**SPECIFIC AIMS**

**Listening** to someone’s voice in a crowded room is a difficult task in many circumstances, but especially so for the hearing impaired. *Behavioral and electrophysiological studies aimed at understanding how we distinguish sounds in an auditory scene have documented that segregation of distinct sound sources, stream segregation, takes time to build up* *(Bregman, 1990; Pressnitzer et al, 2008; Cooper & Roberts, 2007). This buildup process is of considerable research interest, as it is influenced by the strength of streaming cues and by attention (Carlyon; Cusack). We propose a novel approach for describing buildup using ambiguous stimuli which elicit perceptual bistability (Pressnitzer & Hupe, 2006).*

Our goal with this project is to attack the cocktail party problem with new computational methods for data analysis and modeling. Our working hypothesis is that the neural populations which subserve stream segregation can demonstrate bistability between different representations of an auditory scene from unchanging input. We have developed a novel statistical approach to describing buildup*, which relates how long it takes a listener to achieve segregation with an ambiguous stimulus to the dominance durations for each percept. Using the tools of dynamical systems analysis, we propose neuronal-like processes that are sufficient to reproduce these qualities of stream segregation. This may help us isolate the circumstances of success or failure in auditory scene analysis that cannot be accounted for by standard audiological measures.*

*The work proposed in Aims 1-3 is expected to produce novel descriptions and explanations for the dynamics of stream segregation. The positive impact of these results are many and varied; in addition to providing an alternative explanation for buildup, it will introduce new methods for identifying both stimulus-driven and central processes driving segregation, such as strength of streaming cues, timescales of adaptation, and memory.*

***Aim 1: A statistical switching model, without mechanisms for evidence accumulation, can account for the increased probability of stream segregation over time, or buildup.***

*We believe that the buildup psychometric function does not purely reflect the accumulation of sensory evidence, but rather it is just the consequence of averaging over trials of the random and independent switching between two percepts. We are developing a statistical model, an alternating renewal process, which assumes that the independent distributions of percept durations are lawfully related to the buildup psychometric function. The model is consistent with preliminary results from our experiments with both long and short trials with an ambiguous auditory stimulus.*

***Aim 2: Neural competition networks are sufficient to reproduce psychophysical results as well as the behavior of the switching model***

***Preliminary results from an idealized neuronal-like competition model (Shpiro et al, 2009) show good correspondence with the empirical behavioral data. Additionally, we were able to achieve excellent accounting of the competition model’s dynamic buildup and alternations with our switching model. The ad hoc model (general, for perceptual bistability) will be enhanced to reflect feature selectivity, such as tonotopy, so that parameter correspondences in the model become more directly linked to experimental conditions.***

***Aim 3: The effects of previous exposure will manifest in significant changes in both buildup and alternation statistics***

***With new experiments which manipulate previous context, we can measure stream segregation probability, buildup, and alternations in a dynamically changing auditory scene that engages centrally-controlled processes like short term auditory memory. We expect to see a strong effect towards stability of perceptual state during changes, for which, using the computational models we have developed, we make detailed measurements and propose potential mechanisms.***

***3. BACKGROUND AND SIGNIFICANCE***

***While great advances have been made in understanding and improving hearing sensitivity, the processes that allow listeners to segregate sounds belonging to different sources in a dynamically changing auditory scene are still poorly understood. Our research program, if successful, will both advance basic understanding of how the brain groups and identifies sounds and produce novel quantitative techniques that may be useful in experimental analysis and patient assessment.***

***This research has the potential to advance basic research both conceptually and methodologically. A critical barrier to progress in the field of auditory scene analysis is the lack of quantitative descriptions of the dynamic processes that underlie stream segregation. Current models for the neural basis of stream segregation include grouping by coactivation (Micheyl et al, 2005; review), which performs segregation using a discrimination threshold under signal detection theory, and a temporal coherence model (Elhilalai, Shamma). While these methods are useful for determining the steady-state likelihood of segregation for different stimulus parameters, they address neither the time-varying changes in segregation probability nor of stimulus parameters.***

