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Summary Descriptions of Research for the period December 1989 through September 1990

Institute for the Study of Human Capabilities

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13. ABSTRACT (Maximum 200 words)
During the third year of its URI/AFOSR support, two new psychophysical testing stations were used in cross-modality sensory and cognitive research and a third was constructed for auditory-visual projects. Initial experiments underway with these systems include a visual detection task with auditory cuing, a tactile-visual identification experiment, and a basic investigation of cross modality temporal acuity. A conference was planned during this period, to be held on March 21-23, 1990, on the subject of "Human Error." Conference co-chairpersons will be C.D. Wickens, and C.S. Watson. Other speakers include Herschel Leibowitz, David Woods, Peter Hancock and Susan Dumais, and from Indiana University, S.L. Guth, R. Shiffrin, J.T. Townsend, C.S. Watson, and D. Pisoni. The Institute, by these means, has provided partial support of research leading to the publication, during the past year, of sixteen journal articles and book chapters, and the presentation of nineteen papers at meetings of scientific societies. The Institute has also supported travel by faculty investigators to Air Force research facilities where they participated in discussions of current research projects. Institute investigators gave a series of research presentations to scientists visiting from Wright-Patterson Air Force Base.

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Annual Technical Report

Summary

This Technical Report of the URI/AFOSR–supported Institute for the Study of Human Capabilities, at Indiana University describes work done from December 1, 1989 through November 30, 1990. The Institute currently consists of thirteen affiliated laboratories, in which research is conducted by eighteen faculty investigators and a considerably larger number of graduate research assistants, technicians, programmers, and other staff members. One of the primary goals of the Institute is to provide enhanced opportunities for interactions among these investigators, whose appointments are in six departments (Psychology, Speech and Hearing Sciences, Visual Science, Linguistics, Mathematics, Medical Science) and three schools or colleges of the University (College of Arts and Sciences, School of Optometry, School of Medicine). Another goal is to familiarize scientists who conduct basic research on sensory processing, cognition, and decision making with current problems in the field of human factors, or human engineering. The Institute is also available as a source of technical or scientific advice for researchers in government or industry who are working in areas related to those represented in its laboratories.

We continue to make significant progress toward these goals. The Institute maintains an inter–laboratory, work–station based computer network. This system has been in operation for the past four years and is now in regular use for the exchange of information and, in several laboratories, for data analysis, graphics, and modeling. Another way that the institute–affiliated faculty interact is by attending institute–sponsored seminars presented by visiting scientists, and through other interactions with these visitors. Funds made available through the institute continue to be used to maintain, repair, and in some cases upgrade research apparatus in the affiliated laboratories. The Institute employs several part–time technicians, programmers, and graduate student research assistants who conduct research under the direction of the faculty investigators. One half–time computer systems administrator is employed who maintains the inter–laboratory computer network.

During the fourth year of its URI/AFOSR support, one Institute–supported psychophysical testing station was used in cross–modality sensory and cognitive research by a visiting scientist, Ted Bell from UCLA.

A second conference was planned during this period, to be held on March 20–22, 1991, again on the subject of "Human Error." John A. Swets (Bolt, Beranek & Newman, Boston) and C. S. Watson served as conference chairpersons. Other speakers included Phillip Ackerman, Donald Fisher, Arthur (Dan) Fisk, Robert Sorkin and Susan Dumais, and from Indiana University, G. Bingham, D. E. Robinson, R. M. Shiffrin, L. N. Thibos, J. T. Townsend, and M. O. Wilkinson.

The Institute, by these means, has provided partial support of research leading to the publication, during the past year, of 33 journal articles and book chapters, and the presentation of 37 papers at meetings of scientific societies. The Institute has also supported travel by faculty investigators to Air Force research facilities where they participated in discussions of current research projects.

Personnel

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Charles S. Watson, Ph.D., Director	Professor, Speech & Hearing Sciences Professor (part-time), Psychology
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Introduction

This Third Annual Technical Report of the Institute for the Study of Human Capabilities describes work in several areas, all of which focus on problems of skilled human performance. The Institute's investigators are primarily active in the fields of sensory processes including vision, audition, and touch, and in human cognition and decision making; research in those areas is the major content of this report.

Specific projects continue to focus on human subjects' abilities to use information obtained from visual, auditory, and tactile displays. Both empirical and theoretical studies continue to be conducted. Studies of human cognition include a continuing study of optimal strategies for machine–aided detection and recognition, the integration of information from multiple observations, automatization of perceptual processes, and automatization as a mechanism for overcoming attentional limitations. In hearing, a new theoretical limit is proposed for the discrimination of temporal patterns, while studies of the discriminability of several specific types of complex sounds also continue. In vision dramatic increases in apparent contrast were achieved by manipulating interferometric fringes of fixed retinal contrast, and a project was completed evaluating night–vision goggles, under a sensitivity and resolving power using a wide range of viewing conditions. In collaboration with investigators from other institutions, a multi–channel tactile display for speech reception was shown to achieve very nigh levels of vowel recognition for well–trained listeners.

Research Support. All of the research described in this report has been supported either partially or completely by the URI/AFOSR grant to the Institute for the Study of Human Capabilities. It is emphasized, however, that the majority of the investigators also receive project support from other agencies, as listed on page 43 of this report. Institute funds, while a small portion of the total research support of the eleven affiliated laboratories, are the primary reason for the exceptional interdisciplinary cooperation that has developed among its member scientists, during the past three and one–half years. Institute funds have been used, roughly in order of amounts expended to:

(a) support graduate–student research assistants working on Institute–proposed projects;

(b) provide supplementary technical assistance for equipment design, maintenance, and computer program development;

(c) maintain and enhance apparatus for cross–modality investigations;

(d) support visits to the Institute by scientists interested in application of basic research to human engineering problems;

(e) support travel to scientific meetings for the purpose of reporting Institute–supported research; and,

(e) support a one–half time secretary–administrator, and one–third summer salary for the Institute director, C.S. Watson.

Areas of Research. Current research projects in Institute–affiliated laboratories include studies in the following categories:

I Auditory Discrimination: the psychophysics of auditory capabilities, the limits of auditory attentional capacity, the ability to discriminate signals composed of gaussian noise samples.

II Multi–Modality Testing: research in temporal resolution of multi–sensory cues, an adaptive protocol for estimating cross–modal temporal resolution, and cross–modal equivalence.

III Tactile Discrimination: development of tactile arrays, and studies of interference in tactile localization.

IV Visual Discrimination: human peripheral vision, human visual optics, spatial processing of color information, perception of moving objects, and color theory.

V Bioacoustic Research: sound emission patterns, predictive tracking of moving targets by echolocating bats, and the physiology of bird song.

VI Cognition and Decision Making: multi-stage decision making, perception of multidimensional complex sounds, differences between visual and memory search, connectionist models for auditory and speech perception, use of fault trees, and computer-based instruction.

VII Connectionist Models of Sensory and Cognitive Processes: development and testing of neural networks for identification of polysyllabic words and tonal sequences.

VIII New research in the *Speech Research Laboratory*: speech analysis, synthesis and perception, including word recognition and lexical access.

Form and Content of the Reports. It is not our intention to provide sufficient information in the brief project descriptions included here so that any of this work could be replicated. We believe such detail is best reserved for the descriptions of the work that will be submitted to appropriate journals, and specifically discourage any citation of reports which, like these, have not been through the scrutiny of independent peer review. We do hope, however, that the early knowledge of research that is underway or that, because of publication lags, will not appear for some time in the open literature, may be of value to colleagues who are working in closely related areas. We encourage readers of these brief reports to write to individual investigators if further detail is desired on any of the projects. In some instances draft manuscripts are available, and we will do our best to provide whatever information is requested.

New Projects and Personnel. New projects have been begun during the past year in most of the Institute-affiliated laboratories, as described in later sections of this report. However, a few changes are worth special mention. One is that, after three years of service, Jim Craig has "retired" from his position as Associate Director of the Institute, with the gratitude of the members for his many contributions over those years of the growth of this young organization. Rich Shiffrin has agreed to take on this responsibility, and his cooperation will be especially valuable because he also serves as Director of the University's Cognitive Science program. It seems clear that the applied field of human factors, if it is to move ahead with the rest of the scientific community, will need to adapt to (and benefit from) the "cognitive revolution."

The other personnel change is that we are pleased that David Pisoni's Speech Research Laboratory has become one of the Institute-affiliated research facilities. This merely formalizes the relation Dave has had for several years with ISHC and is appropriate since he is one of the original "card-carrying" members of the Human Factors Society at IU.

In 1989-90 the Institute finally occupied a suite of offices in the Poplars Research and Conference Center, where its administrative work has since been conducted. In 1991-92, work will be completed on the rehabilitation of three small research buildings for Institute projects. Two of these are an anechoic and an echoic chamber, originally part of J. P. Egan's laboratory at IU, but which have been used as storage buildings for the past 10-15 years. The other is a small residence that has been refurbished as a human-subjects testing facility.

Institute-sponsored Symposium. The Institute organized a symposium held on March 21-23, 1990, on "Human Error." Professor Christopher Wickens, Director of the Aviation Research Laboratory at the University of Illinois, served as co-chairman. The purpose of the conference was to review the relation of recent advances in basic research to major applied problems in the field of human engineering. The speakers included members of the Institute and several investigators from other organizations whose work combines basic and applied research in the field of human perception, cognition, or decision making.

Reprints. The bibliography at the end of this report lists articles by members of our research groups that have appeared over the past four years.

The design, conduct, and interpretation of experiments in these reports typically reflects the joint intellectual efforts of investigators, research assistants, and many others who participate in the research projects. While we try to give credit where it is due, the ownership of initial ideas is often impossible to establish. We are only certain of who does the work involved in the collection and analyses of data, and who writes the final papers; those persons are formally recognized through authorship, but often a "group as a whole" is as close as we can come to the source of the original ideas for an experiment or for forms of analysis or, most importantly, for a theory. It is a pleasure, at any rate, to work with colleagues who seem to have an inexhaustible reserve of new ways to think about interesting questions.

CSW

I. Auditory Discrimination

Dimension–specific processing capacity for auditory patterns.
Watson, Kidd

Several recent studies of what we have called the "processing capacity" for complex auditory patterns have supported the conclusion that, when a novel stimulus is presented in a discrimination task, the ability to resolve pattern details on a given dimension is affected by the amount of variation on that dimension. When the amount of variation on a dimension is very low, pattern discrimination is determined by absolute physical values (thresholds). However, when the amount of variation is high, discrimination is determined by the proportion of the pattern that is changed (Watson and Kidd, 1987, 1989). We have proposed that the discriminability of a change in any dimension of a complex sound is determined by the sound's current amount of variation on that dimension. This dimension–specific processing capacity hypothesis has been tested in an experiment that measured threshold values of $\Delta f/f$ for changes in a single target tone in nine–tone patterns. The amount of variation per dimension was manipulated in the frequency and temporal dimensions. Variation on these dimensions was manipulated by including different numbers of frequencies and durations in the patterns. A pattern included three, six, or nine different frequencies and durations. The three levels of variation per dimension were factorially combined to produce nine pattern–variation conditions. Results from one group of three listeners has revealed a considerable decrement in frequency–discrimination performance with increases in the number of different frequencies, but little or no effect with increases in the number of different durations. Thus, at least under these conditions, listeners are only affected by changes in the amount of variation in tonal patterns when that variation is on the same dimension as the change to be discriminated. We are continuing to test other combinations of dimensions and other target dimensions to determine the conditions under which this type of result will hold. Our previous research suggests that not all conditions will reveal this same insensitivity to variation on the irrelevant dimension.

Manuscript in Preparation

Kidd, G. R. and Watson, C. S. (In prep.) Proportional target–tone duration limits auditory pattern discrimination.

