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The research project was designed to delineate principles that underlie the perception of complex auditory patterns. During the granting period, nine lines of research were conducted that investigated various aspects of complex auditory perception. These research efforts largely focussed on perception of speech sounds, and provided important information about three aspects of perception. Several of the projects clarified the role that the listener's knowledge of English words can play in decoding speech. Additional studies examined how lower-level representations (spectral patterns, high-frequency sublexical patterns) are processed. Across a number of the research efforts, attentional effects were investigated, to determine how they modulate other processing. Collectively, the research effort made significant progress in clarifying how human listeners decode very complex sounds.

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I. SUMMARY

The research project was designed to delineate principles that underlie the perception of complex auditory patterns. During the granting period, nine lines of research were conducted that investigated various aspects of complex auditory perception. These research efforts largely focussed on perception of speech sounds, and provided important information about three aspects of perception. Several of the projects clarified the role that the listener's knowledge of English words can play in decoding speech. Additional studies examined how lower-level representations (spectral patterns, high-frequency sublexical patterns) are processed. Across a number of the research efforts, attentional effects were investigated, to determine how they modulate other processing. Collectively, the research effort made significant progress in clarifying how human listeners decode very complex sounds.

II. RESEARCH OBJECTIVES

The objective of the research project is to delineate principles that underlie the perception of complex auditory patterns. The stimuli used are speech and musical patterns of varying complexity. A wide array of experimental procedures and analyses are used to try to determine properties that are true of the perception of complex auditory patterns across stimulus domains. In addition, we also are interested in discovering any principles that are domain specific (e.g., as "categorical perception" has traditionally been claimed to be a principle of perception specific to the speech domain). The various experimental investigations in the project may be broadly grouped into studies of signal-based factors, and studies of listener-based factors. The former group includes experiments that explore how properties of the input signal determine perception, while the latter group includes studies of how listeners' expectations influence perception/performance. The former group primarily focusses on early representations of the signal, and the latter includes higher-level factors (including, but not limited to, attentional influences). The long-term goal of the research is to understand both signal-based and listener-based factors, and their interaction in the perception of complex auditory patterns.

III. RESEARCH ACCOMPLISHED

During the period of AFOSR grant 91-0378, we conducted a large number of studies of the perception of complex sounds, working within an information processing framework. A fundamental premise of the information processing perspective is that perceptual and cognitive functioning may usefully be decomposed into levels of analysis. For understanding how complex sounds are perceived, this perspective entails providing a specification of what each level of analysis is, and the relationship of each level to other levels. In specifying a level of analysis, there are many kinds of information that we should want to know. For example, it is important to delineate the domain of operation: Does a process at a particular level of analysis only operate, say, on auditory stimuli, or perhaps only on auditory signals from one ear, or only on signals with certain properties (e.g., musical sounds), etc. To the extent that we can specify the stimulus properties that are critical to an analysis at a given level, we understand the nature of the system. Moreover, we must understand the mechanisms of processors at a given level. Do they, for example, change their output as a function of the stimulation, or are they stable over time? Does the activation of a particular representation have any effect on other representations at the same level, or is each one independent? Similarly, we should try to understand how the activity at one level of the system affects the behavior of processors at other levels.

Broadly speaking, the research conducted in our laboratory can be characterized as focussing on one or more of three topics: (1) Lexical issues -- what influence do pre-existing representations of known words have on the perception of speech? (2) Sublexical representations -- what levels of representation does the perceptual system employ between the initial post-cochlear signal, and the ultimate lexical coding? (3) Attentional allocation -- what are the control processes guiding perception of complex sounds, and how do they affect processing?

During the grant period, we have made significant progress in each of these areas. Most of this progress has been reviewed in our previous Annual Technical reports. Therefore, we will provide only brief summaries of the nine projects we have undertaken. For relatively complete projects, we have already submitted copies of the relevant manuscripts; we will provide such manuscripts in the coming months for the several projects that are approaching completion.