***Of particular interest is the phenomenon called buildup, for which probability of segregation for an unchanging repeated stimulus increases with time from stimulus onset to a steady state value. The standard qualitative account of buildup cites evidence accumulation as the driving factor in the evolution of segregation probability (Bregman, 1990). We introduce novel applications of dynamical models that can quantitatively describe how buildup occurs. Our statistical model (Aim 1) provides an alternative to the accumulation account, which attributes buildup to alternations between bistable perceptual states. The observation of perceptual bistability (Pressnitzer & Hupe, 2006) for ambiguous auditory stimuli enables the application of the alternating renewal process model, and is also indicative of a competitive neuronal architecture (Wilson & Cowan). We are working with ad-hoc neuronal-like models (Aim 2) to describe the interactions between neural populations (eventually networks) representing different groupings of the auditory scene. These simulations also reproduce the dynamic changes in likelihood of segregation for unchanging auditory input. The assumption that the neural networks involved undergo bistability allows us to predict how subjects should perceive dynamically changing auditory stimuli, and the effects of previous context (Aim 3)-- for instance, because of hysteresis, perception in a dynamically changing scene depends on previous stimuli and perceptual state. These results represent a conceptual overhaul of the buildup process, and advance the field's understanding of the neural bases of stream segregation.***

***Along with these conceptual advances, the proposed research should improve methodological difficulties in studying buildup specifically and auditory scene analysis in general. The study of neurophysiological mechanisms of stream segregation is difficult because stimuli and timescales are poorly suited for fMRI, with its loud environment and low temporal resolution. ERP/MEG are more appropriate in timescale, but requires averaging over many events and cannot elucidate trial-by-trial effects. Electrophysiology on animals is useful but limited by the ability of animal models to reliably respond on the basis of their higher level perceptual state. By using subjective reports from psychophysical experiments to inform computational models, we can circumvent these difficulties. Our statistical model (Aim 1) allows easy interconverting between a number of data types-- from duration distributions to buildup functions, or vice versa. It allows comparison between data from short or long trials, with fixed or changing parameters. Our mechanistic models (Aim 2), while presently divorced from electrophysiological measurements, will enable better estimates for the strength of cues for segregation and integration, intrinsic noise, and characteristic timescales of processes like adaptation, inhibition, temporal integration and memory. The employment of computationally-motivated psychophysical investigation, eg, measuring the bandwidth of auditory filters, has historically been a major stepping stone for understanding the features of the auditory system, and we expect the results of our experiments (Aim 3) to yield techniques for estimating dynamic features of higher level auditory processing, eg, time window of short term auditory memory. In addition, while presently optimized for application to psychophysical data, our techniques are in principle appropriate for any measurement of a buildup function.***

***While the primary impact of our proposed work will be on basic research, there is ample opportunity for translational application by our group and others. The patient populations demonstrating difficulty with stream segregation are many and varied. Furthermore, deficits in auditory scene analysis are persistent even with apparent success of interventions to restore basic hearing. The NIDCD has identified a disconnect between the success of interventions for hearing loss on standard audiometric and hearing aid performance measures versus subjective outcomes (PAR-12-101), citing interference from background noise as a common reason for dissatisfaction among patients. Deficits in (or even absence of) stream segregation appear to be present as well in patients with cochlear implants (Huw & Cooper, 2009), even when performance on tasks using more elementary auditory functions like pitch discrimination is reasonably good. In addition, there are a number of patient groups displaying difficulties with higher-level auditory processing in the absence of audiological markers; people with auditory processing disorders (Moore 2006), schizophrenia, and Alzheimer's disease.***

***4. PRELIMINARY STUDIES***

***RESEARCH DESIGN AND METHODS***

***Overview: We are testing the applicability of an alternating renewal process model to describing the buildup function on perceptually ambiguous auditory stimuli. This model describes a system that alternates between two states, with durations in each state described by two independent gamma distributions. If the starting state of the system is known, then the probability over time of being in the other state will change from zero to a steady state value.***

