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EFFICACY OF THREE BACKWARD MASKING SIGNALS

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Efficacy of Three Backward Masking Signals

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Declaration

I hereby declare that the work contained in this report has never been submitted for a degree in any other university. To the best of my knowledge, this report contains no material previously published or written by another except where due reference is made within the report itself.

I further declare that the ethical procedures and principles determined by the University of Montana's document on human research and experimentation have been adhered to in the preparation of this report.

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A Comparison of the Efficacy of Three Backward Masking Signals

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Abstract

Increased backward masking has been correlated with Auditory Processing Disorders (APD). An efficacious test of the backward masking function that is compatible with naïve listeners could have clinical utility in diagnosing APDs. In order to determine an appropriate probe for such a test, three 20-ms signal-types were compared for ease-of-task. Response times (RT) were taken as a proxy for ease-of-task. Seven participants used a method-of-adjustment to track threshold in the presence of a 50-ms broadband-Gausian-noise backward-masker. The signal-types yielded two comparisons: Linear rise-fall on a 1000Hz sine-wave versus a "chirp" (750 Hz-4000Hz); Linear rise-fall vs Blackman gating function on a 1000Hz sine-wave. The results suggest that signal-type is a significant factor in participant response time and hence, confidence. Moreover, the contribution of signal-type to RT is not confounded by any potential interaction terms, such as inter-stimulus interval (ISI). The signal-type that yielded the quickest RTs across all participants, ISIs, and intensity levels was the 20-ms, 1000 Hz sine-wave fitted with a trapezoidal gating function. This may be the most efficacious signal-type to serve as a probe in a clinical test of backward masking.

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CHAPTER ONE

Introduction and Review of Literature

Introduction

Backward masking is a phenomenon that affects sensory perception. It occurs whenever the perception of a target signal is obscured by the advent of another signal that follows it in time (Raab, 1963). Backward masking is a special case of temporal masking, which is to say, the signal and masker do not have synchronous onsets or offsets. Masking can occur in every perceptual domain; for example, a very strong smell can mask a weaker smell (Geldard, 1953), or a bright flash of light may hide a dimmer one (Breitmeyer & Ogmen, 2000). In terms of language, one speech sound may mask another and degrade the understanding of speech (Repp, 1975). The current study is concerned with masking in auditory system, and in particular, the backward masking effect on the detection of auditory stimuli.

Many auditory backward masking studies have been conducted over the last 60 years; researchers have modeled the auditory system by describing its breakdown under masked conditions (McLachlan & Wilson, 2010; Carlyon, 2004; Grimault, et al., 2002; Braida & Durlach,1988; Cudahy & Leshowitz,1974; Elliot,1964; Guttman, et al., 1960;Garner & Miller, 1947). Masking in the auditory system has proven to be one of the most powerful tools to investigate the parameters of central (i.e., cognitive) and peripheral (i.e., perceptual) processing (Watson, 1987). Differences in auditory thresholds between individuals, under a backward masking condition, have been correlated with auditory processing disorders (APD) (Hartley & Moore, 2002; McArthur & Hogben,

2001). In fact, Massaro (1972) proposed that masking could be used to draw inferences about individual processing speed. APDs are concomitant with many diagnoses and have etiologies that are congenital, developmental, neurogenic, or toxic-metabolic in nature.

Abnormalities in backward masking profiles may present in persons with language processing disorders and hence have implications in the perception of speech (Johnson, et al., 2007; Marler & Champlin, 2005; Marler, et al., 2002). Temporal masking has been shown to conform to a broader masking principle known as the "upward spread of masking" in which a lower frequency masker will obscure a higher frequency target but not *vice versa* (Oxenham & Moore, 1995; Murnane & Turner, 1991; Lumer, 1985). This property makes backward masking a likely factor in speech processing disorders because vowels, which have higher amplitudes due to their periodicity, sonority, and longer duration, are defined by relatively low frequency formants, and often follow consonants that are acoustically weaker and have important phonological cues in a high frequency range (Repp, 1975; Pisoni & McNabb, 1974; Kirstein, 1973). Speech sounds within a speech stream follow each other very rapidly, often on the order of milliseconds, so that an initial consonant could be masked in a person with a normal audiogram because retrograde masking from the following vowel could spread upward in frequency, and obscure the distinctive features that mark the consonant. Degradation of speech features could contribute to decreased speech perception in the absence of pure tone hearing loss.

Backward masking appears to increase as a function of age in decade increments (Strouse, et al., 1998). Comparisons between younger and older adults have revealed a pattern of exponential decay in absolute sensitivity under backward masking conditions

(i.e., in a backward masking experiment) with increasing age even when absolute sensitivity without the masker has been controlled for (Vander Werff, & Burns, 2010; Gehr, & Sommers, 1999; Cobb, et al., 1993). Further research, using auditory evoked potentials (e.g., Electro Encelphelography (EEG), Auditory Brainstem Response (ABR), etc.) to objectively study the transmission of acoustic stimuli up the auditory pathway, has examined the increased backward masking found in children with specific language impairments (Johnson, et al., 2007; Marler, & Champlin, 2005). Age-related differences in masking patterns have been noted between children and adults. For example, Buss, et al. (2000) noted a 12.5 dB group threshold difference under a backward masking condition between adults and children, with adults having the better threshold, whereas the two groups maintained equivalent thresholds under simultaneous masking conditions. Allen and colleagues (1998) reported similar results but tested for differences in the use of auditory cues with age. Adults appeared to integrate multiple cues (spectral[1], temporal, frequency) while children relied on temporal cues alone, which are less available to the auditory system under temporal masking conditions (Hirch, 1959; Puleo & Pastore, 1980). The large body of research in this area has illuminated the presence of backward masking during oral language perception.

Despite the plethora of research, backward masking has remained a phenomenon that is instructive to the basic scientist, but limited in its clinical application. The methods used to test backward masking are various, with carefully controlled experimental conditions and vetted subject-participants. Despite their abstract and carefully curated

[1] "Spectral" in a psychoacoustic context refers to the harmonic envelope of complex stimuli (i.e. the relative intensities of the harmonic components of a tonal complex).

nature, these tasks remain obscure and difficult for all but highly trained listeners to accurately and reliably complete (Amitay, et al., 2006). Moreover, inter-study and inter-rater comparisons show transitory effects that are listener and stimulus dependent (Leshowitz & Cudahy, 1973; Sparks, 1976; Yost, et al., 1976).