A. An Empirical and Meta-Analytical Study of Phonemic Identification

Recent studies using Ganong's (1980) identification task have produced discrepant results. This project helped to resolve these discrepancies by examining the influence of methodological factors on phoneme identification and differences in data analysis techniques. Three factors were examined across two experiments: position of target phoneme, phonetic contrast, and two task conditions in which stimulus quality (S/N ratio) or cognitive load varied. A meta-analysis was then performed on the results from all identification studies in the literature, in an effort to obtain additional insight into factors that influence the task. The experiments and meta-analysis identified the importance of a number of methodological factors in affecting identification, most notably, position of the target phoneme (early or late in a word).

B. Lexical Influences in Perceptually Restoring Deleted Phonemes

A critical issue in modelling speech perception is whether high-level representations (e.g., lexical) can affect the processing at lower levels (e.g., phonemic). Previous research, using studies of phonemic restoration, has provided support for such top-down influences. However, there have been a number of failures to find these effects in restoration studies. This project examined the coming and going of lexical effects, and provided an account of when such effects will and will not appear. Part I demonstrated the fragility of lexical effects and shows that the originally-reported lexical effects are in fact reliable. In Part II, a new methodology was introduced, a methodology that provides very good approximations to the underlying distributions of perceived intactness that are assumed in signal detection analyses of phonemic restoration. This methodology provides a much more sensitive technique for determining the conditions that are necessary for lexical feedback to occur. These conditions were created in Part III, and a reliable lexical influence on phonemic perception resulted. Collectively, the four experiments illustrate that lexical activation does influence lower-level processing, and that these influences are quite fragile. These results for phonemic restoration are consistent with results from several other domains. The theoretical implications of real but fragile lexical effects are discussed.

C. A Test for Lexical Inhibition

In the very influential interactive model TRACE, a critical mechanism is lexical inhibition: The activation of one word is hypothesized to inhibit the activation of others, due to competition between similar lexical items. This project, in its preliminary stages, provides an empirical test of lexical inhibition, with encouraging results. Subjects were presented with a (word or nonword) target visually, followed by the dichotic presentation of monosyllabic auditory stimuli. There were three dichotic cases: word-word, word-nonword, and nonword-nonword. The central question was whether recognizing a target would be hindered by the simultaneous presentation of a (theoretically lexically-inhibitory) word. In fact, exactly this result was observed: words were detected significantly more slowly when they were competing with another real word than with a nonword. This initial result provides preliminary support for TRACE's assumptions regarding lexical inhibition.

D. The Migration Paradigm and Lexicality

Models of speech recognition differ with regard to the potential influence of lexical and semantic knowledge on speech perception. This project addresses the issue of lexical influence through a paradigm that has been little used in speech studies, particularly in English, namely the paradigm of linguistic unit migration. This technique entails presenting an auditory target (e.g., "preferable") followed by a dichotic pair of items where the information necessary for perception of the target has been distributed between the ears (e.g., "priferable"-"glezanukef"). Migration of the missing unit (/E/, in this example), that leads to

the illusory perception of the target ("preferable"), has been shown to tap early stages during the recognition process. This study tested whether the migration phenomenon is affected by the lexicality of the target and the position of the critical unit in the items. The results, although not yet definitive as to the functional architecture of the speech perception system, provide valuable information about the migration paradigm and its sensitivity to several experimental factors.

E. Lexical and Sublexical Facilitation of Perception

Currently, there are two qualitatively different model classes in the field of spoken language understanding. Autonomous models allow only bottom-up information flow, whereas interactive models allow higher level representations (e.g., lexical) to affect processing at lower levels (e.g., phonemic). Part 1 of this project included a test of a prediction that differentiates the two model classes: Is phoneme monitoring faster for targets in real words than in pseudowords, even before the word could in principle be recognized? The results indicate that this lexical advantage does occur, in accord with the predictions of interactive models. In Part 2, speech compression and expansion were used to assess the sufficiency or necessity of bottom-up evidence and of processing time in accomplishing lexical access. The results of Parts 1 and 2 suggested that in addition to the lexical effects posited by current models, sublexical activation may also plan an important role. The two experiments in Part 3 supported this interpretation. Collectively, the experiments in the current study support interactive models of lexical processing, and indicate that additional sublexical processes are necessary as well.