***Subjects:***

***Stimuli:***

***Analysis:***

***Potential Pitfalls: Inertia-- previous investigators have shown that the first percept is characteristically longer than other coherent percepts throughout a trial.***

***Approach- Aim 2***

***Overview:***

***Approach- Aim 3***

***Overview: The experiments undertaken in Aim 3 will provide data on the effects of auditory context on the dynamic properties of stream segregation, and will explore the effects of changing stimulus parameters continuously within a single presentation. The models and analysis proposed in Aims 1-2 will be used and updated to describe the experimental data.***

***Subjects:*** *Ten healthy adults will participate in the experiments. They will be screened for normal hearing thresholds and family history of hearing loss.*

***Stimuli: We will use a repeating ABA\_ stimulus, with A and B being pure tones at two different frequencies separated by some interval (dF, semitones). Two types of stimuli will be constructed- static and dynamic. Static stimuli will have fixed dF throughout a trial. Dynamic stimuli will vary dF continuously throughout a trial.***

***Task: Subjects hold down one of two buttons to indicate whether they hear an integrated percept with a galloping rhythm, or a segregated percept with two regular tempi. They continuously report their percept throughout the length of the trial. These button presses are binarized and sampled discretely to form experimental timecourses.***

***Experiment 1: Static stimuli will be 20 second sequences of ABA\_ (about 40 triplets) with one of four fixed dFs- 3, 5, 7, and 9 semitones between the A and B tone. There will be 20 trials for each dF condition.***

***Analysis: We will average over trials and subjects to construct buildup curves for each dF condition. From the buildup curves and experimental timecourses we will obtain estimates gamma parameters for duration distributions for both integrated and segregated percepts, using fits from the ARP model (Aim 1). We will use the statistics gathered from short trials to predict the dynamic behavior for long trials, and then test with long trials (4 minutes, 3 trials).***

***Experiment 2: Dynamic stimuli will be 120 second sequences of repeating ABA\_ with dF slowly varying over the range used for static stimuli, either ascending to descending, or descending to ascending. There will be 30 trials for each sequence.***

***Analysis: We will generate predictions for likelihood of segregation as a function of time in sequence, and evolving dF values, using the gamma parameters we obtain in Experiment 1. We will use Monte Carlo simulations based on random samples from these and interpolated distributions (for intermediate dF values), using the alternating renewal process to generate percept duration samples composing simulated timecourses. These simulated timecourses will be averaged and compared to the averaged experimental timecourses to determine whether probability of stream segregation in a dynamic scene can be predicted by the steady state statistics of fixed scenes.***

**Experiment 3: *The dF will be chosen based on the results of experiment 1, such that both integrated and segregated percepts are possible and buildup is not too fast or slow, but likelihood of segregation at the end of the trial is high, eg 7 semitones. When a trial ends, one of five silent inter-trial intervals (ITI) will intervene-- 1.2, 2.4, 3.6, 4.8, and 6 seconds.***

***Experimental timecourses will be averaged to construct buildup functions for each preceding ITI. We will then calculate the change in probability of segregation during the first 1 s as a function of ITI, and use that function to fit parameters for mechanistic model simulations.***

***Potential Pitfalls:***

***In our first experiment, we will***

***we will measure buildup functions and derive duration distributions using ARP model (Aim 1) for several different dF's in static presentations. We will then present a dynamically changing auditory scene that slowly progresses through all the dF's tested statically. Using the steady state statistics (ie parameters of duration distributions for each perceptual state) we collect for static presentations we should be able to simulate the likely responses to dynamic presentation, so long as the variations in the parameters are slower than the characteristic dynamics of the alternations.***

1. ***ABA\_ stimulus- measure buildup from silence for a number of frequency differences (dF), maybe show a plot of van Noorden***
2. ***Construct slowly varying ABA\_ stimulus that progresses through the dF's measured at a certain rate***
3. ***Interpolate the statistics gathered for each dF to match the rate of variation***
4. ***Simulate perceptual timecourses by drawing from the interpolated distributions according to ARP***
5. ***Average over the simulated timecourses, compare to averaged experimental timecourses***

