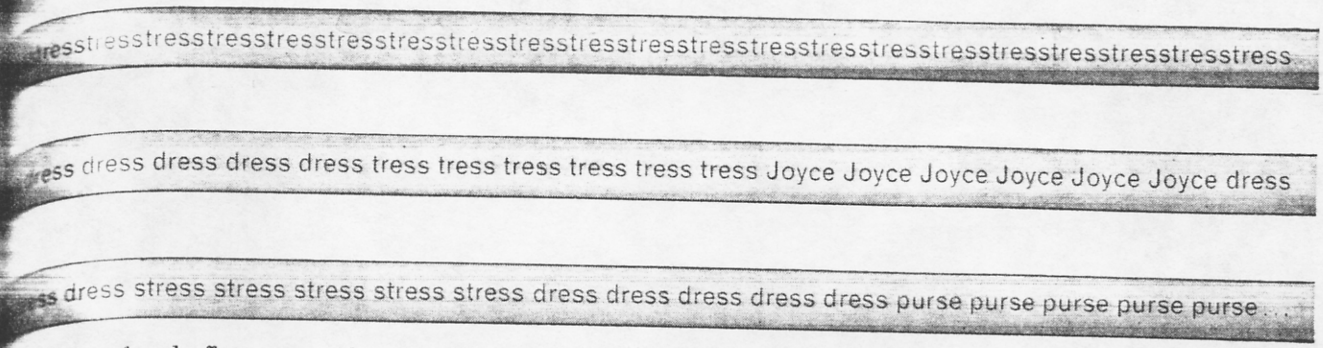

…ore profound effect: most subjects experience illusory … involving substantial distortion of the stimulus. A man listening to "tress" repeated 360 times in three minutes heard 16 changes involving eight different words, some illustrated here (*b*).

… attempts to synthesize speech … electronically.

… subjects did no better than … the first time they attempted to … the order of the sounds. By delet… 50-millisecond portion of each sus… vowel and replacing it with a si… …p, we made the sequence sound …ke normal speech, and then iden… …n of order was possible for half …w group of subjects. The subjects …ched a perfect score only when …sented vowels of the same dura… 150 milliseconds separated by 50 …conds of silence) but recorded …he normal qualities of vocal onset …ecay that are characteristic of sep… …hort utterances of vowel sounds. …pears, in short, that accurate per… …n of temporal order may be possi… …nly for sequences that resemble … encountered in speech and in …-special sequences in which the …nent sounds are linked together, …ing specific rules, into coherent …ges.

…ring the 1950's Colin Cherry of the …al College of Science and Tech… … in London wrote about the "cock… …arty problem," the task of attend… …o one chosen conversation among …al equally audible conversations. …ently such cues as voice quality …patial localization help the listener …ep fixed on a single voice among … When a person attends to one of …erbal sequences, he excludes the …, so that presumably it would not …ssible for him to relate the tem… …osition of a phoneme in one con… …on (or other extraneous sounds …s coughs) to the temporal position …onemes in the attended conversa… …ch observations lead us to specu… …t the inability to perceive the cor… …rder of stimuli that do not form …ized sequences of speech or music … represent a flaw or defect of our …ual skills. Rather, this restriction …poral pattern perception may be …ntial step in the continual process of extracting intelligible signals from the ubiquitous background of noise.

Musical and verbal passages have an organization based on the temporal order of their sounds; this organization furnishes a context for the individual sounds. Verbal context, as we pointed out above, can determine completely the synthesis of illusory speech sounds; phonemic restorations are heard when the context is clear but part of the stimulus is absent. Another illusion arises when the stimulus is clear but the context is absent. If one listens to a clear recording of a word or phrase repeated over and over, having only itself as context, illusory changes occur in what the voice seems to be saying. Any word or phrase is subject to these illusory changes, usually with considerable phonetic distortion and frequently with semantic linkages. These illusory words are heard quite clearly, and listeners find it difficult to believe they are hearing a single auditory pattern repeated on a loop of tape. As an example of the kind of changes heard, a subject listening to "tress" repeated without pause heard distinctly, within the course of a few minutes, such illusory forms as "dress," "stress," "Joyce," "floris," "florist" and "purse." This illusion, which we call the verbal transformation effect, has provided unexpected glimpses of hitherto unexplored perceptual mechanisms for organizing speech sounds into words and sentences.

The implications of the verbal transformation illusion were not appreciated fully in 1958, when one of us (Richard Warren) and Richard L. Gregory first reported the discovery of "an auditory analogue of the visual reversible figure." We had been looking for an auditory illusion resembling the one observed in such ambiguous figures as the Necker cube, whose faces seem to pop into different perspective orientations as one looks at it. We reasoned that ambiguous auditory patterns would undergo similar illusory shifts; for example, the word "rest" repeated clearly over and over without pause should shift to "tress," then back to "rest" and so on. We did find such closed-loop shifts but we also found some other illusory changes—to "dress" and "Esther," for instance. At the time, although we noted that perceptual distortion of the stimulus had occurred, we considered it only a curious side effect.