These complications do not affect the relevance of backward masking to basic research into auditory processing, but they do call into question its validity or reproducibility in a clinical context.

Three significant questions have driven research into backward masking: *1)* what is the neural locus of temporal masking, *2)* can it help to develop and test accuracy of neural processing models, and *3)* does the backward masking function have clinical implications. Research has focused on the first two of these approaches (Oxenham & Moore, 1994; Plack & Moore, 1990;Oesterreich, 1966); however, there is a dearth of experimentation that targets clinical application (for exceptions see: Marler & Champlin, 2005; Helenius, et al, 1999; Festen & Plomp, 1981). Backward masking studies in aged, hearing impaired, and other populations with auditory processing disorders imply a diagnostic potential for a concise and reliable test of backward masking.

The backward masking function describes the relationship of masker-probe-proximity to the amount-of-masking, which is defined as the change in threshold for detecting—or in some cases discriminating—the probe from the unmasked to the masked condition. Under most conditions, the backward masking function has a broader temporal window in which it operates than a corresponding forward masking condition. However, the curve of the backward condition may be described with a decaying exponential

function, whereas the corresponding forward condition may be modeled by a line with negative slope (Figure 1).

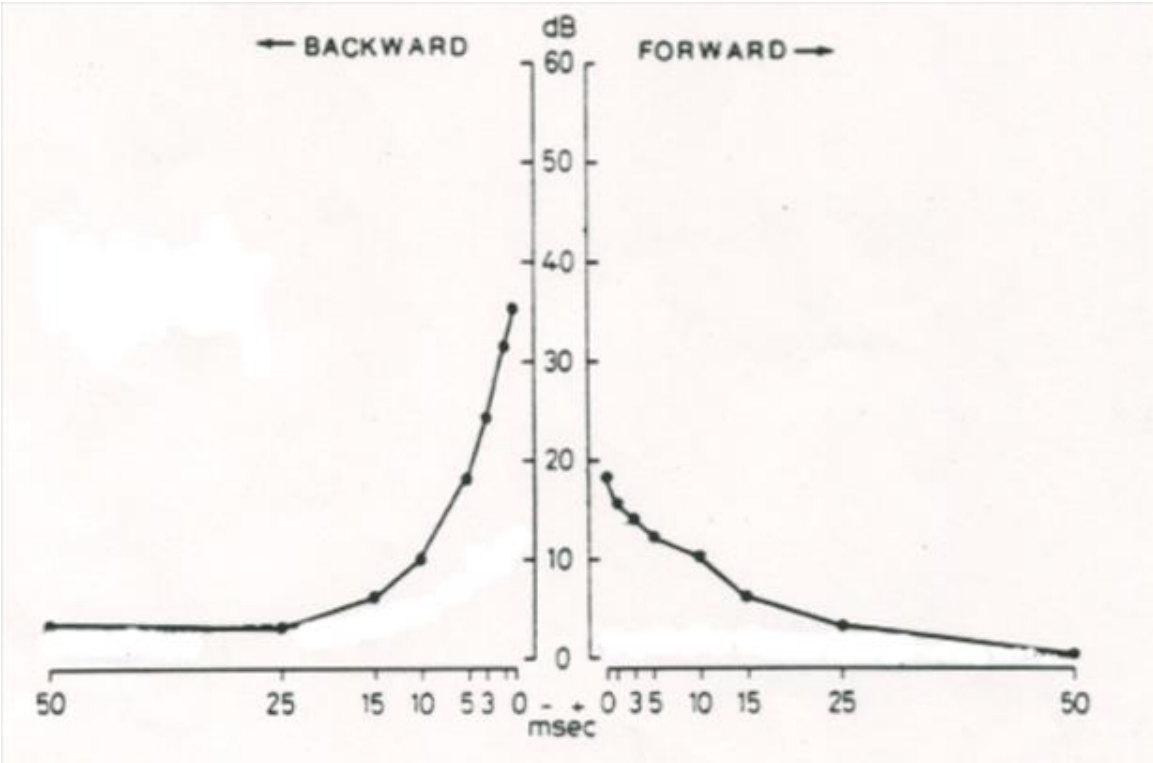

Fig. 1: Backward vs Forward masking curves (Eliot, 1964)

Backward masking is thus a more difficult phenomenon to explain than forward masking, and yet seems to be stronger and more persistent. The connection of temporal masking to clinically relevant speech-related psychophysical responses begs the question of whether backward masking protocol could be integrated into a diagnostic process.

Historical perspective

The earliest recorded investigation into auditory temporal masking was published in 1876; Alfred Mayer examined the masking effect of a clock's pendulum on a pocket watch's tick when they were systematically observed from varying distances (Mayer, 1876). Duifhuis (1973) calculated Mayer's results in modern terms based on reported

data and found that temporal masking occurred in Mayer's experiment between six and 18 milliseconds (ms) depending on probe intensity (attenuated by distance between observer and timepiece).

Miller (1947) picked up the theme of auditory temporal masking. His seminal experiment used a pulsing tone paradigm, so that a probe tone could be masked by a following probe tone of the same duration and frequency. Within two decades, Raab (1963) surveyed the already copious extant literature to compare the similarity of temporal masking—especially backward masking—effects in the auditory system with those in the visual system. Masking behaved similarly across the two sensory systems with the exception that visual temporal summation tended to decrease the perceived brightness of a stimulus whereas auditory stimuli were perceived as louder with extended exposure.