***Simpler experiment: vary the gap between short trials from 0.5-20 seconds***

1. ***Explain the importance of the problem or critical barrier to progress in the field that the proposed project addresses***

***- we don't have a quantitative understanding the dynamic processes contributing to stream segregation***

1. ***Explain how the proposed project will improve scientific knowledge, technical capability, and/or clinical practice in one or more broad fields.***
   1. ***Knowledge- propose possible central mechanisms that could show the kind of behavior we see with stream segregation***
   2. ***technical capability- could help with cochlear implants?***
   3. ***Clinical practice- could lead to improved assessments and long term measure***
2. ***Describe how the concepts, methods, technologies, treatments, services, or preventative interventions that drive this field will be changed if the proposed aims are achieved.***
   1. ***Concepts in the field- largely depend on accumulation. We don't look at accumulation, we look at alternation, which is characteristic of a specific known type of brain architecture***
   2. ***methods- data from long and short trials can be compared; better estimates can be made for stimulus strength, adaptation, underlying distributions, characteristic timescales***

*Continue training in dynamical systems theory, auditory psychophysics and mechanistic computational modeling (with or without neural, patient data). Training in clinical research?(?!?)*

*Develop assessments of “strength” of representations subserving integration / segregation, both from examining sensory cues/stimulus characteristics as well as from behavioral responses*

*SIGNIFICANCE*

*translational*

* *NIDCD issued “Development of Measures to Determine Successful Hearing Health Care Outcomes”*
* *cite failure of speech recognition measures as “gold standard” of HA evaluations*
* *predictors of successful hearing aid fittings are external to both the hearing aid and audiological status of patient (as currently assessed)*
* *standard audiometric assessments are not strong predictors of success for non-severe HL.*
* *Even severe HL can show recovery on standard audiological exams with persistent deficits in everyday experience.*
* *CI listeners have been shown to have characteristically distinct responses to the standard van Noorden stimulus for stream segregation-- failure to respond to tone repetition rate (Huw & Cooper, 2007). May be only demonstrating channel discrimination.*
* *Even more disturbing than the failure of intervention for HI patients to restore ordinary auditory processing is the prevalence of deficits in segregation for people who demonstrate otherwise normal hearing- patients with auditory processing disorders, dyslexia, schizophrenia...*
* *NIDCD has identified a need to distinguish patients with APD, SID, and dyslexia*
* *Moore (2006) has identified the need to use non-verbal assessments to diagnose APD*

*basic*

* *central mechanisms of auditory system are poorly understood*
* *many current models only describe frequency discrimination*
* *study of neurophysiological mechanisms of stream segregation is difficult because stimuli/timecourse are poorly suited for a scanner, ERP/MEG gives little info for brain locus and animals cannot reliably report complex percepts*
* *combination of psychophysical and computational techniques is excellent for identifying characteristics of peripheral channels, and should also identify central processes.*
* *Our approach specifically targets top-down contributions to stream segregation likelihood, such as previous exposure and context.*

*Technological*

* ***better CASA will lead to better technologies for sound segregation, such as speech recognition, which will lead to new avenues of intervention for patients suffering from ASA deficits.***

***Titles: Dynamical systems theory for fixed and dynamically changing auditory environments***

***PROJECT NARRATIVE***

***Difficulties listening in the presence of background noise are persistent in hearing impaired (HI) patients and a number of other patient groups, despite advances in interventions to improve hearing sensitivity. This project will develop inexpensive, computationally driven techniques for evaluating and describing listeners' dynamic abilities to segregate sounds in auditory scenes that change over time.***

***TO GET ELYSE's RESULTS WITH CONTEXT STIMULI iN DIFFERENT FQ BANDS:***

***maybe put recurrent excitation in the feedforward stimulus-driven network, such that the identity of the frequency bands contributing to coherence/segregation cues matters for memory/ state maintenance.***