F. Lexical Inhibition and Attentional Effects in Word Recognition

An interesting and relatively unique prediction of the interactive TRACE model of word recognition is that the activation of one lexical candidate inhibits alternative candidates. In one of the only direct tests of this hypothesis, Frauenfelder, Segui, and Dijkstra (1990) found no evidence for it. Three experiments in our lab have shown that such effects may indeed be present, but difficult to find due to attentional effects that are caused by aspects of the experimental procedures. Experiment 1 provided a very clear replication of Frauenfelder et al.'s null effect, using comparable conditions (but English, rather than French, stimuli and subjects). In Experiment 2, changes were made in the details of the experimental design, involving the probabilities of words, nonwords, and the locations of phoneme targets that subjects were supposed to listen for. The manipulations succeeded in shifting the pattern of results, indicating that attentional allocation is sensitive to these factors. In a third experiment, subjects were presented with speech in one ear, and tones in the other, and had to monitor for both specified phonemes and frequency modulations of the tones. This dual-task methodology indicated that both attentional allocation effects and lexical inhibition appear to play a role in the observed results.

G. Are There Lexical or Cognitive Influences on Speech Adaptation?

The selective adaptation technique has been used in scores of studies, and has proven very useful in determining the types of analysis used in perceiving complex sounds. In this project, the technique is used in a slightly different manner than usual. Here, the goal is to find the upper bound on adaptation effects. Previous research has demonstrated adaptation-induced effects at three levels of processing. The most abstract of these three is at roughly a phonemic level of analysis. In four experiments, the current study examines higher levels of representation. The results indicate that adaptation does not operate at these higher levels. For example, the lexical status of the adaptor (word vs. nonword) does not influence the size of the adaptation effect. Similarly, it does not matter if the test items are words or not. Moreover, adaptation is unaffected by whether or not the listener is attending to the adapting sound. Collectively, these experiments indicate that adaptation does not operate at higher levels in the perception of complex sounds.

H. Using Selective Adaptation to Clarify Levels of Analysis

A fundamental goal of an information processing approach to speech perception is to specify the levels of analysis that occur between the initial sensory coding of the signal, and the recognition of the phonetic sequence that it conveys. A series of four experiments provided evidence to support the hypothesis that there are at least three qualitatively different levels of analysis involved in the perception of speech and other complex sounds. The experiments specify several properties for the representations of each level, including a locus (peripheral/monaurally-driven versus central/binaurally-driven), a stimulus domain, and the mechanisms involved in response adjustment as a function of repeated stimulation. The stimulus domains for the three levels are, respectively, (1) processes that deal with simple acoustic patterns, (2) ones that integrate more complex acoustic patterns, and (3) processes that represent categorical or phonetic information. The convergence among several different approaches used to determine levels of analysis supports the three-level model.

I. Perceptual Degradation: Sound-source and Processing Cycle Effects

It has been known for four decades that alternating a message between the two ears (over headphones) causes a large drop in intelligibility when the alternation rate is approximately 3-4 Hz. At faster or slower alternation rates, intelligibility is not impaired. In addition, the critical alternation rate is not a constant -- it covaries linearly with presentation rate of the message. This project includes a large set of experiments intended to determine the mechanisms that cause this non-monotonic performance. The working hypothesis is that the phenomenon is caused by the problematic interaction of two processes that normally allow listeners to perceive complex sounds accurately. One process is sound-source assignment: Incoming sounds must be sorted on the basis of their sources (e.g., a voice must be disentangled from background sounds). The second process is one which

involves successive analyses of an individual sound stream (e.g., a series of analyses of high-information points within the speech stream). The experiments done to date have manipulated the fundamental frequency, and the spectral makeup, of speech signals, as well as more traditional tests using variation in location (right versus left ear). At this point, the results have provided some support for the working hypothesis, but further tests are needed, and are underway.