The perception of relative–duration information in tonal patterns.
Kidd, Watson

This work continues our research on the perception of relational information in sequences of tones. Our strategy has been to test listeners' abilities to detect changes in a single target tone within a sequence of tones that has been transposed in frequency or time (i.e., a relative–frequency preserving increase on a log–frequency axis or a relative–duration preserving expansion of all tone durations.) Since these changes are defined in terms of relations among the tones rather than the absolute properties of the target tones, the listener must attend to the context tones as well as the target tone to discriminate between changed and unchanged patterns.

We do not yet have as complete a picture for the perception of relative duration as we do for the perception of relative frequency. In the case of frequency transposition we have found that under high uncertainty conditions, even small amounts of transposition of tonal sequences make the task extremely difficult (mean threshold values of $\Delta f/f$ around .2 to .4), but under low uncertainty, listeners do quite well ($\Delta f/f$ around .03).

With time transposition, it is clear that the elimination of pattern uncertainty also results in greatly improved performance overall, but to a lesser extent than with frequency transposition. In addition, we find an interaction of Δt direction and amount of transposition such that performance improves with transposition for positive Δt values, but it deteriorates for negative Δt values. We have found that this is not due to uncertainty with respect to the temporal pattern, the amount of transposition, the pattern rate, or the direction of Δt. We believe that this interaction is based on the relation between the direction of time transposition and the direction of the Δt. It may be that comparison patterns with changes in target–tones that make their durations closer to standard–pattern durations tend to sound like correct transpositions. We plan to test this hypothesis in experiments with time contraction (in which comparison patterns are faster than the standard pattern).

Manuscript in Preparation

Kidd, G. R. and Watson, C. S. (In prep.) Detection of relative–frequency changes in auditory patterns.

Recognition of synthetic speech by hearing–impaired elderly listeners.
Humes, Nelson, Pisoni

The Modified Rhyme Test (MRT), recorded using natural speech and two forms of synthetic speech, DECtalk and Votrax, was used to measure both open–set and closed–set speech–recognition performance. Performance of hearing–impaired elderly listeners was compared to two groups of young normal–hearing adults, one listening in quiet and the other listening in a background of spectrally shaped noise designed to simulate the peripheral hearing loss of the elderly. The results revealed significant effects of both group and talker. Votrax synthetic speech yielded significant decrements in speech recognition compared to either natural or DECtalk synthetic speech for all three subject groups. There were no differences in performance between natural speech and DECtalk speech for the elderly hearing–impaired listeners or the young listeners with simulated hearing loss. The normal–hearing young adults listening in quiet out–performed both of the other groups, but there were no differences in performance between the young listeners with simulated hearing loss and the elderly hearing–impaired listeners. When the closed–set identification of synthetic speech was compared to its open–set recognition, the hearing–impaired elderly gained as much from the reduction in stimulus/response uncertainty as the two younger groups. Finally, among the elderly hearing–impaired listeners, speech–recognition performance was correlated negatively with hearing sensitivity, but scores were correlated positively among the different talker conditions. Those listeners with the greatest hearing loss had the most difficulty understanding speech and those having the most trouble understanding natural speech also had the greatest difficulty with synthetic speech.

Manuscripts and Abstracts

Humes, L.E., Nelson, K.J., and Pisoni, D.B. (In press). Recognition of synthetic speech by hearing– impaired elderly listeners. *J. Speech Hear. Res.*

Speech–identification difficulties of the hearing–impaired elderly: The contributions of auditory–processing deficits.
Humes, Christopherson

The present study examined the performance of four subject groups on several temporarlly based measures of auditory processing and several measures of speech identification. The four subject groups were: (a) young normal–hearing adults; (b) hearing–impaired elderly subjects ranging in age from 65–75 years; (c) hearing–impaired elderly adults ranging in age from 76–86 years; and (d) young normal–hearing listeners with hearing loss simulated with a spectrally shaped masking noise adjusted to match the actual hearing loss of the two elderly groups. In addition to between–group analyses of performance on the auditory–processing and speech–identification tasks, correlational and regression analyses within the two groups of elderly hearing–impaired listeners were performed. The results revealed that the threshold elevation accompanying sensorineural hearing loss was the primary factor affecting the speech–identification performance of the hearing–impaired elderly on both a group and an individual basis. However, significant increases in the proportion of speech–identification score variance accounted for were obtained in the elderly subjects by including various measures of auditory processing.

Manuscripts and Abstracts

Humes, L.E. and Christopherson, L. (In press). Speech–identification difficulties of the hearing–impaired elderly: The contributions of auditory–processing deficits. *J. Speech Hear. Res.*

Modeling the effects of sensorineural hearing loss.
Humes, Jesteadt

We have been investigating a model of the effects of sensorineural hearing loss on auditory perception. The model makes use of the modified power–law with compressed internal noise (Humes et al. #34; Humes and Jesteadt, #61) to describe the growth of loudness with sound intensity. This loudness–growth function has just one free parameter; the exponent of the power–law, P. Optimal values of P have been found to be in the range 0.1 to 0.3 for normal, noise–masked normal, and hearing–impaired listeners. The result is a compressive input–output function that is not unlike those described in auditory physiology. The more rapid growth of loudness (recruitment), observed in listeners with sensorineural hearing loss, is accommodated in the model by simply replacing the normal quiet threshold with the elevated quiet threshold of the impaired listeners. That is, no change in exponent, P, is required for the two groups of listeners.

To make the model more comprehensive, the modified power–law function is incorporated into the excitation–pattern model of Zwicker. The modified power–law model simply replaces Zwicker's equation for the transformation from excitation to specific loudness. Different rules, based on our work on the additivity of masking, are also used in this model to combine the excitation for individual components of complex multi–component signals. Essentially, it is demonstrated that the combined excitation of multi–component signals is more accurately determined if the combination takes place in the specific–loudness domain and is transformed back into excitation, rather than simply combining the excitation, as is typically done. This feature of the model results in a more accurate representation of the peripheral encoding of complex sounds, such as speech, in normal and sensorineural ears than obtained with previous excitation–pattern models.

Rules for the combination of excitation patterns.
Humes, Lee

Excitation patterns derived from masking patterns measured for single–component maskers have been used frequently to estimate the excitation patterns for multi–component stimuli, such as vowels. In doing so, one essentially derives excitation patterns for each component of the multi–component stimulus and then combines the separate patterns using linear power summation. Thus, if the excitation patterns for two adjacent components of a multi–component stimulus produce the same amount of excitation at a given location, then the combined excitation would be 3 dB greater. Recent modeling of masking additivity (Humes and Jesteadt, #61), however, suggests that such a linear combination rule is inappropriate and will underestimate the excitation for multi–component stimuli. To evaluate this possibility, masking patterns were obtained for noise lowpass–filtered at 1400 Hz, bandpass–filtered from 2500–2800 Hz, and highpass–filtered at 4000 Hz. Masking patterns were obtained for each masker separately, for each possible 2–masker combination, and for the 3–masker stimulus. Results are discussed in terms of the rules used to combine excitation patterns.

Thresholds for formant-frequency discrimination in isolated vowels.
Kewley-Port, Woods

The threshold of discrimination of a shift in formant frequency is thought to be in the range of 3-5% based on the frequently cited paper by Flanagan [1955, *J. Acoust. Soc. Am.*, 613-617], and supported in several replications of that germinal study. This range may not, however, represent the limits of resolution in the auditory system because, for most experiments, subjects were not well-trained and stimuli were not presented under minimal uncertainty conditions (i.e. several different stimulus pairs were randomized across trials). Studies with both complex non-speech patterns (e.g., Watson, #18) and speech sounds (e.g., Kewley-Port, et al., #35) have shown these experimental considerations to be important determinants of discrimination performance.

In the present experiments, thresholds were obtained from four well-trained subjects listening to vowels under minimal stimulus uncertainty using an adaptive-tracking paradigm. The stimuli consisted of the ten vowels, /i, I, e, ɛ, æ, a, ʌ, o, U, u/ synthesized from measurements of a female talker. Four formants were specified to generate the steady-state vowels 155 ms long. In the main experiment, the F0 was constant at 200 Hz, although a rise/fall amplitude contour was specified. In the second experiment (called the F0 variation experiment), a subset of vowels with different F0 contours were tested. Thresholds were determined for both increments and decrements in the frequencies of the F1 and F2 formants for each vowel. In each trial, stimuli were presented in a S/2AFC format. Thresholds for each vowel condition were estimated for each subject at a d' = 1. The JND for each vowel is reported as the median threshold value for the four subjects.

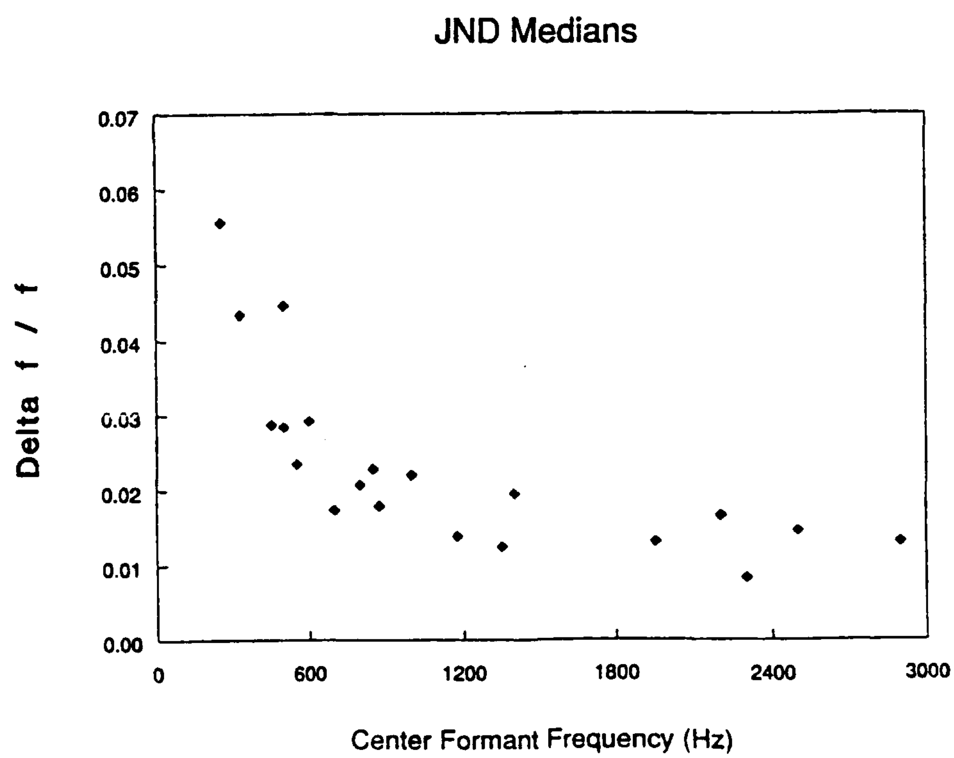

Figure 1

The JND for formant-frequency discrimination under minimal stimulus uncertainty appears to be in the range of 1-2% (Fig. 1). This is a factor of three lower than previous estimates. Significant differences in thresholds are obtained for the same formant by varying the fundamental frequency contour. A model of the differences in the vowel spectra in the auditory periphery can at least partially account for the obtained thresholds.

Manuscripts and Abstracts

Kewley–Port, D. (1990). Thresholds for formant–frequency discrimination in isolated vowels. *J. Acoust. Soc. Am.*, **87**, S159.

II. Multi–Modality Testing

Multi–sensory temporal resolution.
Bell, Watson

Three experiments compare within–modality with cross–modality temporal resolution. Previous experiments have shown departures from Weber's Law, particularly when cross–modal judgments are required, implicating differential contributions from peripheral and central processes.