Raab (1963) distinguished between masking and perceptual blanking—where the target stimulus is completely obliterated—because in many cases a target stimulus may be presented below the masked threshold yet still have a palpable effect on how the masking stimulus is perceived. The quasi-recognition of a masked stimulus that Raab identified has been studied under the umbrella of subliminal effects (Smith & Henriksson, 1955; Smith, 1957; Kolers, 1957). When performing in auditory temporal masking experiments, subjects often report a perceptual smearing of the target and masker so that neither is distinct but the resultant experience is different from either the target or the masker alone (Lakey, 1976). Christovich (1959) distinguished three phases of the target-plus-masker perceptual experience, 1) under 2 ms the masker sounds louder than it would without the initial tone (*cf.* temporal summation), 2) between 2 and 50-100

ms the target-plus-masker sounds rough or else notched (*cf.* temporal uncertainty), 3) at interstimulus intervals longer than 100 ms the perception of two sounds, tone and masker, becomes distinct (*cf.* temporal resolution). This type of subliminal effect may relate to auditory fusion and the following discussion of streaming, grouping/fusing, and perceptual moments.

Von Bekesy (1960) describes a physiological mandate for perception, which governs human neural systems. In his interpretation, the event that is to be perceived by the neural system must be temporally isolated from competing stimuli lest it be masked. If the neural system of an observer detects an event that differs statistically from the noise floor of the auditory system and of the acoustical environment, it must be temporally insulated from other such events, else be suppressed or extinguished. When an event occurs too close to another, it loses its temporo-spatial isolation and is lost or discounted as noise by the system. Von Bekesy (1960) suggested that the louder event, the masker in a backward masking context, becomes the auditory object that is temporo-spatially isolated (because the initial signal is weaker and may be suppressed) and is marked for neural coding as a significant acoustic event. Thus, in Bekesy's view, the target is not extinguished by the masker, but rather the masker becomes the more important psychoacoustic event and draws the neural focus so that the target is reanalyzed as lying in the sensory "refractory area" that drapes like a shadow on either side of the masker. Because time and intensity are the dimensions that the auditory system primarily uses to localize sound origin, the designation "temporo-spatial" can be justified in both a physical and psychophysical sense.

Backward masking is one of two conditions that compose temporal masking (Lakey, 1976). Temporal masking describes a condition in which the stimulus and the masker do not overlap in time. Backward masking is the particular case where the target stimulus precedes the masker. The complimentary case—forward masking—happens when the masker is presented before the target in time (Figure 2). It seems reasonable to assume that the two forms of temporal masking share the same neural etiology; however, a series of experiments have cast doubt on this intuitive assumption and suggest that they arise from different neural processes.

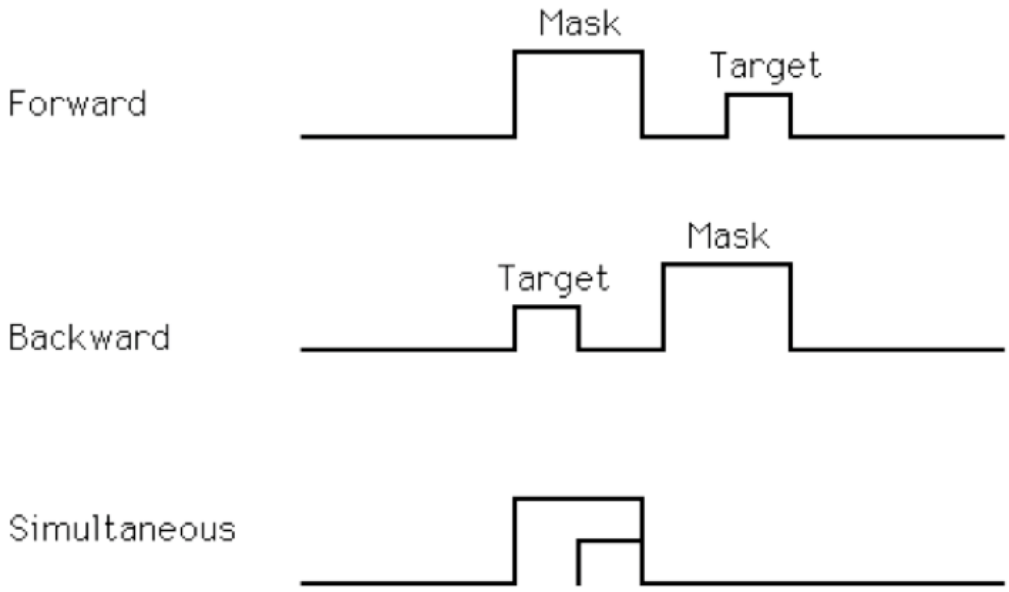

Fig. 2: Representation of three masking conditions

Patterson (1971) found that the masking effect of a combined forward and backward masking condition was greater than the sum of the two independent masking conditions. If a backward masker with an onset asynchrony of 30 ms increases the subject's threshold by 20 dB and in a separate condition, a forward masker is applied to the same target (probe) with an equivalent onset asynchrony of 30 ms produces a shift in

threshold of 15 dB, the combined condition, in which the forward masker and the backward masker are applied to the probe in the same presentation causes a shift in threshold for detection of the probe that is greater than the 35 dB that might be expected. In fact, the additional masking was as much as 15 dB; in the example above that would be 50 dB of masking in the combined condition. His conclusion was that the two extremes of temporal masking tap different neurological processes. If both stemmed from the same neural process, then the masking contributions of the two conditions should simply shift the threshold by their sum. This summation would result because, following the offset of the forward masker, the same neural resources would be taken up with the onset of the backward masker so that a seamless transition of one masker's effect into the next would result.

Evidence of additional masking in combined forward and backward conditions has been robustly demonstrated (Wilson & Carhart, 1971; Robinson &Pollack, 1973; Penner & Shiffrin, 1980). Penner (1980) did not discount the possibility that forward and backward masking may be relicts of distinct physiological properties of the hearing system; however, he bypassed this question by providing a data driven model of the auditory system in which intensity is coded according to a non-linear compressive function that accurately simulates the additional masking. If the cochlear compressive function is non-linear, then the sum of two internal perceptual masking processes would not be expected to grow in a linear fashion and this line of reasoning no longer serves to defend or refute the proposed dichotomy between forward and backward masking processes.

The psychophysical tuning curves collected in temporal and simultaneous masking conditions by Moore (1978) show asymmetry that could not be explained by a linear cochlear response. Notably, Oxenham and Moore (1995) found that age-related changes in the resonating properties (mass and stiffness) of the basilar membrane caused combined forward and backward masking to add linearly**.** For more evidence in support of non-linear cochlear compression, see Neely, et al. (2003).