Further study by the present authors has drawn attention to basic differences between the visual and auditory illusions, however. The auditory effect is not limited to ambiguous patterns; any word or phrase will do. Changes are impossible to predict, vary greatly from individual to individual and often involve considerable distortion of the stimulus pattern. A subject listening to the word "see" repeated over and over may hear a phrase as far removed from the stimulus as "lunchtime," particularly if the time is about noon! Changes occur frequently: when a single word is repeated twice a second for three minutes, the average young adult hears about 30 changes involving about six different forms.

There are some remarkable effects of age on the frequency of verbal transformations and the types of illusory changes. These age differences seem to reflect basic changes in the way in which a person processes verbal input over a life-span. Children at the age of five experience either very few or no verbal transformations. At six half the children tested heard illusory changes, and those who did experienced them at the rapid rate characteristic of older children. By the age of eight all the children tested heard verbal transformations. The rate of illusory changes apparently remains approximately constant into the twenties and then declines slowly during the middle years; for listeners over 65 the rate was found to be only a fifth the rate for young adults and was approximately equal to the rate for five-year-olds. This decrease after middle age is not due directly to any decrease in auditory acuity with aging. Actually the aged are generally more accurate in this task than the young, reporting common English stimulus words correctly and continuing to respond to the stimulus as it actually is—the same word repeated over and over without change. Moreover, if young adults hear a word played indistinctly against a background of noise (which should simulate a decrease in acuity), they still hear many more illusory changes than the aged.

Besides counting the number of changes, we have examined the groupings of speech sounds to determine the units of perceptual organization at different ages. Children respond in terms of the sounds of English but may group them in ways not found in the language. For example, with the word "tress" repeated over and over, a child might report "sreb" even though the initial "sr" sequence is not found in English words. Young adults group speech sounds only in ways that are permitted in English, but they do report nonsense syllables: given the stimulus "tress," they might report "tresh" as one of the sounds they hear. Older people, on the other hand, report only meaningful words. Presented with "tress," they tend to hear "tress" continuously, and when infrequent changes do occur, they usually are to such closely related forms as "dress." If an older person is presented with a repeated nonsense syllable, there is an interesting result. If "flime" is the stimulus, for example, the older listener generally distorts the word into a phonetically close English word such as "slime" and tends to stay with the sense-making (but illusory) word throughout.

Our observations with verbal transformations have suggested that as people grow older they employ different perceptual mechanisms appropriate to their familiarity with language and their functional capacities, both of which change with age. We believe specific mechanisms associated with the skilled use of verbal context underlie the age differences in the frequency and nature of verbal transformations. Repeated words do not flow past us as normal components in the stream of language do; like a vortex, they move without progressing. In the absence of the semantic and grammatical confirmation ordinarily provided by verbal context, perception of repeated words becomes unstable for all but the very young and the old. And since each successive perceptual organization is subject to the same lack of stabilizing context, it suffers the fate of its predecessor.

The absence of illusory changes at age five suggests that young children have not yet reached the stage in language development where storage with skilled reorganization comes into play. The loss of susceptibility in alert and healthy elderly listeners suggests that they no longer have the functional capacity for this mechanism. It is rather well established that short-term memory is less effective in the aged when intervening activity is required between input and retrieval. Concurrent processes of coding, storing, comparing and reorganizing may therefore not be possible, so that the optimum strategy is to employ only [illegible] past context of the message as an aid [illegible] organization of the current input. The fact that in the presence of repe[illegible] stimuli the aged report only meaningful words is consistent with this view. If this interpretation is correct, one would ex[illegible] pect that phonemic restoration for elderly people would be limited to repl[illegible] ment of speech sounds identified by [illegible] context; the use of subsequent conte[illegible] the manner of young adults, would [illegible] be possible. We plan to do experim[illegible] testing this prediction.

In summary, it appears that phon[illegible] restorations and verbal transfo[illegible] tions provide new techniques for st[illegible] ing the perceptual organization of [illegible] speech, particularly the grouping [illegible] speech sounds, the correction of the lis[illegible] tener's errors and the resolution of acous[illegible] tic ambiguities. The observations we have described for the perception [illegible] auditory sequence indicate that special perceptual treatment of the sounds of speech (and music) allow us to extract order and meaning from what would otherwise be a world of auditory chaos. It is curious that in studying illusions and confusions we encounter mechanisms that ensure accurate perception and the appropriate interpretation of ambiguities.