These studies systematically vary stimulus duration at a constant criterion (d' of unity). The literature (especially Sinex, 1979) indicates that temporal resolution within modality is better than resolution involving multiple sensory modes. Smaller changes in duration are discriminable at fixed performance levels when in a single modality than when multiple modalities are employed. Further, as the duration approaches zero, auditory and tactile within–modality or auditory–tactile cross modality is better than either auditory–visual or visual–tactile comparisons. Only certain conditions lead to departures from Weber's Law, however, that $\Delta T/T$ is constant. These results imply possible categorical processes involving cross–modal resolution and show differences in the point of subjective simultaneity. The present experiment used an adaptive strategy converging on a d' of unity to select stimulus durations. This procedure determines the just noticeable difference in temporal duration at a constant criterion level.

It was necessary first to establish a criterion–free method to study cross–modal temporal resolution. An algorithm was developed that directly computed d' and related measures (b, maximum expected percentage, and actual percentage), and adaptively changed test parameters to converge on a specific value, unity in the present experiment. d' was calculated every 50 trials under minimal– uncertainty conditions. On each trial, the subject compared a fixed time interval (Ts) to a comparison interval (Tc) and responded "same" or "different". The comparison interval was equally likely to be identical to the standard interval or incremented by a constant value, ΔT, that was adaptively changed to converge on d' of unity. After five reversals in direction, the adaptive algorithm was halted and new parameters for the initial ΔT and step size were assigned. The values of Ts were in the range of 60–240 msec, and the initial ΔT in step size were varied depending on the Ts. Subjects were well–trained on judgments of this type and had previously completed approximately 30 – 60 hours of testing.

The algorithm adapts quickly to the just resolvable difference for d' of unity. After 400–600 trials, performance was stable in a narrow range of ΔT. Linear regression lines predicting the ΔT from trial blocks were flat, indicating asymptotic performance. The values for ΔT for each Ts at d' of unity agree with values interpolated from pilot experiments comparing fixed intervals.

Experiment 1: Auditory, tactile and visual temporal resolution: Within– and cross–modality judgements.

Subjects were seven young adult participants recruited from Indiana University. All subjects had normal hearing thresholds and reported no deficits in vision. Subjects participated approximately 120 hours and were paid for their participation. Standard intervals were 40, 60, 120, or 240 msec in duration. The comparison interval was equally likely to be the same or to increase by a fixed ΔT. The intervals were marked by either visual, tactile, or auditory signals.

The vibrotactile stimulator delivers to the fingertip an array of vibrators capable of producing spatial patterns; typically, this device is used to present alphanumeric characters. The tactile stimulus employed in this experiment, however, was an asterisk presented in the center of the array. Visual stimuli were presented on a rapid decay phosphorous screen, and consisted of a small asterisk presented to the center of the screen. The auditory stimulus was a 1,000 Hz–tone of 20–msec duration with 5–msec rise and fall times. The auditory tone pips were presented at 83 dB, SPL.

All stimulus presentation and data collection were controlled by a PDP laboratory computer system, model 11/83 with a real–time 18MHz clock. This processor controlled a Krohn–Height 5500 Ar oscillator as well as a digitally controlled attenuator. An external noise generator was also used, and all three were .outed into a signal conditioning package including a mixer, filter, another attenuator, and a tone shaper for ramping auditory stimuli. The 11c83 processor also controlled high speed phosphor display (model HP 1340 A display and a telesensory systems opticon model R1C). Auditory stimuli were presented monaurally by earphone (model TDH–49 earphones encased in MX–41 cushions). A stimulus response box was also connected directly to the processor.

Within–modality thresholds were generally smaller than cross–modality thresholds over the range of Ts used in this experiment. These results are consistent with previous literature. The ratio of $\Delta T{:}T$ is shown as the average across subjects in the conditions for all modality combinations. The 60–msec duration produced the highest ratios ranging from .4–1.6 and the ratio, rather than remaining constant, decreased with increases in the time interval systematically for all conditions. According to Weber's Law, these results should be relatively flat; these data are monotonically descending. Also, the within modality judgments, auditory–auditory, tactile–tactile, and visual–visual are the flattest of the functions, which would be expected. So although all results deviate from Weber's Law, the within–modality judgments are relatively closer in agreement than are the between–modality judgments.

Experiment 2: Auditory–visual temporal discrimination with increased memory demands.

To estimate contributions stemming from memory processes or central processes, a second experiment examined the effect of increasing the interstimulus comparison time from the 600 msec used in the previous experiment to two seconds. Thus, after the warning light, the standard interval was given, then a 2–sec delay before the comparison interval was presented. Only auditory and visual modalities were employed for this experiment, and the same adaptive procedure converging on d' of unity was used to estimate the ΔT associated with that value.

Three subjects who previously participated in experiment one continued for this experiment, thus, they were very practiced at the task. The ΔT at d' of one were lowest for the within–modality conditions. The auditory–auditory and visual–visual thresholds were lower than the auditory–visual and visual–auditory thresholds. The auditory within–modality thresholds were the lowest of all, averaging approximately 10 msec. The visual thresholds were somewhat higher, at 15–20 msec on the average.

Experiment 3: Auditory–visual temporal resolution at short ISI intervals.

A third experiment was performed to examine the effect of a very small interstimulus interval. The thought was that the first marker for the comparison tone would interfere with the final marker of the standard tone. Thus, the 60 msec interstimulus interval was employed. The hypothesis was that the auditory conditions would particularly interfere with other auditory stimuli and auditory and visual would not interfere with each other since the 60 msec delay is within the backward recognition masking for sensory stimuli.

Subjects had previously completed Experiment 2, thus were well practiced. The results indicated that the within–modality thresholds for the auditory sense were higher than the others, but that the visual sense were not.

These results are probably due to the ability to perceive the four markers as a single percept, a rhythmic pattern, as opposed to discrete markers.

Conclusion:

Cross–modality thresholdss are not in accordance with Weber's law (that ΔT/T remains constant). Within–modality trials were relatively in agreement with psychophysical predictions and were more finely discriminable implicating automaticity and more peripheral processes. Results are robust with respect to the interstimulus interval between Ts and Tc up to 2 seconds or longer. The longer delay did not interfere with the within–modality conditions; this result implies that a central representation must be used even for within–modality comparisons since performance is unaffected by delay. Experiment three further shows that an ISI of 60 msec showed no auditory backward masking effects, thus further implicating a central representation for within–modality judgements as well. Departures from Weber's law may not be due to peripheral versus central markers, but rather to attentional demands and STM processing.

Semantic–phonetic inteference in word recognition: A "Lexical Stroop Effect."

Bell, Hennessey, Byers

Two experiments were conducted to examine the phonetic and semantic processing of words, in particular, semantic–related interference on phonetic or lexical processing. A same/different paradigm was used to measure response times (RT) as a function of phonetic or semantic properties. The stimulus set varied with respect to the phonetic and semantic relationships between pairs of stimulus words, and phonetic and semantic judgements are required of subjects. These conditions allow for comparisons between phonetic, lexical, and semantic influences in word identification processes, and further describe the influence of automatic and controlled processes.

Experiment 1:

Forty homophonic word pairs and their corresponding synonyms formed the stimulus set. Two words were presented simultaneously and the subject was to respond "same" or "different" by pressing a key. There were four conditions varying by the arrangement of homophones and synonyms. One of the conditions (ID) used the same word twice, this condition serves as a baseline. There were three other conditions or Pair types: the two words were either homophones, synonyms, or synonyms of the homophone.

Experiment 2:

A second experiment was designed with a list of unrelated words substituted for the synonym of homophone pairs used in Experiment 1. It was hypothesized that the new unrelated paris would eliminate interference.

Conclusion:

These experiments have demonstrated a "Lexical" stroop interference effect. The automatic semantic processing of a word that means the same as a homophone of the other target word produces interference or response competitions that require additional time to resolve. The "sound–alike" word was automatically activated due to the spreading of the semantic activation. Distinct meanings lead to an ambiguous phonetic encoding, biasing a "same" response when a "different" response would be required. When the semantic component is removed from the distractor condition, the effect vanishes completely. These data imply the direct use of phonetic codes rather than lexical codes in making semantic relatedness judgements. If the representation were lexical or orthographic, there would be no confusion regarding the distinct meaning of words. Therefore, there appears to be a direct downward connection from semantic to phonetic encodings that bypass lexical stages. Further, these data suggest a Parallel Distributed Processing account of this Stroop–like interference effect, specifically requiring continuous automatic processes under attentional control.

III. Tactile Discrimination

Tactile attention.
Evans, Craig

Several experiments examined the ability of subjects to identify the direction of movement of a pattern across the skin. Subjects were required to identify the direction of movement of a pattern presented to one fingerpad (target location) in the presence of another moving pattern presented to an adjacent fingerpad (nontarget location). Subjects were instructed to attend only to the target location. The results showed that accuracy was consistently higher, and reaction times were consistently faster, when the two patterns were moved in the same direction than when they moved in opposite directions. Both effects were largest when the two patterns were presented simultaneously. In an additional experiment, the nontarget pattern was presented to the contralateral hand. In this case, performance was unaffected by the presentation of the nontarget. Taken together these results suggest that movement information is processed across adjacent fingers even when subjects are explicitly instructed to attend only to one finger. Subjects do appear to be able to restrict attention to a single hand.

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Tactile speech.
Weisenberger, Craig, Abbott

A number of devices have been developed for the presentation of speech information to the skin. The present investigation takes advantage of principal component analysis, a statistical data reduction technique designed to eliminate redundant information. Principal–component analysis has shown promising results as a speech coding strategy in auditory perceptual studies. In our device developed using principal component analysis, the first two principal components of an input speech signal were displayed on two– dimensional arrays of vibrators contacting either the fingertip or the forearm. Initial testing of the device with closed–set recorded speech tokens showed fair recognition performance for consonants and vowels. Modifications to the processor algorithm designed to improve vowel recognizability resulted in higher levels of performance. A real–time prototype was constructed implementing the revised algorithm.

Live–voice testing was conducted with 6 normal–hearing subjects, 3 of whom had previous training with the Queen's University vocoder, a multi–channel tactile vocoder that has shown promising results. Performance of these "trained" subjects for both single–item and connected speech tasks was excellent, equalling levels obtained with the Queen's vocoder. These results suggest that a principal components design may be a promising alternative to a vocoder strategy for a tactile aid. Results for the "naive" subjects did not reach the levels attained by the trained subjects, a finding partially attributed to the short training period available to these subjects. The higher levels of performance for the trained subjects, as compared to the naive subjects, suggests that the former were able to transfer learning with the Queen's vocoder to the principal components device.

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IV. Visual Discrimination

A. Human Vision

Contrast perception.
Thibos, Bradley, Wilkinson, Cannon

Unlike threshold vision, several studies have shown that at suprathreshold levels apparent contrast is nearly independent of spatial frequency. Georgeson and Sullivan (1975) used a contrast matching paradigm to demonstrate this phenomenon, termed Contrast Constancy, and hypothesized that a contrast compensation mechanism must be operating during suprathreshold vision to restore previously attenuated contrast at high and low spatial frequencies. The obvious implication of their results, and of their hypothesized contrast enhancement mechanism, is that if the optical attenuation of the eye were to be avoided, then the apparent contrast of grating targets ought to increase with spatial frequency. We tested this hypothesis directly by employing an interferometric stimulator to avoid the eye's optical attenuation due to defocus and diffract ion. When interferometric fringes of fixed retinal contrast were swept from low to high spatial frequencies, contrast enhancement became immediately obvious as a dramatic increase in apparent contrast. This initial qualitative observation was supported quantitatively in two experiments using a contrast matching paradigm. In the first experiment, the contrast of gratings displayed on a natural–view monitor and fixed at 4 c/d were adjusted to match that of the interferometric fringes. Log contrast required in the natural–view grating to match the fringes increased roughly linearly with log spatial frequency of the fringes. In the second experiment, the interferometric fringe contrast was adjusted to match that of the 4 c/d gratings displayed on the natural–view monitor. Log contrast of the fringes required to match the monitor decreased roughly linearly with increases in log spatial frequency of the fringes. The results of both experiments indicate that by using the interferometer to bypass the optical attenuation of the eye, the neural contrast enhancement which normally yields Contrast Constancy is manifest instead as an over–compensation that is measurable as an increase in apparent contrast.