Despite Penner's (1980) skepticism, Wiegrebe and Krumbholz (1999) built a strong case that forward and backward masking have separate neural etiologies. Their data replicated the different auditory separation thresholds for the two temporal masking conditions (i.e., the effect of a forward masker extends longer in time than the equivalent backward masker) that have been broadly attested in the literature (Elliot, 1964, 1971; Wilson & Carhart, 1971). In addition, their computational model accurately simulated the asymmetrical temporal functions for the backward and forward masking conditions by positing different synaptic properties and auditory fiber types between the two conditions. Thus, convincing psychoacoustic as well as physiological evidence suggest that forward and backward masking do not arise from the same neurologic principle and so it is more fitting to treat them separately, rather than as two instances of a single temporal masking phenomenon.

Models of backward masking

Numerous auditory models of the peripheral auditory system have sought to explain the perceptual mechanisms that result in backward masking. The following is a treatment of the most pivotal, including: the *Discrete Perceptual-Moment Hypothesis* (Robinson & Pollack, 1971); the *Peripheral Intensity-Latency Model* (Guttman, et al.,

1960); *Backward Masking Regimes* (Braida & Durlach, 1988; Wright, 1964); *Lag vs. Lead—"Precedence" Effect* (Kaltenbach, et al., 1993; Wallach, 1949); *Transient Masking* (Duifhuis, 1973); the *Object Attribute Model* (Mclachlan & Wilson, 2010); and the *Peripheral Channeling Hypothesis* (Hartmann & Johnson, 1991).

Discrete Perceptual-Moment Hypothesis

The discrete perceptual moment hypothesis arose concurrently with the modern computing age and was pioneered in the visual-perceptual system by Stroud (1955). Computers stream bits of data sequentially in a pulse train so that each data bit forms a discrete moment or event. Robinson and Pollack (1971) tested Stroud's (1955) model in the human auditory system. They described a human analog to the computer in which parallel processing allows multiple data streams to occur simultaneously. Within this model, the perceptual apparatus of the brain is conceived of as a staggered array of data trains partitioned into discrete moments. These moments are defined temporally. Robinson and Pollack hypothesized that events assigned to a single perceptual stream, which occur during one temporal moment, would be fused into a single acoustic image. It follows that if two sounds happen to fall into the same perceptual moment the louder one will mask the other as if the two sounds had occurred simultaneously rather than in series.

The perceptual fusion of temporally related acoustic events is generally termed 'temporal integration'. The discrete moment hypothesis draws on the work of Zwislocki (1960) who first asserted that spectrally related events (i.e. sounds that share spectral features) that have a close temporal proximity sum their psychophysical intensities. Wright (1964) incorporated a description of this phenomenon into his interpretations of backward masking experimental results. The Wright (1964) model dovetails with

Robinson and Pollack's in that closely associated temporal events are likely to fall within a single perceptual moment and, hence, to be integrated.

More recently, Heil and colleagues (2013) have modeled temporal integration, also called temporal summation, as a product of statistical sampling by the auditory system such that the probability of auditory neural firing, and hence signal detection, is a function of the number of sampled amplitude modulations within a temporal envelope or "window". A stochastic model of signal detection fits especially well with events that occur at auditory threshold levels because threshold (absolute sensitivity) itself is defined in probabilistic terms (i.e., the level at which a signal is detectable a certain percentage of the time). Moreover, the discrete perceptual-moment hypothesis may explain the temporal uncertainty that is characteristic of auditory masking conditions in general (Hirch, 1959; Puleo & Pastore, 1980; Watson, 1987). When sounds are assigned to separate discrete moments that are being processed in parallel, the exact temporal relationship between the discrete moments could be lost before the information is coded at higher neural centers.

Other researchers disagree with the assertion that temporal integration causes masking. LaRiviere and colleagues (1975) drew on the work of Massaro (1972) to claim that the temporal integration of acoustically related events actually gives release from backward masking in speech processing tasks such as identifying a consonant followed by a vowel (CV). This assertion could support a hypothesis that backward masking occurs across data streams rather that within a data stream. In this case temporally integrated signals do not compete with each other but fuse into a single auditory object, whereas signals that retain their temporal independence are vulnerable to temporal

uncertainty during processing at higher neural levels; and thus masking or blanking may present. For example, temporal resolution of stimuli order for short stimuli can be as large as 200ms (Henning, & Gaskell, 1981).

There exists, then, a conflict between the results of extant studies in that auditory fusion can inhibit some signals but bolster others and auditory streaming can create temporal uncertainty, yet improve resolution of signals from noise. While it is tempting to directly compare these conflicting explanations, Sparks (1976) cautions against synthesizing the results of various studies because backward masking has proven to be sensitive to the psychometric method and the degree of subject training. Several studies have described a release from masking as the target and masker become spectrally more distinct (Watson, et al., 1976; Loeb& Holding 1975; Divenyi & Hirch, 1975). Among them, Holding and colleagues (1972) concluded that masking is strongly dependent on which perceptual category a signal fills.

Peripheral Intensity-Latency Model

At short inter-stimulus interval lengths, un-tuned latencies[2] in neural timing could explain backward masking. Guttman and colleagues (1960) developed the peripheral latency-intensity model in which backward masking could constitute a special case of forward masking. They postulated that the difference in intensity between the stimulus and the masker and the temporal proximity (<2ms) could create a delay in the peripheral neural transmission of the weaker signal [stimulus] with respect to the stronger [masker]

[2] "Un-tuned latencies" refers to neural firings that do not line up in time. For example, two neurons that are stimulated at the same time may have different reaction times due to idiosyncrasies in the thresholds for each neuron's action potential; and the resulting conduction times up the auditory pathway may accentuate these "un-tuned" neural latencies.

so that the stronger would arrive at some central processing point ahead of the weaker signal. Thus, even though the weaker signal in the backward masking condition was presented first, the stronger signal could progress more quickly up the auditory pathway so that what had been presented as a backward masker might become a forward masker.