IV. LIST OF PUBLICATIONS

Pitt, M. A., and Samuel, A. G. (1993). An empirical and meta-analytic evaluation of the phoneme identification task. Journal of Experimental Psychology: Human Perception and Performance, 19, 1-27.

Samuel, A. G. (1994). Does lexical information influence the perceptual restoration of phonemes? Submitted to Journal of Experimental Psychology: General.

Pitt, M. A., and Samuel, A. G. (1994). Lexical and sublexical feedback in auditory word recognition. Submitted to Cognitive Psychology.

Samuel, A. G., and Kat, D. (1994). Early levels of analysis of speech. Submitted to Journal of Experimental Psychology: General.

Wurm, L. H., and Samuel, A. G. (1994). Attentional allocation during speech perception: Evidence from phoneme monitoring. In preparation.

Mattys, S., and Samuel, A. G. (1994). A test of the autonomy/interactivity question with the migration paradigm. In preparation.

Samuel, A. G. (1994). Are there lexical or cognitive influences on the adaptation of speech percepts? In preparation.

V. PERSONNEL

Principal Investigator: Arthur G. Samuel, Professor of Psychology at the State University of New York at Stony Brook. Ph.D. from University of California, San Diego, 1979.

Senior Research Specialist: Donna Kat, B. A. in Psychology from University of California, San Diego, 1979.

Graduate Student: Lee Wurm. Mr. Wurm joined our lab in 1992 and is conducting research funded by AASERT Grant # 93NL174.

Graduate Student: Sven Mattys. Mr. Mattys joined our lab in September 1993, and is conducting research on lexical issues and attention.

VI. LIST OF INTERACTIONS

The P.I. has been extremely active in national service, serving on the Editorial Boards of leading journals. During the granting period, these journals included Cognition, Memory and Cognition, the Journal of Experimental Psychology: Human Perception and Performance, and Perception & Psychophysics. Beginning this January, he will also be on the Editorial Board of the Journal of Memory and Language. He is also a member of the Perception and Cognition Review Panel for NIMH. These editorial and grant review activities provide a rich source of interaction with top scientists from around the country.

Presentations During the Grant Period

Samuel, A. G. Perceptual restoration, perceptual bias, priming, and pseudowords: Insights from a newer methodology. Presented at the Psychonomic Society, San Francisco, November 1991.

Pitt, M. A., and Samuel, A. G. Is auditory word recognition serial or interactive? Presented at the Psychonomic Society, San Francisco, November 1991.

Samuel, A. G. Probing words and pseudowords: Evidence for interactive activation models of word recognition. Presented at the Max Planck Institute for Psycholinguistics, Nijmegen (the Netherlands), August 1992.

Samuel, A. G. Levels of analysis and the roles of attention in the perception of speech and music. Presented at the New York Academy of Sciences, May 1993.

Wurm, L. H., and Samuel, A. G. Can lexical knowledge inhibit phoneme perception? Presented at the Acoustical Society of America, Denver, October 1993.

Samuel, A. G. Is perceptual degradation caused by a confused sound source assignment process? Presented at the Psychonomic Society, Washington, D. C., November 1993.

Samuel, A. G. What makes our perceptual system fail? Presented at the Psychology Department, Princeton University, December 1993.

Samuel, A. G. Levels of analysis of speech and other complex sounds. Presented at the Laboratory of Experimental Psychology, Brussels (Belgium), April 1994.

Samuel, A. G. Lexical and sublexical feedback in auditory word recognition. Presented at the Workshop on Word Recognition in the Spoken and Visual Modality, Brussels (Belgium), April 1994.

Wurm, L. H., and Samuel, A. G. Attentional allocation during speech perception: Evidence from phoneme monitoring. Presented at the Acoustical Society of America, Cambridge (Mass.), June 1994.