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Spatial vision.
Ye, Bradley, Zhang, Thibos

According to standard geometrical optics, monocular visual direction for a defocused image is determined by the chief ray which locates the center of the resulting blur circle. Recent studies of chromostereopsis have indicated that photoreceptor optics, i.e., the Stiles–Crawford effect (SCE), also affects apparent visual direction of defocused images. Because photoreceptor directional sensitivity peaks near the normal pupil center, marginal rays are less effective stimuli. If the pupil is displaced with respect to the SCE peak, the effective image may be shifted with respect to the chief ray by the SCE. Using wave optical analysis of a simple water eye model with an apodized pupil to account for the SCE, we calculated that visual direction of defocused images is significantly shifted when the model views through a displaced aperture. We have experimentally measured the effect of the SCE on apparent visual directions by comparing perceived visual directions of defocused images when subjects view through a displaced aperture under photopic and scotopic conditions. As our model predicted, the visual direction under scotopic conditions (no SCE) was determined by the chief ray, but visual direction at photopic levels was significantly different by an amount predicted by the midpoint of zero–crossings in the defocused retinal image in the apodized model eye.

Manuscripts and Abstracts

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Chromostereopsis.
Ye, Zhang, Bradley, Thibos

We have shown that, with small pupils, chromostereopsis can be accounted for completely by monocular transverse chromatic aberration induced by displacement of the pupils from the visual axes. However, this simple model, which predicts chromostereopsis by the disparity between the short and long wavelength chief rays, cannot explain our observation that chromostereopsis declines with increasing pupil size. Several hypotheses may be advanced to explain the loss of chromostereopsis with large pupils. First, because of other monochromatic aberrations (e.g. coma) there may be less disparity in the retinal images with large pupils. Second, the neural image may be shifted with respect to the chief ray by the Stiles–Crawford Effect (SCE) such that the optical chief ray no longer determines apparent visual direction. Finally, chromostereopsis may decline with increasing pupil size because stereopsis is degraded with the reduced image quality that accompanies increased pupil size. The latter hypothesis was rejected by the result of a control experiment which showed that changes of monocular visual direction caused by pupil displacements also decline with pupil diameter. Using wave optical analysis of a simplified model eye, we found that the separation between long and short wavelength images caused by pupil displacement is virtually unaffected by spherical aberration and coma, but becomes significantly attenuated when a fixed SCE is included in the model. Experimentally, we tested this explanation by measuring chromostereopsis with large pupils photopically and scotopically. As our model predicted, chromostereopsis with large pupils increased under scotopic conditions where the SCE is almost absent. This result is precisely predicted by the visual direction of the brightest point in the defocused, SCE–weighted, retinal image. We conclude that, at photopic levels, the SCE reduces chromostereopsis for large pupils by altering the apparent visual direction of blurred images.

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Color vision.
Bradley, Zhang, Thibos

Neurophysiological and psychophysical studies of human color vision have sought to selectively stimulate only one of three channels (Achromatic, R/G, B/Y). Isoluminant color modulation along the constant–R&G and constant–B axes isolate the B/Y and R/G systems respectively, while not modulating the Achromatic system. We have shown previously this technique is compromised because chromatic aberrations introduce luminance artifacts into the retinal images of isoluminant grating stimuli. Here we show that lateral chromatic aberration also introduces color artifacts. We modeled the effect of chromatic aberration created by displacing the pupil 0.75mm from the visual axis (3 arcmin between 632.8 nm and 441.6 nm). We examined the effect of this aberration on isoluminant grating stimuli that were modulated through the white point along either the constant–B or constant R&G axes. Such stimuli may be created by mixtures of three monochromatic primaries (632.8 nm, 514.5 nm, 441.6 nm). Because both types of grating require simultaneous modulation of all three primaries, differential phase shifts in the image create the following effects. First, as previously noted, luminance modulations are introduced. Second, the modulation along the desired color axis is attenuated. Third, and most significantly for the isolation technique, color modulations are no longer restricted to a single axis. For example, CIE space, the color modulation of a 5 c/deg R/G grating changes from a straight line into a ellipsoid with the minor axis 20% as long as the major axis. We conclude that experiments which depend critically upon the functional isolation technique may be significantly contaminated by lateral chromatic aberration which can convert a single axis color modulation in object space into a retinal image that simultaneously modulates along all three axes (Luminance, constant–B, constant R&G).

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B. Human Factors and Applied (Clinical) Research

Visual capabilities with night vision goggles.
Bradley, Wilkinson, Thibos, Horner

During the last year, there has been a tremendous interest in the visual capabilities and limitations of current Night Vision Goggle (NVG) technology. The argument in favor of using NVGs is simple: they enhance night vision and therefore expand the range of possible nocturnal activities. The argument against the NVGs is that they do not provide normal daytime visual function and therefore there are many activities that cannot be performed as acurately or safely ith the NVGs. Put succinctly, both arguments are weak because of a glaring paucity of data describing visual capabilities with NVG's. We have performed a detailed evaluation of NVG–aided visual capability with a broad battery of tests that included standard Snellen letter acuity, contrast sensitivity, static vernier acuity, dynamic vernier acuity (e.g. how well can a pilot align a cross–hair with a moving target, or a refueling hose) and depth perception. We compared aided (with NVG) and unaided vision from twilight, Full Moon, 1/2 Moon, 1/4 Moon, Starlight, to Cloudy Starlight. We detailed the gain in visual performance achieved relative to the naked eye over a wide range of light levels, and we specify the results in terms of the increased range of light levels over which a particular criterion performance can be obtained, and the increased performance level achieved at a specific light level.

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Entopic visualization of retinal vascular detail.
Bradley, Applegate

In order to reach the site of phototransduction in the human eye, light must first pass through a dense vascular network in the retina. The vascular supply is essential to the functional integrity of the human retina, and it is symptomatic of and responsible for many types of retinal disease. We have examined the hypothesis that the neural retina supplied by this retinal vascular system can resolve details of the vascular pattern better than the physician with current technology for viewing the retina. Preliminary data from normals support this hypothesis. The value of this observation will be greatly enhanced if patients with retinal vessel abnormalities can detect and monitor their vascular disease.

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Evaluation of clinical tests of contrast sensitivity.
Bradley

Contrast sensitivity has been examined experimentally for over 20 years, but it has only recently become available to the average clinician. Tests of contrast sensitivity are designed to be diagnostic for certain types of disease, but perhaps more important, they provide a more complete documentation of a patient's visual disability. Attempts have been made in the USAF and in several other professions employing visually demanding tasks to include contrast sensitivity as a test procedure by which to select or eliminate individuals. We are in the process of evaluating the sensitivity and reliability of clinical contrast sensitivity tests.

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C. Human Visual Optics

Measurement of ocular chromatic aberration.
Bradley, Zhang, Thibos

Longitudinal chromatic aberration (LCA) of the human eye has been evaluated extensively but there is only one published experimental attempt to measure the ocular chromatic difference of magnification (CDM). Data from that study were inconsistent with the theoretical predictions from known models, perhaps because the magnification difference between short and long wavelengths is likely to be very small (less than 1%). Nevertheless, according to Ogle, stereopsis ought to be sensitive enough to measure an interocular difference of magnification of this magnitude. Accordingly, we have examined the effect of chromatic differences in magnification on the tilt of the Apparent Frontal Parallel Plane (AFPP). Subjects viewed a tilting plane apparatus binocularly. Interocular size differences were introduced using two techniques. First, afocal magnifiers were placed in front of the right or left eyes, and secondly, different interference filters were placed in front of each eye. The experiment was designed to identify the lens magnification necessary to nullify the interocular difference in magnification caused by the chromatic differences in the two monocular images. For example, if there is a long wavelength (e.g. 650 nm) image in the right eye, and a short wavelength (e.g. 450 nm) image in the left eye, the frontal plane appears tilted away from the right eye because the right eye's 650 nm image is larger than the left eye's 450 nm image. We determined the lens magnification necessary to cancel this tilt. Results on three subjects show: 1) Ocular CDM can be considerably less than the published theoretical predictions; 2) Unlike longitudinal chromatic aberration, large inter–subjective differences exist for CDM; and 3) CDM increases when using an artificial pupil in front of the eye. Therefore, current theoretical model eyes need to be modified in order to predict CDM. Also, because axial position of the pupil is a critical determinant of CDM, experimental use of artificial pupils can degrade peripheral retinal image quality for polychromatic stimuli.

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Optical correction of chromatic aberration.
Zhang, Ye, Bradley, Thibos

Visual sensitivity is not uniform across the pupil. Sensitivity peaks near the pupil center and is reduced at the pupil margins (Stiles–Crawford effect or SCE). Is there any functional advantage derived from this property? The SCE can be considered equivalent to apodization of the pupil, but no functional value of this apodization has been observed for well–focused images 1–3. However, the most significant effect of SCE may be to increase depth of focus. Using a wave–optics model of the human eye, we incorporate apodization by changing the pupil transmission function from a uniform function into an SCE function. We calculate the influence of SCE on the OTF with defocus error or ocular spherical aberration. Our results show that (1) Stiles–Crawford apodization significantly improves contrast for defocused images for large pupils, and (2) The Stiles–Crawford apodization is also effective at improving image quality when the eye exhibits significant spherical aberration.

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Retinal image quality and visual performance.
Thibos

The reduced schematic eye (the "water eye") accurately describes the magnitude of both transverse and longitudinal chromatic aberration of the human eye. The modulation transfer function (MTF) of this model, including the effects of diffraction, is easily calculated for monochromatic light and the results integrated across wavelength to produce a white–light MTF. We investigated how sensitive this MTF is to changes of wavelength–in–focus (i.e., the mean refractive error) and to changes in pupil diameter for a typical (2800 K tungsten) white source. The results indicate that both parameters have significant impact and clear maxima exist. For this source, 570 nm is the optimal wavelength–in–focus for any pupil diameter and a 3mm pupil is optimal for any wavelength–in–focus. These results are understandable as follows. Although the model is emmetropic for 590 nm, the weight of the luminous efficiency curve shifts the optimal wavelength–in–focus towards shorter wavelengths. The optimal 3–mm pupil balances the tradeoff between the effects of diffraction for small pupils and chromatic blur for larger pupils.

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D. Event Perception

Visual perception of lifted weight.
Bingham

Observers viewing displays created by filming people lifting weights from 5lbs to 65lbs so that only bright patches attached to the major limb joints can be seen in the displays have been shown to be able to judge the amount of weight lifted. The natural question is how mere motions can provide visual information for amount of lifted weight. The original studies used standard displays in which observers where told the amount of weight lifted. We have replicated these studies without standard displays demonstrating that they are not required for the result. Further, we have varied the size of the lifters from 115 lbs to 190 lbs in displays containing no static information for lifter size (e.g. image size of patches or the distribution of patches) and varied the range of weights lifted by each lifter and shown that observers remain able to judge lifted weights. This implies that the motions provide information for lifter size. Current experiments are investigating this possibility. We have isolated aspects of human lifting motions as potential information, in particular, different types of leans performed to preserve posture in the face of the weight perturbation. Results indicate that these sources cannot account for the accuracy of judgments with full displays.