Physiological data presented by Duifhuis (1973) supports the claim that neural latencies exist for short tones and additionally, that the neural latencies of long stimuli are not as transient with respect to onset and offset of the stimulus. This means that the neural response to longer acoustic stimuli is not as likely to produce a delayed psychoacoustic "echo" of the acoustic event; however, long stimuli are vulnerable to decay or distortion of temporal fine structure in the presence of competing stimuli. This is because asynchrony or transience in the neural latencies may cause overlap in the neural response to the stimulus and the following masker. In this case the stimulus would be subject to temporal summation. The masked portion of the stimulus may experience perceptual blanking, which results in a shorter probe and a reduced probability that the neural system will detect the tone. Hence temporal summation might cause an effective decrease in probe duration, which necessitates a proportional increase in probe intensity to maintain an equal detection rate (Wright, 1964). Duifhuis (1973) did not find significant frequency related changes in neural latencies.

Neural latencies alone are not sufficient to explain backward masking. Psychophysical data, replicated across many studies, shows backward masking to extend in excess of 100ms, depending on the stimulus/masker types that are presented (Massaro, 1975). This time frame is well beyond even a generous allowance for neural latency. For example, Raab (1961) masked a click with another click of greater intensity in both

forward and backward masking conditions and found that the backward masking effect encompassed a larger inter-stimulus interval than can be explained by a peripheral latency-intensity model, given the electrophysiological parameters of the auditory system.

This conflict highlights the need to settle alternative hypotheses. Either, *1)* backward masking is a homogeneous effect with a single etiology and the peripheral latency-intensity model is false, or *2)* backward masking is actually a composite of psycho-acoustic phenomena that operate in more than one time-regime (i.e., 0-2ms, 2-20ms, etc.) in which case several etiologies could be expected. If the second proposition is correct, the first regime could be governed by neural latencies, the second by the discrete perceptual-moment hypothesis, the third by temporal uncertainty or else temporal summation, the fourth by interruption of attention, the fifth by displacement in the working memory, *etc.*

Backward Masking Regimes

Data reported by Wright (1964) agree with this regime-based model. He divided the backward masking effect into three phases 1) between 0-25ms, 2) between 25-50ms, 3) between 50-200ms. He described the first and third phases as being vulnerable to temporal summation and the second as being independent of it (recall Christovich's (1959) description of the regimes of subjective backward masking experience). Further support for backward masking as a layering of regimes may be found in the work of Braida and Durlach (1988) who proposed a model of intensity resolution in the auditory system that predicts errors in discrimination due to decay of auditory images first at a sensory level and then at the level of auditory memory; Yost, et al. (1976)

corroborated that masking affects auditory memory. The transition between the two stages occurs when the silent interval between stimuli reaches a critical length. At short inter-stimulus intervals, decay in sensory tracing—precipitated by the masker onset—causes error in discrimination or detection; this can be thought of as errors in perceptual coding. At longer inter-stimulus intervals, decay in auditory memory—also caused by the onset of the masker—is responsible for breakdown in perception; this can be considered a breakdown in context (semantic) coding.

Naatanen and Winkler (1999), following the work of Cowen (1988), also divide auditory processing into two stages, the first being pre-attentional and occurring within 200ms of the stimulus onset wherein the auditory features of the stimulus are coded and the second being moderated by attention which assigns meanings and allows the auditory object to be fused with a temporal signature. Mckay and colleagues (2001) agree that auditory processing occurs in two stages but posit that temporal integration, partitioned into seven ms temporal sampling windows, precedes integration of frequency.

More recent investigation favors parallel processing, such that the two stages are concurrent; features of auditory identity are dependent on timbre, which is neurally encoded before tonotopic evaluation (Ballas, 1993), have been shown to be processed in the *planum temporale* whereas temporo-spatial information appears to be processed in the *planum polare* (Griffiths & Warren, 2002; Warren, et al., 2003). These two neural streams are integrated in the auditory core, which is geographically situated between them. Given two neural loci with independent purview over the processing of distinct auditory features, it is probable that timbral and temporo-spatial data are processed in parallel rather than in sequence.

Extending the interval in which backward masking is significant, Repp (1975) explored a dichotic presentation of consonant-vowel (CV) syllables under masking conditions that were analogous to monotic temporal masking designs. He described stronger backward than forward masking at inter-stimulus intervals up to and above 250 ms. The error patterns in this regime of backward masking cannot be attributed to peripheral processing limitations but instead are artifacts of an interrupted central process. Repp postulated that as processing demands on the central nervous system exceed capacity—as might be expected when complex signals are presented dichotically and with varying degrees of asynchrony—the noise floor of the neural system increases and may obscure important characteristic distributions of speech signals, thus degrading the signal and leading to confusion of phonetic elements. Data from Kirstein (1973) and Pisoni, et al., (1974) support this claim.

The common ground between the hypotheses discussed above lies in the suggestion that at least two separate neural processes govern the observer's experience of backward masking and that the boundaries, which partition masking regimes are closely tied to temporal displacement. Because masker effectiveness is directly proportional to intensity and intensity discrimination is tied to temporal factors, such as temporal summation, backward masking is likely to be a bimodal system (i.e., subject to intensity and spectral character of stimuli as well as to time).

Lag *vs.* Lead (Precedence Effect)

Porter (1975) specified that in later stages of auditory processing, speech signals are more vulnerable to backward masking than speech-like non-speech sounds such as "chirps" (simulating formant transitions) and "bleats" (simulating acoustic bursts). He

aligns this finding with the “lag-effect” reported under similar dichotic conditions and with similar stimuli in the work of Studdert-Kennedy, et al., (1970) and Berlin, et al. (1970).

The “lag-effect” is the compliment of the “precedence effect”—first observed by Wallach (1949)—in that the “lag-effect” gives advantage to the following stimulus in a dichotic presentation whereas the “precedence effect” advantages the lead stimulus. Notably, the “precedence effect” only occurs at very short interstimulus intervals (<5ms). During this interval two acoustically similar stimuli are fused into a single, spatially located auditory object. When greater inter-stimulus intervals are employed the two objects separate into a sound plus an echo. With longer delays between the two stimuli the lead loses its tendency to suppress the lag and the lag begins to behave as a backward masker so that the lag becomes more discernable than the lead (Litovsky, et al., 1999). Kaltenbach and colleagues (1993) posited forward masking as a peripheral stage of echo suppression that enhances the precedence effect. Current models, then, connect the “precedence effect” with forward masking and the “lag effect” with backward masking.