Visual perception of tree size.
Bingham

Two aspects of the shape of trees are constrained by scaling laws that produce a relationbetween tree size and tree shape. We are investigating tree shape as information about tree size by producing tree silhouettes via computer graphics simulations that have been borrowed from research in tree morphology and that model the physical processes underlying the relevant scaling laws. Observers have been asked to judge tree height merely from the silhouettes, all of the same image size and without any background structure. Results compare favorably with results when the same observers were asked to judge the height of real trees observed around the campus.

E. Perception/Action

Optic flow generated by eye movements.
Bingham

As the point of perspective moves in cluttered surroundings optical texture is revealed or hidden at boundaries corresponding to occluding edges. The point of perspective in the eye is located near the lens and pupil at a distance of about 11 mm from the center of rotation of the eye. Thus, even with the head immobilized, the point of perspective moves as the eye is rotated during eye movements. The resulting accretion or deletion of optical texture occurs at optical boundaries which sweep across the retina in phase with the accretion/deletion. Can observers detect such optical flows? Five observers were tested in monocular viewing. OUs head was immobilized via a biteboard with the center of rotation of the right eye located at the intersection of centerlines extended from 2 optical benches, one lying along the line of gaze parallel to the sagittal plane of the head (straight ahead) and one lying along a line of gaze at a visual angle from straight ahead of either 20!, 30!, or 40! nasalward. Two white surfaces were adjusted via translation platforms with micrometers so that a red area on the rear surface was just occluded by the left edge of the front surface as O looked straight ahead. The amount of red texture revealed and detected as O looked nasally at a target located on the second bench was measured by translating the rear surface to the right until the texture was no longer detected by O (method of adjustment). Twelve configurations of surface distances were tested with the 3 angles of eye rotation. Predicted visual angles of revealed texture somewhat overestimated measured angles. A subsequent test with 4 OUs using a criterion free signal detection method at 2 configurations of the surfaces revealed that the texture could be detected up to the predicted angles.

Object shape as visual information about the center of mass.
Bingham

Grasps are often organized and located with respect to the center of mass in an object. The stability of a precision or pincing grasp is determined by where the axis extending between opposing pincers passes with respect to the center of mass. An axis above the CM results in stabile equilibrium while one below is unstable. Passing the axis through the CM results in neutral equilibrium such that the object will remain at any orientation in which it is placed by rotating about the axis. How might observers visually assess the location of the CM preparatory to a grasp? We investigated symmetry properties as information in planar objects. Objects with from 0 to 4 axes of reflective symmetry as well as objects with various periods of rotational symmetry were used. Observers were asked to place the points of a set of tongs at the location at which that would grab the object to achieve neutral equilibrium in a grasp. The orientation and the size of the objects were also varied. Random errors were significantly affected by both size and symmetry. Systematic errors were affected by orientation. Additional studies were performed to investigate information used in the absence of symmetry.

F. Color Vision

Model for color perception and visual adaptation.
Guth

Figure 1 shows a schematic diagram of a model for color perception and visual adaptation that has been developed by Dr. Guth with full support from the Institute. The model is now "in press" as a major paper in the *Journal of the Optical Society of America*, and it represents an important advance in the visual sciences. That is, given specification of a light being viewed, the model (with few exceptions) allows predictions of the light's detectability, brightness, hue, saturation, and whether or not the light will be discriminably different from other nearby lights or background fields. Furthermore, predictions can be made for vision under any adaptation condition. Although the model requires additional development to extend the luminance range over which it is applicable, and to incorporate spatial and temporal parameters, it already is applicable to an exceptionally large body of data.

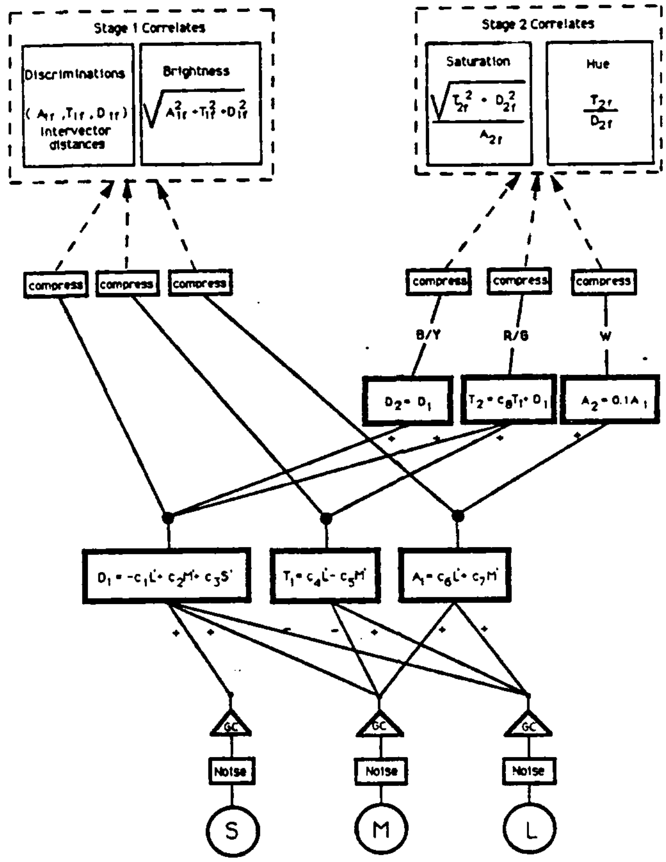

Figure 1

Because the model allows predictions that must be made by engineers and others who are concerned with visual displays and with color problems, the model indicates that a large portion of the basic science of visual psychophysics is soon to be made available for application to practical problems.

This work was carried out with the assistance of Wancheng Wang and Ricky Houghton.

V. Bioacoustic Research

Effect of unilateral denervation on the acoustic output from each side of the syrinx in singing mimic thrushes.
Suthers, Hartley

Microbead thermistors implanted in each primary bronchus of adult male catbirds (*Dumetella carolinensis*) and brown thrashers (*Toxostoma rufum*) were used to record the acoustic contribution from each side of the syrinx before and after unilateral denervation of the syringeal muscles. Thermistors responded to air movement produced by the vibrating syringeal membranes. In these birds, paralysis of the muscles on either side of the syrinx resulted in an abnormal song, but the effect was usually slightly greater after the left side was paralyzed. Denervation of either the left or right side of the syrinx increased the number of syllables to which that side contributed sound. Few or no syllables were produced by the intact side alone and most post–operative syllables contained simultaneous contributions from both sides of the syrinx. The sound generated on the denervated side usually consisted of a fundamental with an abnormally low frequency and multiple harmonics. The frequency of this fundamental typically pralleled changes in the rate of airflow on that side of the syrinx, which in turn followed changes in the driving subsyringeal pressure. Sound from the intact side was essentially normal. The abnormal post–operative song in these birds is primarily due to their inability to regulate resistance or membrance tension on the operated side of the syrinx. We postulate that since the denervated side can no longer be silenced by adduction, its relaxed medial tympaniform membrane vibrates at a frequency determined by the rate of airflow across it.

Manuscripts and Abstracts

Hartley, R.S. (1990). Expiratory muscle activity during song production in the canary. *Respiration Physiology*, **81**, 177–188.

Hartley, R.S. and Suthers, R.A. (1990). Lateralization of syringeal function in the canary. *J. Neurobiology*, **21**, 1236–1248.

Suthers, R.A. (1990). Contributions to birdsong from the left and right sides of the intact syrinx. *Nature*, **347**, 473–477.

Suthers, R.A. and Hartley, R.S. (1990). Effect of unilateral denervation on the acoustic output from each side of the syrinx in singing mimic thrushes. *Society for Neuroscience* Abstracts **16(2)**, 1249.

VI. Cognition and Decision Making

Dynamic field theory of decision making.
Townsend

Over the past year, my colleagues and I made progress on a dynamic field theory of decision making in collaboration with Jerome Buremeyer of Purdue University. This mathematically expressed theory begins establishing a more biologically and psychologically realistic view of decision making. It moves away from the rather static utility theory conception that has been traditional since the work of von Neumann and Morgenstern in the 1940s. Application of the theory to classic experimental paradigms as well as some designs that are better able to exploit the new framework has begun.

Manuscripts and Abstracts

Townsend, J.T. and Busemeyer, J.R. (1989). Approach–avoidance: Return to dynamic decision behavior. In Chizuko Izawa (Ed.), *Current Issues in Cognitive Processing: The Tulane Flowerree Symposium on Cognition* Hillsdale, NJ: Erlbaum Asso.

Busemeyer, J. and Townsend, J.R. (Submitted). Decision field theory: A dynamic–cognitive approach to decision making. (Ms. under revision).

General recognition theory.
Townsend

Development of the General Recognition Theory (of F. Gregory Ashby and J. Townsend) in collaboration with Helena Kadlec of Purdue University has continued. This work synthesizes Townsend's laboratory's previous methodologies using signal detection theory with multi–feature displays and the Ashby and Townsend theory with regard to perceptual independence and separability.

Manuscripts and Abstracts

Kadlec, H. and Townsend, J.T. (In press). Signal detection analysis of multidimensional interactions. In: F.G. Ashby (Ed.), *Probabilistic Multidimensional Models of Perception and Cognition* Hillsdale, N.J.: Lawrence Erlbaum Asso.

Kadlec, H. and Townsend, J.T. (In press). Implications of marginal and conditional detection parameters for the separabilities and independence of perceptual dimensions. *Journal of Mathematical Psychology.*

Self–terminating vs. exhaustive processing.
Townsend

Theoretical development of tests of self–terminating vs. exhaustive processing has continued (i.e., can a very rapid processor, e.g., a "reader", stop when sufficient information has been gained for a response or must it proceed until all items have been processed?).

Manuscripts and Abstracts

Townsend, J.T. and VanZandt, T. (1990). New theoretical results on testing self–terminating vs. exhaustive processing. In H.G. Geissler and H. Schroeder (Eds.), *Proceedings of the International Fechner Symposium.* Amsterdam: North Holland.

VanZandt, T. and Townsend, J.R. (Submitted). Self–terminating vs. exhaustive processes in rapid visual and memory search: An evaluative review. (Ms. under revision).

In addition, work is continuing on *General methodology, epistemology and philosophy of science re: Psychology.*

Manuscripts and Abstracts

Townsend, J.T. (1990). Lefebvre's human reflexion and its scientific acceptance in psychology. In H. Wheeler (Ed.), *The Structure of Human Reflexion.* American University Studies, Series VIII, Vol. 7. New York: Peter Lang.

Townsend, J.T. (1990). Serial vs. parallel processing: Sometimes they look like tweedledum and tweedledee but they can (and should) be distinguished. *Psychological Science*, 1, 46–54.

Townsend, J.T. and Kadlec, H. (1990). Mathematics and psychology. In R.E. Mickens (Ed.), *Mathematics and Science.* Singapore: World Scientific Publishing Co.

Townsend, J.T. (In press). Chaos theory: A brief tutorial and discussion. In *Festschrift for W.K. Estes.* Hillsdale, N.J.: Lawrence Erlbaum Asso.

Townsend, J.T. (In press). On the proper scale for reaction time. In H. Geissler, S. Link, and J.T. Townsend (Eds.), *Cognition, Information Processing and Psychophysics: Basic Issues.* Hillsdale, N.J.: Lawrence Erlbaum Asso.

Townsend, J.T. (In press). The truth and consequences of ordinal differences in statistical distributions: Toward a theory of hierarchical inference. *Psychological Bulletin.*

Comments on linear models: Implications for the lens model.
Castellan

Linear models are widely used to evaluate decision strategies. While some research has been done to show that linear models of various types (regression, equal–weighting, etc.) can give good accounts of performance, most such studies have been simulation studies. This research analyzed the relations between models and bounds for such relations were found and evaluated.

Manuscripts and Abstracts

Castellan, N.J., Jr. (In press). Relations between linear models: Implications for the lens model. *Organizational Behavior and Human Decision Processes.*

Shuffling arrays: Appearances may be deceiving.
Castellan

In experiments and tasks involving the presentation of complex information and in simulations, it often is necessary to permute arrays of data (or stimuli). Although the properties of random number generators have been analyzed extensively, it appears that permutation algorithms have been given only cursory examination. This paper analyzed two widely published permutation algorithms and found that while one does shuffle an array appropriately, the other introduced systematic and serious bias into the permuted sequences. Such bias could have serious implications for research which relied on such an algorithm for shuffling or permuting arrays. (Manuscript submitted and accepted subject to revision.)

Manuscripts and Abstracts

Castellan, N.J., Jr. (In press). Shuffling arrays: Appearances may be deceiving. *Behavior Research Methods, Instruments, and Computers.*

Human factors in computer–based instructional modules.
Castellan, Lamblin

There is widespread use of computer–based instruction in undergraduate education. Software written for this purpose varies widely in the user interface. It is the purpose of this project to evaluate a variety of instructional software from the view of Human Factors design. This evaluation, while comparative, will lead to a final report in which specific recommendations may be made concerning the design of the user interface in computer–based instruction.

Individual and group decision making.
Castellan

Much research has been done on the comparison of individual and group decision making. One seeming paradox which has frequently been reported in research on the problem is that in binary decision tasks, a group may make a different decision than the individuals. (That is, individuals may prefer alternative A, but the group may prefer alternative B.) Many psychologists have worked hard to develop models concerning how the interaction among the members of a group can lead to such reversals. Analytical analysis of the problem has begun and an explanation has been developed for such reversals that does not depend upon group interaction, but a simple pooling of resources. It is too early to tell the full implications of this work, but it suggests that group interaction may involve much less complex processes than some theories allege. A preliminary report on this will be completed in the Spring of 1991.

In addition to these projects, work is continuing on two other long–term projects involving the use of information in decision making. One involves the manner in which information is combined in complex judgment tasks, and examines the conditions under which judgment can be construed as a simple additive or cumulative process, and conditions in which information is combined in complex, interactive ways. The other involves the evaluation of witness credibility when either conflicting or collaborative testimony is also available. Preliminary reports on these projects were given at the Midwestern Psychological Association meeting in May 1990.

Presentations

Castellan, N. J., Jr. (1990). Decision Making: Processing Probabilistic Informaton. Presented to American Psychological Association (Boston, August).

Mendell, L. L. and Castellan, N. J., Jr. (1990). Search strategies in sequential decision making: Information accumulation, search termination, and information presentation effect. Presented to Midwestern Psychological Assocation (Chicago, May).

Pickel, K. and Castellan, N. J., Jr. (1990). Juror's evaluations of relevant and irrelevant eyewitness testimony. Presented to Midwestern Psychological Association (Chicago, May).

Attention and automatism.
Shiffrin

Nancy Lightfoot (a current graduate student) has been following up research begun by Mary Czerwinski (a former graduate student now at Rice and Compaq Corporation) on the mechanisms by which visual search is automatized, the ways in which attentive processes are used to guide search, and the ways in which such attentive processes are learned. Mary's initial set of studies with letters, bigrams, and words established that: 1) Consistent training is not by itself sufficient to establish automatic, parallel, search: The task must use stimuli sufficiently small in number, low in confusability between targets and distractors, and high in similarity between distractors. 2) Under low loads such that automatism can develop in consistent conditions (CM), inconsistent training (VM) can also lead to efficient learning of attentive strategies to the point that the two training regimens (VM and CM) do not show differences. However, a reduction in capacity caused by imposition of a dual task reveals CM advantages due to automatic search. 3) The density of repetitions of stimuli across trials, as well as the total number of trials in all, determines the amount and asymptotic level of automatism that develops. These three sets of results illustrate important limitations on the process of automatization, and demonstrate important effects of learning attentive strategies. They highlight crucial differences between memory search and visual search (suggesting modifications of the Shiffrin and Schneider (1977) theory of automaticity). Nancy Lightfoot has extended these results to search for novel characters. The results confirm the earlier ones, but allow one to examine perceptual learning as well. Enormous effects of unitization of stimuli were observed, such that search slopes dropped from almost 300 msec per comparisonto about 50 msec over 15 sessions of training.

The results are being written up for publication in Shiffrin, Czerwinski, and Lightfoot (1991a) and Shiffrin, Czerwinski and Lightfoot (in preparation).

Memory and retrieval.
Shiffrin

Ratcliff, Clark, and Shiffrin (1990) and Shiffrin, Ratcliff, and Clark (1990) examined the list-strength effect (the lack of a detrimental effect of strengthening some list items on recognition of other list items) and its implications for models of memory storage and retrieval. All models were found wanting, and most could not be modified to handle the results. A version of the SAM model developed by Raaijmakers and Shiffrin could be made to handle the results if item repetitions were assumed to accumulate in a single, stronger, trace, and if a differentiation assumption was added (an item cue activates a stronger memory image that does not match the cue less).

Murnane and Shiffrin (in press, a) extended the results to sentences and fit a quantitative version of the SAM model to the results. They showed that a positive list-strength effect could be produced if the subject could be made to store repetitions separately rather than in one memory image.

Shiffrin (in press) took up the implication of the findings for mechanisms of interference and forgetting, and argued that models positing destructive interference among items at storage were not tenable; such models include many current composite vector and matrix models, and many connectionist and neural net models. Functionally separate storage of items seems to be necessary to handle the list–strength findings.

Murnane and Shiffrin (in press, b) ruled out a variety of alternative empirical and artifactual explanations of the list–strength findings by using end–of–session testing. They also established new empirical constraints that any theory must satisfy, and showed that the augmented SAM model could handle these constraints.

Clark and Shiffrin (under revision) examined limitations on retrieval capacity through the use of cued recognition and a variety of related tasks. They demonstrated conditions under which cues would and would not improve recognition performance (improvement occurs when the deleterious effect of the cue using up retrieval capacity is overcome, either by context sensitive encoding or by unitizing a set of items studied together into a single memory unit and cue).

Manuscripts and Abstracts

Clark, S. and Shiffrin, R.M. (Under revision). Associations, retrieval capacity, and cued recognition. *J. Exp. Psychol.: Learning, Memory, and Cognition.*

Murname, K. and Shiffrin, R.M. (In press, a). Word repetitions in sentence recognition. *Memory and Cognition.*

Murname, K. and Shiffrin, R.M. (In press, b). Interference and the representation of events in memory. *J. Exp. Psychol.*

Ratcliff, R., Clark, S. and Shiffrin, R.M. (1990). The list–strength effect: I. Data and discussion. *J. Exp. Psychol.: Learning, Memory and Cognition*, **16**, 163–178.

Shiffrin, R.M. (In press). Composition, distribution, and interference in memory. In W.E. Hockley and S. Lewandowsky (eds.), *Relating Theory and Data.*

Shiffrin, R.J. and Raaijmakers, J.G. (In press). The SAM retrieval model: A retrospective and perspective. In A. Healy, S. Kosslyn, and R.M. Shiffrin (Eds.), *Essays in Honor of William K. Estes.* Erlbaum Assoc., Hillsdale, NJ.

Shiffrin, R.M., Ratcliff, R. and Clark, S. (1990). The list–strength effect: II. Theoretical mechanisms. *J. Exp. Psychol.: Learning, Memory, and Cognition*, **16**, 179–195.

VII. Connectionist Models of Sensory and Cognitive Processes

A Connectionist approach to the acquisition of morphophonemic rules.
Gasser, Lee

This research is concerned with the question of how people or intelligent machines might acquire the capacity to produce and recognize words. Previous work in this area has focused on the "competence" and the "underlying representations" that are behind linguistic performance. We seek to model the process by which competence arises as the system is exposed to input meanings or forms together with target meanings or forms. We model both acquisition and processing using a simple recurrent connectionist network in which input and output layers include both meaning and form. Formal input consists of sequences of phonemes. We have shown that this approach allows the processes of recognition and production to be integrated into a single system. The key task that unites these processes is that of predicting the next phoneme. Training on this task provides the network with some of the knowledge it needs to perform the recognition and production tasks. Additional training on recognition (input form, output meaning) and production (input meaning, output form) then permits the network to perform both tasks.

In previous work, we have shown that such networks can learn simple morphophonemic rules involving suffixing and prefixing and the model fails to learn reversal rules of a type that are unknown in human language. This year we tested the network on various categories of deletion and insertion rules. In general, we find that the network has more difficulty with rules which are rare or non–existent in human language. While such a network can learn some simple morphological and phonological rules, it cannot handle reduplication. Reduplication requires a short–term memory for recent sequences of segments, one which permits them to be regenerated or to be compared with a later sequence. It is a primacy–oriented memory which is needed, and this type is not available in the framework described above.

A recent experiment was designed to show how, given information about what the syllables in a set of words are, a network could learn static primacy–oriented representations of those syllables which allowed it to learn reduplication rules. The network used consisted of two subnetworks, one trained on prediction at the level of the segment and another on the same task at the level of the syllable. The syllable–level subnetwork showed clear evidence of having learned the reduplication rule.

Modeling the development of the concept of sameness.
Gasser, Smith

This project seeks to develop a neural network model of perceptual and language development in children. We are interested in particular in modeling the perception of sameness relations and the use of language to refer to sameness relations.

The specific aims are:

(1) to develop computational approaches for understanding and studying the nature of developmental change in cognition.

(2) to build a computational model that fits the extant developmental data on one of the most fundamental problems in cognition and behavior, the nature of similarity.

(3) to demonstrate the value of and provide the field with a prototype for studying and quantitatively modelling developmental change.

We model the phenomena of interest using a connectionist network in which visual inputs, lexical inputs and outputs, and internal representations take the form of patterns of activation across sets of processing units. The network consists of two interconnected components. The COMPARISON subnetwork is dedicated to the tasks that make use of the notion of the similarity between two objects. The CATEGORIZATION subnetwork is responsible for associations between "pre-perceived" object representations and lexical categories, as well as among lexical categories. A key feature of the model is that the way in which dimensional input yields internal representations of objects (on the PERCEIVED OBJECT layer) which are usable both in categorization and in sameness judgements.

Our experiments to date have focused on two issues, (1) categorization of objects by attribute and by complex categories, and (2) the use of the same representations in attribute identification and sameness judgement tasks. In these simulations we make use of an approach to training the networks by which the target depends on the system's output. We have shown that it is possible to train a network on categorization tasks using targets which depend on the system's outputs in a manner which is more plausible than a completely supervised approach to learning. We have also shown how the system can learn to factor out dimensions other than the one being questioned and how this ability improves when it is trained on sameness judgement tasks. This result is in agreement with data which indicate that young children's judgements of sameness along a dimension tend to be contaminated by other dimensions.

Published articles

Gasser, M. (1990). Connectionism and universals of second language acquisition. *Studies in Second Language Acquisition*, **12**, 179–199.

Gasser, M. and Lee, C.–D. (1990). Networks that learn phonological feature spreading rules. *Connection Science*, **2**, 265–278.

Lee, C.–D. and Gasser, M. (1990). Learning morphophonemic processes without explicit rules and underlying representations. *Proceedings of the Seoul International Conference on Natural Language Processing*. Seoul: Language Research Institute, Seoul National University.