Adaptive response of subjects after multiple exposures to stimuli in both “precedence” and “lag” conditions have led to the conclusion that both result in part from central processing. However, in light of rapid neural adaptation of the brainstem reported by Skoe, et al. (2013), the brainstem may house primary loci that yield these psychoacoustic effects. Skoe and colleagues (2013) used evoked auditory brainstem responses to track changes in processing according to probabilities of patterns in the sound-stream. This would imply a top-down influence, whereby an observer’s attention modifies which parts of the sound-stream the brainstem would code. Thus, training-

improved responses on backward masking paradigms in the laboratory setting could be attributed to rapid, temporary changes in the firing patterns of *loci* in the brainstem in response to top-down directives from the cortex. This finding promotes the brainstem to the primary organ for the perception of statistically significant patterns in auditory stimuli, but recognizes the auditory cortex for its role in shaping this perception.

Transient Masking

Duifhuis (1973) observed a transitory effect involving neural latencies wherein the peak amplitude of neural response occurs after the onset and offset of short stimuli. He hypothesized that this latent excitatory peak could then overlap in time with the more intense and longer lasting masker when the masker is presented after the probe tone. He called this process "transient masking" and attributed the effects of auditory backward recognition masking to it.

The transient neural latencies predicted by Duifuis' (1973) derived from a model of the monaural hearing system as series of integrators. This model was proposed initially by Jeffress (1967) who described the cochlea as a bank of band-pass filters that were recombined by means of a "leaky" integrator. The 'leaky' epithet refers to the steady loss of data from the running tally chalked up by the integrator. This designed loss of information assures the processing of only strong signals—weak signals decay due to the signal attrition before summation. The bank of band-pass filters simulates the tonotopic layout of the cochlear response. Each filter within the bank has a frequency selectivity that is governed by the bandwidth that is allowed to pass and the characteristic or central frequency on which the filter is focused.

As predicted, given the assumptions of this model, Festen and Plomp (1981) found an inverse relationship between auditory filter width—given by bandwidth of a noise stimulus—and the temporal window over which a backward masker was effective. The bandwidth of the filters responds in part to the precise anatomical locations that are stimulated and in part to the overall loudness of the signal (louder signals are thought to stimulate a wider band of hair-cells and thus to be less frequency specific).

In agreement with this, Mori and Ward (1992) determined that backward masking affects intensity coding up to 100 ms after the target offset, whereas it does not affect frequency coding. They suggested that this is because frequency is coded by neural location rather than group [neuronal] responses and duration, as is intensity. The coding of intensity, being a product of time and population sampling could be compromised by interference from a competing signal up to 100ms. This finding defends the position that filter bandwidth is sensitive to stimulus intensity (Weber, 1978).

Strangely, the relationship between filter bandwidth and intensity is not monotonic in temporal masking conditions. Weber (1978) found that as a masker's bandwidth increases so does its masking effectiveness until a critical bandwidth is reached above which there is a release from masking, alternatively framed as a rebound [improvement] in target threshold. This rebound in target threshold is described as a suppression of the masker's effectiveness. Suppression and its opposite, sharpening, are neurological factors that further complicate the temporal masking paradigm. Like masking itself, these opposing phenomena can be commandeered as probes to test functional models of the auditory system.

Sharpening *vs.* Suppression

Sharpening is the term used to describe a heightening of neural sensitivity when a particular auditory filter is focused on a specific central frequency so that nearby frequencies are steeply attenuated (Evans, 1975). This heightening is perceived as an unpleasant loudness to the observer. In familiar terms this is the experience of aural pain that happens when a shrill screech strikes the ear. Current research suggests that sharpening of spectro-temporal[3] neural tuning curves may also be a consequence of corticofugal[4] modulation of spectro-temporal response fields in the inferior colliculus (Fritz, et al., 2007; Tan, et al., 2006; Wehr & Zador, 2005).

Suppression is the antidote to sharpening. As a range of frequencies are stimulated the contribution of each is lessened; in the above example, if a bass voice is added to the screech and the intensity of the screech is kept constant, the perceived loudness or annoyance of the screech will be lessened (Houtgast, 1972). Suppression is a result of distributing the same neural energy over a broader bandwidth. It is important to note that the overall intensity of the screech plus basso is greater than the screech alone although it is *perceived* as softer.

Sharpening and suppression work in concert so that the sharpening of an auditory filter by a strong signal can have the effect of "dulling" another—inhibiting its detection (Lakey, 1976); conversely, the suppression of a bandwidth of frequencies can have the effect of "sharpening" the signals that boarder that band—so called "edge-effects" (Festen & Plomp, 1981). This same phenomenon was described by von Bekesy (1960) as

[3] Refers to the harmonic distribution and the time sensitive envelope of a stimulus.
[4] i.e. efferent neurons that project from the cortex.

the “refractory area” (*sc.* ‘area’ refers to the temporal space surrounding an acoustic event). Several investigators have empirically tested suppression of masker effectiveness (Shannon, 1976; Tyler & Small, 1977; Weber & Green, 1978; Weber, 1978; Plack, 1996). Suppression of the masker can be affected by addition of a second masker that is correlated with the first in duration, intensity, phase, or frequency.

Weber and Green (1978) determined that backward and forward masking respond to masker suppression at inter-stimulus intervals of up to 50 ms. They attributed this to shared peripheral processing between the two temporal conditions. However, at inter-stimulus intervals longer than 50 ms only backward masking showed release from masking. Their conclusion was that forward masking is explicitly a peripheral phenomenon whereas backward masking has both a peripheral and central phase. The description of forward masking as a peripheral process is corroborated by physiological data (Smith, 1977; Harris, 1977) and earlier psychoacoustic data (Plomp & Bouman, 1959; Penner, 1974).