Presentations

Gasser, M. (1990). Reduplication and simple recurrent networks. Presented at the First Midwest Connectfest, Bloomington, IN (November, 1990).

Gasser, M. and Lee, C.–D. (1990). A short–term memory architecture for learning morphophonemic rules. Presented at the Third Conference on Neural Information Processing Systems, Denver (November, 1990).

Papers accepted

Gasser, M. and Lee, C.–D. (Forthcoming). A short–term memory architecture for learning morphophonemic rules. In D. Touretzky (Ed.), Advances in Neural Information Processing Systems 3.

Lee, C–D. and Gasser, M. (Forthcoming). Where do "underlying representations" come from? A connectionist approach to the acquisition of phonological rules. In J. Dinsmore (Ed.), Connectionist and symbolic models: Bridging the gap. Hillsdale, NJ: Lawrence Erlbaum.

Gasser, M. (Forthcoming). Learning lexical entries with distributed structure [review article]. Neural Network Review.

Submitted papers

Gasser, M. (Submitted). Hierarchies of simple recurrent networks in a model of word recognition and production. AAAI Spring Symposium on Connectionist Natural Language Processing.

Gasser, M. (Submitted). Reduplication in a connectionist model of word recognition and production. 17th Annual Meeting of the Berkeley Linguistics Society.

Recognition of tone sequences by dynamic connectionist models.
Port, Anderson

We are building functional models that can directly process auditory information in time. We employ recurrent networks, that is, networks with many recurrent or feedback connections. These systems 'reverberate' to sequentially presented input patterns that they have been trained to respond (Port, 1990). We believe there may be significant similarities between subject performance on well-learned auditory patterns (Spiegel and Watson, 1981; Leek and Watson, 1988) and the behavior of our recent simulations (Port, 1990; Anderson and Port, 1990). We call the clique of reverberant nodes — the ones that recognize the pattern by tracing a trajectory of activation states which lead to a final state that is distinct for each learned sequence — a Dynamic Memory. This model constitutes an implemented hypothesis about the form of representations used by human listeners when they have learned a complex auditory pattern well. By comparing the performance of various forms of dynamic memory on various tasks with the performance of human subjects (where it is known), we should improve our understanding of human processing of temporal patterns.

Manuscripts and Abstracts

Anderson, S. and Port, R. (1990). A network model of auditory pattern recognition. Indiana University, Institute for the Study of Human Capabilities, Technical Report No. 1.

Network architectures.
Port

Our networks have a set of input nodes corresponding to the channels of a bank of filters, as shown in Figure 1. Melody-like patterns are presented, a spectrum slice at a time. The Dynamic Memory is the next layer of nodes which are fully connected. Its recurrent connections store information about the history of the signal after the training process. The specific response trained into the system was for one of these nodes to produce maximum output for the last two time frames of each target pattern. The gradient-descent teacher-driven learning algorithm we use is known as Recurrent Backpropagation (Williams and Zipser, 1990). This algorithm can be used with fully connected networks such as the Dynamic Memory.

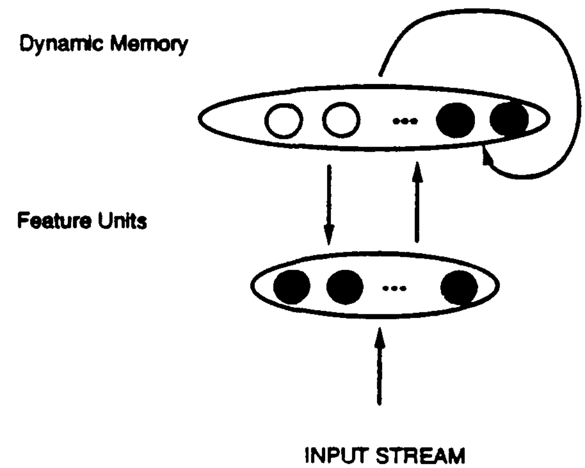

Figure 1. Dynamic network used for the melody recognition task in Anderson and Port (1990). There are five input feature nodes (the note A left out here to reduce the number of nodes) which feed to seven fully connected dynamic memory nodes. Two of the memory nodes are trained to serve as identification nodes: one must turn on and the other off on the last two frames of the two targets. Real-time recurrent learning (Williams and Zipser, 1989) was used to optimize the weights.

Simulation experiments.
Port

A number of simulations were conducted during this year. The stimuli were typically those used in our earlier research (Anderson, Merrill, and Port, 1988). In many of these simulations, the targets were two very similar one-measure fragments of tunes ('Frere Jacques' and 'Ode to Joy') produced by hand on an electronic keyboard which were digitized and FFTd. In one simulation (Port, 1990), the network was fed randomly ordered measures in a stream and trained to recognise occurrences of the two target measures. The response of the dynamic memory to the trained signals is illustrated in Figure 2. The system could generally distinguish two target measures from all others with d' larger than 2.0. When the two most similar target measures were used as the two targets, they distinguished from each other with of d' of only about 1.64. In another simulation, we tested the performance of the network when the tempo was slowed down by a factor of two. After training for recognition of two target sequences at the standard rate of presentation, the network was tested — with no additional training — on stimuli that were slowed down by a factor of two. The dynamic memory produced trajectories for the slow versions that are very similar to the trajectories for the normal-tempo tokens. That is, the model is able to automatically adapt to many changes in rate of presentation. Human subjects are apparently also able to 'automatically' adapt to changes in tempo of presentation (Kidd and Watson, 1989). The dynamic memory system 'listens' in a continuous fashion, without an apriori input window other than the sampling rate of spectral analyses. Of course, this input sampling rate also serves as the rate of internode communication within the network itself, but, unlike other models for auditory memory, the update clock of the network does not control the dynamics of the pattern recognition process. Instead, dynamic memory allows the input pattern itself to entrain the response of the network. Apparently this system is robust enough to handle considerable natural variation in inputs. This is a step toward a continuously functioning dynamically controlled perceptual system for auditory patterns. Further developments will continue next year.

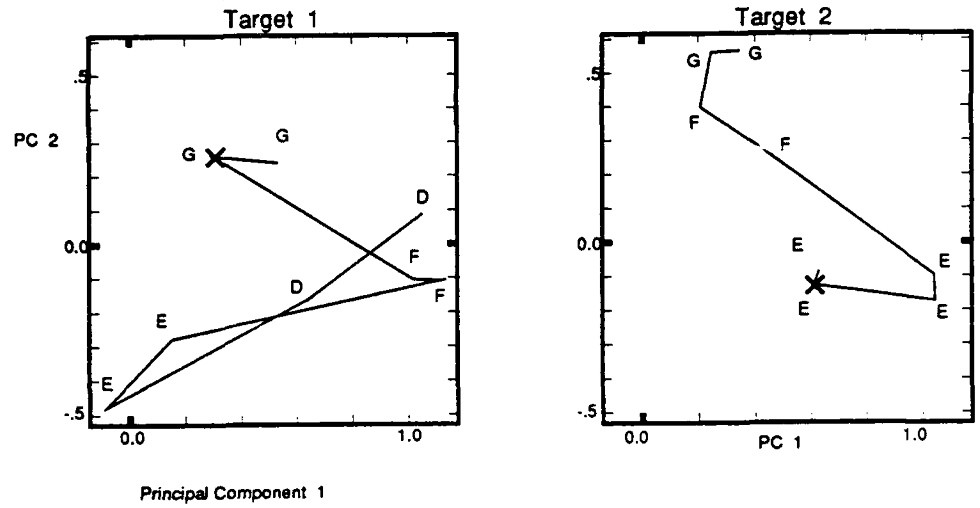

Figure 2. The first two principal components for the dynamic short–term memory node activations. The dark line follows the memory state during the eight frames of pattern presentation. The X marks the second frame. For Target 1, the first two frames were a G, then two Fs and so on. There were eight frames for each target measure and they are connected in the order in which they were presented. Note that similar input notes (e.g. G and F) have very different locations in each pattern. All the non–target measures lie in a single small attractor near the center of the space. See Anderson and Port (1990) for more information.

Manuscripts and Abstracts

Anderson, S. and Port, R. (1990). A network model of auditory pattern recognition. Indiana University, Institute for the Study of Human Capabilities, Technical Report No. 1.

Port, R. (1990). Representation and recognition of temporal patterns. *Connection Science*, 151–176.

Port, R. and Anderson, S. (1990). Dynamic network models for audition. Technical Report Series ISHC–TR01–RP–01. Institute for the Study of Human Capabilities, Indiana University, Bloomington, IN.

Formal properties of cognitive representations.
Port, van Gelder

Since September, 1990, Timothy van Gelder (Philosophy) and Port have been investigating general properties of cognitive representations from a global and philosophical perspective. Their goal is to spell out a conceptual framework for representations in which the traditional formal structures of cognitive science (such as 'perceptual features', classical categories, 'frames', 'declarative data structures', etc.) and the 'distributed representations' of connectionist models (Smolensky, 1988; van Gelder, 1990) can both be seen as special cases. Difficult problems arise if dynamic temporal patterns, such as those employed by Watson (Spiegel and Watson, 1981; Leek and Watson, 1988) or illustrated in our dynamic memories (Port, 1990) are employed as the primitive atoms of a 'symbol' system. How can such primitives compounded into complex units? It appears to us that representational systems can be compared along 3 primary axes. (1) What are the formal properties of the atoms of the system? In particular, are they dynamic or just static vectors? (2) How does compounding of tokens take place? Concatenation, superimposition (Pollack, 1990), or what? And (3) what is the functional role of the symbol–like units? That is, how is control of the executing system managed — from the top down or partly from the bottom up? Our work on this problem will lead to an essay that will attempt to clarify the relationship between the older–style of artificial intelligence (which assumed symbolic primitives) and the new cognitive science. The new cognitive science, in contrast, eschews naive assumptions about static atoms of complex representations. Instead, much more sophisticated dynamic models for sensory processes are relied upon.

Manuscripts and Abstracts

Port, R. and van Gelder, T. (Submitted). Representational systems and language. Manuscript submitted to the American Association for Artificial Intelligence for the Stanford University Spring Symposium.

van Gelder, T. (1990). Compositionality: A connectionist variation on a classical theme. *Cognitive Science*, **14**, 355–384.

VIII. Speech Research Laboratory

D.B. Pisoni

On–going research in the Speech Laboratory is concerned with a wide range of basic and applied problems in spoken language processing. All of these include research on speech analysis, synthesis and perception. Several recent projects have been concerned with spoken word recognition and lexical access as well as spoken language comprehension.

A long–standing research interest has been the development of evaluation and assessment techniques to study the perception of synthetic speech produced by rule. Studies of phoneme intelligibility, word recognition in sentences and comprehension are carried out to learn more about the differences in perception between natural speech and various kinds of synthetic speech produced automatically by rule using several text–to–speech systems. This work also involves studies designed to examine speech perception under high information load conditions, in order to learn more about how listeners allocate processing resources when the signals do not contain the redundancy of natural speech. Other studies are concerned with developing new methodologies to assess the real–time comprehension of fluent passages of connected synthetic speech produced by rule.

Research in the Speech Lab is also focused on acoustic analyses of speech. In one series of studies, supported by a contract with the Air Force, we have been interested in the differences in speech production when the talker is required to communicate in severe environments such as high ambient noise levels or high cognitive load. In another series of studies, we have been interested in the effects of alcohol on speech production. There is reason to believe that alcohol acts as a central nervous system depressant, slowing down the timing of the motor control needed for precise articulation of some speech sounds.

Finally, we have a long–standing interest in perceptual learning, particularly as it might be applied to the reacquisition of non–native phonological distinctions. A major project has been concerned with the acquisition of English /r/ and /l/ by native speakers of Japanese.