In a follow up study Weber (1978) attributed the suppression of masking in a forward condition to a decrease in the steady state response of peripheral neurons. Change in the spontaneous rate of fire for afferent neurons is also called adaptation (this changes the probability of neural spikes being detected within a given temporal window). By contrast, he characterized the suppression of backward masking as an alteration of transient response (i.e. latency of peak neural impulse) following the work of Duifhuis (1973).

Plack (1996) suppressed masker effectiveness by adding a second and weaker probe tone to a target before the masker. He interpreted improved intensity discrimination

as a consequence of temporal integration with the difference in intensity between the two probe tones giving cues that allow coding of the probes' intensity relative to the masking noise. Presumably the frequency similarity between the two probes and the relative weakness of one caused sharpening rather than suppression.

Suppression may provide an explanation for the behavior of some forward and backward fringe conditions in which a tone simultaneously masked by a noise becomes more audible when a backward fringe is added to the noise (Kidd & Wright, 1994). In this experimental condition the target is shorter in duration than the masker and is presented concurrently, but positioned so that a portion of the masker precedes or follows the portion with the embedded target. Kidd and Wright (1994) compared fringe effects to temporal masking. It follows that detection of a signal with a concurrent masker can be improved by the addition of a backward masker. That is to say that more masking actually reduced the effective masking (*i.e*, the additional masker gives "release" from masking).

Wehr & Zador (2005) described an intracortical and a thalamocortical synaptic depression (plasticity via synaptic chemical communication, versus connectivity, regulated by neighboring neurons) that may be the physiological correlate of suppression. Similarly, Fritz and colleagues (2007) recorded suppression of a reference stimulus in the auditory cortex of ferrets that corresponded to an increase in the ability to discriminate changes in stimuli. This leads to the conclusion that suppression of neural response to a familiar stimulus frees up neural resources for identification of novel or unexpected stimuli.

Suppression, then, adds evidence to the claim that the auditory system acts as an adaptive filter that tunes itself based on expectation and habituation. This hypothesis has been investigated under the epithet "auditory streaming," and has resulted in several convincing models of auditory processing (Snyder & Alain, 2007; Mclachlan & Wilson, 2010; Skoe, et al.2013).

Object Attribute Model: A *connection between backward masking and auditory streaming*

Because backward masking, unlike forward masking, has been shown to have a strong relationship to central auditory processing—or at least to have a central regime—models that describe oscillatory central processes, such as streaming, could help explain the paradox of backward masking (Mclachlan & Wilson, 2010). In Mclachlan and Wilson's (2010) object-attribute model, cortical projections from the auditory core, which is located in Heschyl's gyrus between the *planum temporale* and *planum polare*, modify the coding of spectral "cross-sections" in the *inferior colliculus.* Spectral cross-sections are freeze-frame images of a sound's timbre, sampled across short temporal windows—on the order of 6 ms (cf. Viemeister & Wakefield, 1991). The coded cross-sections are then routed afferently through the *medial geniculate body* (MGB) of the *thalamus* where they regulate the formation of an "echoic trace" that primes and activates a similar but more robust trace in the auditory working memory—likely housed in the *planum temporale* (Halpern, et al. 2004).

Once an active trace has been established in the auditory working memory, acoustic features can be matched to sound identities that have been stored in long-term memory and a semantic auditory object may be formed. An intra-cortical feedback loop

provides the mechanism by which auditory objects can be grouped or streamed based on timbral properties (Woods, et al., 2009). Holding and colleagues' (1972) conclusion that masking is strongly dependent on which perceptual category a signal fills roughly correlates with the McLachlan and Wilson's (2010) supposition that an auditory object must be identified to initiate streaming. In turn, this implies that temporal masking could have a direct relationship with auditory streaming.

After a sound stream forms it can bypass the MGB and route directly to relevant spectro-temporal response fields in the auditory cortex (Mclachlan, 2009). Automated streaming will continue until an offset, gap, or new onset is detected, at which point the filtered data from the *inferior colliculus* will again be routed through the MGB of the thalamus. An interruption to automatic auditory streaming must be greater than 120 ms to reset the system (Hsieh & Saberi 2007).

If a signal that has been perceptually organized into an auditory stream contains a gap longer than 120 ms, mismatch negativities may be measured on an evoked potential (Naatanen & Winkler, 1999). This timeframe corresponds to the period necessary for auditory working memory to be primed and expectations to be generated. Thus, an expectation at the level of auditory working memory must be violated in order to break the perceptual illusion of continuity of a sound stream. This process can be attested behaviorally by reference to pulsation threshold data and current work on glimpsing (Cook, 2005; Houtgast, 1972).

Interestingly, gap detection thresholds—where a silent interval is inserted into a noise burst—are as low as 5ms, prompting researchers to assign this level of temporal resolution to the auditory system (Viemeister & Wakefield, 1991). This apparent paradox

may be allayed by an alternate interpretation in which the noise does not constitute a stream but rather the silence—marked by an onset and an offset—becomes the auditory object of interest.

In summary, the object-attribute model hypothesizes an oscillatory processing loop that involves afferent and efferent modulation of auditory stimulation such that the entire auditory system acts as an adaptive filter whose bandwidth is focused by attention and object recognition.

Peripheral Channeling Hypothesis

The object-attribute model stands in contrast with the peripheral channeling hypothesis. Hartmann and Johnson (1991) first explained auditory streaming as the outcome of peripheral, tonotopically specific channels relaying data to the auditory cortex. Tonotopic arrays have been documented in the auditory cortex of primates (Kaas & Hackett, 2000); and channels corresponding to cochlear layout that project to auditory cortex have been mapped anatomically and physiologically in humans (Handel, 1989; Fishman, et al., 2004; Woods, et. al., 2009). Moreover, tonotopic activation of spectral response fields in the auditory cortex have been reliably witnessed in functional Magnetic Resonance Imaging (fMRI) studies (Fishman, et al. 2004).

Fishman and colleagues (2004) assert that ongoing stimulation of a particular channel—beginning at the cochlear level—will generate an ongoing stream that is then processed in the auditory cortex and association areas. Similarly, Sparks (1976) posited that channel processing (or data streaming) could provide a source of release from masking noted in some experimental conditions.