The Speech Laboratory is well–equipped with extensive hardware and software for presenting complex acoustic signals to subjects and recording their responses in real–time. Three PDP–11/34 computers are used for perceptual experiments with human observers. There are also extensive computer resources for analyzing acoustic waveforms and generating experimental signals with a variety of speech synthesizers. In addition to the PDP–11/34 minicomputers, the lab currently has a dedicated DEC VAX–11/750 computer system and three DEC VAX work stations that serve as dedicated speech processing stations. The SRL VAX serves as the main computing facility for researchers in the Speech Lab. Each member of the laboratory has a CRT terminal at his/her desk. Additional graphics terminals are located throughout the lab and in several offices in the Psychology building. All computing facilities in the lab are interconnected using Ethernet. In addition, the Speech Lab VAX is interconnected to the campus computing system to facilitate transfer of files to colleagues in other laboratories, both on campus and at other institutions.

Detailed reports of research in the Speech Lab are not included here, in part because that work is more fully described in the annual progress report series entitled *Research on Speech Perception*. Institutions and individuals may obtain copies from the Administrative Assistant, Speech Research Laboratory, Department of Psychology, Indiana University, Bloomington, Indiana 47405.

Research in the Speech Lab has been supported by grants from NIH and NSF and contracts from the U.S. Air Force Office of Scientific Research.

Other Sources of Support

Auditory Research

AFOSR 87–0300 9/1/87–9/30/90	Perception of Complex Auditory Patterns C.S. Watson – $390,411
NIH (NIDCD) R01 DC 00250 12/1/87 - 11/30/92	Discrimination and Identification of Auditory Patterns C.S. Watson – Total Direct Cost, Year 3; $79,913
NIH (NIA) RO1 AG8293 5/1/90 - 4/30/95	Speech Recognition by the Hearing–Impaired Elderly L. E. Humes – $530,000
NIH (NIDCD) RO1–NS14709 (subcontract) 7/1/89 - 6/30/96	Frequency Analysis in Normal and Impaired Listeners L.E. Humes – $188,792
NIH (NIDCD) R43 DC00893 7/18/90–1/17/91	Indiana Speech Training Aid: Stage 2 D. Kewley–Port – $49,828
Indiana Corporation for Science & Technology 2/1/91 - 11/30/91	Indiana Speed Training Aid: Stage 3 D. Kewley–Port – $44,566

Vision Research

National Eye Institute, PHS #R03 EY07638–01 4/1/88–3/31/90	Perceptual Aliasing in Human Amblyopia A. Bradley – Direct costs $24,981
Indiana University Intercampus Fund 7/90–7/91	Evaluation of Potential Visual Function in Cataract Patients A. Bradley, L. Casser, L.Thibos – Direct Costs $5,000
Anti–reflection Coating Council of America 7/90–7/91	A Visual Evaluation of Anti–reflection Coatings A. Bradley, Ross – Direct costs $10,000
NASA Ames Research Center, Moffett Field, CA 2/91–1/93	Visual Capabilities with Night Vision Goggles A. Bradley – $40,000 annually (pending)
NIH (NEI) R01–EY05109 4/1/89 - 3/31/91	Functional Analysis of Retinal Ganglion Cells L. Thibos – Direct costs $59,477
NIH (PHS) SO7 RR7031 L Biomedical Research Grant 11/89 - 3/31/91	Change of Perspective with Eyeball Rotation and Near Space Perception G. Bingham – $9905

Cognition and Decision Making Research

NIH2R01MH12717 12/1/85 - 11/30/89	Information Processing, Search and Retrieval R.M. Shiffrin – $240,604
NSF BNS 8710163 9/1/87– 8/31/90	Research on Identification of Mental System Architecture James T. Townsend – $164,915
NIH PHS R01NS9783–18 7/1/86 - 6/30/93	Cutaneous Pattern Perception J. C. Craig – $997, 361

NIH PHS NIDCD DC00-111
3/1/88 - 11/30/94

Speech Recognition and Spoken Word Recognition
D. B. Pisoni - $1,637,392 (Total direct costs)

Bioacoustic Research

NSF BNS 87-20192
2/1/88 - 7/31/91

Sonar Tracking of Moving Targets by Echolocating Bats
R. Suthers - $267,151

Connectionism

IU Dean of Faculties Multidisciplinary Ventures Fund
Spring 1990 - Spring 1991

A Simulation of the Emergence of the Concept of Same
M. Gasser - $1750

Extramural Activities

C. S. Watson is the director of the Institute for the Study of Human Capabilities and serves as an advisor to the National Research Council's Committee on Hearing, Bioacoustics and Biomechanics (CHABA). He is currently chairman, CHABA Working Group 95, on Personal Speech Perception Aids for the Hearing Impaired. He is also a member of ASA Standards Committees S3–63 on Acoustical Warning Devices, and S3–76 on Computerized Audiometry. Watson serves as a reviewer for the *Journal of the Acoustical Society of America*, *Journal of Speech and Hearing Research*, and *Perception and Psychophysics*.

R.M. Shiffrin serves as the associate director of the Institute for the Study of Human Capabilities. He is the first director of the Indiana University Cognitive Science program and serves on the National Science Foundation review panel for Cognition and Perception. He is consulting editor for *Acta Psychologia*, *Memory & Cognition*, *Psychological Review*, and *Journal of Mathematical Psychology*.

T. S. Bell is an Assistant Professor in the UCLA School of Medicine visiting the Institute as a Research Associate. He serves as a member of the ASA Standards Committee for Revision of the Articulation Index and is a member of the American Psychological Society, American Speech–Hearing–Language Association, and the Acoustical Society of America. He also serves as an editorial consultant for the Journal of the Acoustical Society of America, the Journal of Speech and Hearing Research, Journal of Speech and Hearing Disorders, Perception and Psychophysics, and Music Cognition.

G.P. Bingham serves as a referee for the *Journal of Experimental Psychology: Human Perception and Performance; Journal of Motor Behavior; Ecological Psychology; Behavioral Methods, Instruments, and Computers; Human Movement Science* and for the National Science Foundation. He is a member of the Psychonomic Society, Sigma Xi, the International Society for Ecological Psychology, and the American Psychological Society.

A. Bradley serves as editorial reviewer for the Journal of Neurophysiology, American Journal of Optometry and Physiological Optics, Vision Research, Journal of the Optical Society of America, Clinical Vision Research, Investigative Opthalmology and Visual Science, Ophthalmic and Physiological Optics, Gordon Heath Symposium Papers, Butterworths Scientific Publishers, Optometry and Vision Science, Behavior Research Methods, Instruments, & Computers, Developmental Psychobiology. He is also grant reviewer for National Science Foundation and NIH. He was recently appointed to the editorial group of the "Dictionary of Visual Science" and Program Chair for the 1992 Non–invasive Assessment of the Visual System Annual Meeting.

N.J. Castellan, Jr. is the editor of *Behavior Research Methods, Instruments, and Computers* and *Judgment/Decision Making*, a newsletter. He serves on the editorial boards of *Organizational Behavior and Human Decision Processes*, *Behavioral Decision Making*, *Social Science Computer Review*, and *Interactive Learning International*. He is chair of the Forum on Research Management, one of three standing committees of the Federation of Behavioral, Psychological and Cognitive Sciences.

J. C. Craig recently completed a tenure as Associate Director of the Institute for the Study of Human Capabilities. He serves as a member of special review panels of NSF, NIH, and SBIR as well as having been a member of the NIH Study Section on Sensory Disorders and Language. He recently served on the Task Force on the National Strategic Research Plan for the new National Institute on Deafness and Other Communication Disorders. He is the recipient of the NIH's Javits Neuroscience Investigator Award, July, 1986 – June 1993.

M. Gasser served as co–organizer of Midwest Connectfest, a meeting of connectionist researchers in the Midwest. He is a member of AAAI, Association for Computational Linguistics, ACM, Cognitive Science Society, Linguistic Society of America, and International Neural Network Society.

S. L. Guth is an ad hoc member of the U.S. Committee of the International Commission on Illumination and a Fellow of the Optical Society of America. He is a referee for grant proposals submitted to NIH and NSF as well as a referee for articles submitted to *Journal of the Optical Society of America, Vision Research, Psychological Review, Journal of Experimental Psychology, Perception, Journal of Color Research and Application, Perception & Psychophysics*, and *Science*. Dr. Guth is currently affiliated with the vision group at the Laboratory of Applied Physics of the French Center for Scientific Research in Paris where he is collaborating with Hans Brettel and Francoise Vienot on his color perception and visual adaptation model.

L.E. Humes was appointed this year to the Advisory Board of the new American Academy of Audiology and the Editorial Board of the *Journal of the American Academy of Audiology*. He continues as a member of the Executive Committee of CHABA and as an Associate Editor of the *Journal of Speech and Hearing Research.*

D. Kewley–Port has just finished her tenure as Associate Editor for Speech Processing and Communication Systems of the *Journal of the Acoustical Society of America*. She referees grant proposals for NSF and has served as a member of several NIH review panels. She also reviews manuscripts for *The Journal of Speech and Hearing Research, IEEE Transactions on Acoustic, Speech and Signal Processing*, and *Computer Users in Speech and Hearing*.

G. Kidd is a member of the American Psychological Society, the Acoustical Society of America, the International Society for Ecological Psychology, and an associate member of the Psychonomic Society. He has reviewed manuscripts for *Journal of Experimental Psychology: Human Perception and Performance, Language and Speech, Journal of the Acoustical Society of America*, and *American Journal of Psychology.*

D.P. Maki is a member of the American Mathematical Society, the Society for Industrial and Applied Mathematics, and the Acoustical Society of America and is a Governor of the Mathematical Association of America.

D.B. Pisoni is director of the Speech Research Laboratory at Indiana University. He serves on the editorial boards of *Computer Speech and Language* and *Speech Technology.* He is a recipient of the Jacob K. Javits Neuroscience Investigator Award (1987–1994).

D.E. Robinson continues to serve as a scientific advisor to CHABA and on the Science Advisory Board of the Parmly Hearing Institute, Loyola University, Chicago. In the last year, he served on the paper sorting committee for the Fall meeting of the Acoustical Society of America. He has reviewed papers for the *Journal of the Acoustical Society of America*, the *Psychological Bulletin*,and *Developmental Psychobiology. Manuscripts and Abstracts.*

R. A. Suthers is on the editorial board of *Experimental Biology* and is a reviewer for the *Journal of Comparative Physiology, Ethology, Animal Behavior, Science, Behavioral Ecology & Sociobiology,* and the *Canadian Journal of Zoology*. He has been an invited lecturer at numerous national and international symposia, including being an invited participant in the 2nd International Congress of Neuroethology which was held in Berlin September 10–16, 1989.

L.N. Thibos serves as editorial reviewer for the Journal of the Optical Society of America, Optometry and Vision Science, and Vision Research and as grant reviewer for the Air Force Office of Scientific Research, the National Science Foundation and the National Health and Medical Research Council of Australia. He is a member of the national program committee for the annual meeting of the American Academy of Optometry.

J. T. Townsend recently finished his tenure as Editor of the Journal of Mathematical Psychology, as well as his term on the Executive Board of the Society of Mathematical Psychology. He previously served as President of the Society of Mathematical Psychology. He continues to serve as Associate Editor of Journal of Mathematical Psychology and is a member of many professional societies including: Psychonomic Society, Society for Mathematical Psychology, Society for Judgment and Decision Making, International Neural Network Society, and Mathematical Association of America. Dr. Townsend serves as an editorial consultant and reviewer for a number of journals and granting agencies.

Bibliography

The following is a cumulative list of archival publications by Institute investigators from January, 1987 – November, 1990.

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