Following the peripheral channel hypothesis, Fishman and colleagues (2001) predicted that streaming would correspond to activation of distinct neural populations whereas auditory fusion would correspond to activation of overlapping neural populations. In spite of strong evidence to support the existence of peripheral-cortical tonotopic channels, the peripheral channel hypothesis cannot reconcile psychoacoustic data in which sequences of sounds that excite overlapping peripheral channels form separate auditory streams (Vliegen & Oxenham, 1999; Grimault, et al., 2000; Roberts, et al., 2002).

Deutsch (1974) provided another argument against the peripheral channel hypothesis. Her seminal work on melodic streaming has been corroborated more recently by Carlyon (2004); it documents the fusion of sounds that alternate between the ears into a single auditory stream. This would preclude the auditory periphery as the source of streaming because mixing of the signals from each ear requires central processing. The conclusion is that peripheral channeling is critical for the tracking of spectral and frequency information but is not directly involved in the creation of auditory streams.

In addition, several studies have implicated the role of attention in the auditory stream formation (Snyder, et al., 2006; Micheyl, et al., 2007). Snyder and colleagues found that over the course of an experimental trial a “build up” of event related potentials (ERP) corresponded with streaming of stimuli per participant report. They interpreted this build-up as an electro-physiological marker of attention, because the latency of the build up corresponded to the time frame in which higher cognitive processes—such as attention—take effect.

In this model the role of attention is to integrate successive tones over seconds and sharpen neural tuning curves by partitioning their response domain. This agrees with the object-attribute model in that attention and expected response shape the firing pattern of more peripheral neurons via suppression or inhibition. Sherman (2007) found that the response of the medial geniculate body changed with increased observer confidence in auditory objects. These studies make a clear argument for the involvement of attention in the creation of auditory streams.

Snyder and colleagues (2006) found a right hemisphere dominance for streaming, which they correlated to a preference for frequency in stream formation. However, Micheyl and colleagues (2007) added that time, build-up of ERP, and amplitude modulation—all attributed to the left hemisphere—are key to the formation of auditory streams. Additional research supports the importance of temporal cues, and hence left hemisphere involvement (Grimault, et al., 2002; Bregman, 1990). Streaming and by extension, backward masking (forward masking being solely peripheral), is a product of synthesis involving both hemispheres at peripheral and central levels.

Backward Masking: An Evolutionary Advantage?

Streaming and masking studies are not confined to humans. These auditory principles have been documented in common laboratory species including: macaque (Brosch, et al., 1998), gold fish (Fay, 2000), bat (Simmons, et al., 1992), chicken (Lurie, et al., 2006), primate (Izumi, 2002; Fishman, et al., 2001), guinea pig (Killian, et al., 1994), cat (Oesterreich, 1966), and dolphin (Moore, et al., 1984). Thus, streaming and masking are established as a shared feature of the Vertebrate hearing system. If this phenomenon is so widespread it makes sense to question whether the backward masking

effect is itself an evolutionary advantage or is a side effect from another adaptation for survival. To form a cohesive precept within an auditory scene, the neural system must categorically sort stimuli and maintain justified acoustic identities (Bregman, 1990). For example, backward masking may have a role in the development of a stable auditory object, by eliminating spurious signals relayed from a gamma-tone filter bank as modeled by Patterson, et al., (1992). Is it a coincidence that the precedence effect, critical for localizing sound sources operates within a 5 ms window, which is the same duration as the smallest gap-in-noise that the auditory system can detect and in turn is the size of the temporal sampling window proposed in the perceptual moment hypothesis—or is there a relationship between the auditory fusion necessary for echoic precedence and the backward masking of signals that fall within the same perceptual moment?

Consider the following thought experiment: the Doppler shift, whereby a steady-state pitch produced by an approaching object increases in pitch height (and chroma) from the perspective of an observer, gives an acoustic cue as to the motion of a sonic object; an analogous psychoacoustic illusion of tonal shift occurs in laboratory experiments when the fundamental frequency of a complex tone is held constant but the harmonic spaces above that tone are changed by a fixed increment (Smoorenburg, 1970). The compression of the pitch height generated in the lab mimics what might happen when a sound undergoes the Doppler shift. This creates the auditory illusion that the fundamental frequency has either increased or decreased proportionally to the sign and size of the fixed increment. Conversely, when the harmonic spaces are changed by a logarithmically increasing increment—so that there is no uniform compression or extension of pitch height—no tonal shift occurs. This psychoacoustic phenomenon may

be a trick of the lab that uncovers the calculus used by the auditory system to detect approaching or retreating sound sources. Similarly, backward masking observed in the lab may reveal the action of an important psychoacoustic filter that allows animals to organize their sonic environment; one possible activity of the filter could be suppression of the noise floor to enhance detection of novel stimuli by reallocating neural resources. In other words, the auditory system may be equipped to increase resolution of signal to noise (cf. Weber Fraction) within an auditory scene via suppression of steady state or predicted stimuli. In the controlled conditions of the lab this may present as temporal masking. Kaltenbach and colleagues (1993) suggested the forward masking measured electro-physiologically in the dorsal cochlear nucleus of hamsters may have a role in echo suppression, a critical feature of the precedence effect.

Clinical Test of Backward Masking

As early as the 1970s, Goldstein and colleagues (1971) noted the similarity between psychophysical and physiological tuning curves. From a clinical perspective, psychophysical curves could be a useful analog to neurophysiological tuning curves (McGee, et al., 1976; Zwicker, 1974; Christovich, 1957). If psychophysical curves accurately model neurophysiological tuning curves, the relatively inexpensive procedure could reveal patterns in neural firing that are clinically relevant. Moore (1978) asserted that psychophysical measures probably do not converge on the underlying neural tuning curves due to confounding factors such as lateral suppression, beats, and combination tones. What is more, variations in a subject's absolute sensitivity to sound complicate the interpretation of results when behavioral responses are monitored close to a masked threshold; unfortunately, responses *must* be monitored near threshold when determining

tuning curves as too great an intensity will excite a wider band of critical frequencies and compromise neural specificity (Moore, 1978; Patterson, 1976). However, temporal masking may provide more accurate approximations of neural tuning curves than other psychoacoustic measures because fewer of the confounding variables mentioned above are present (Houtgast, 1972). Thus, backward masking may provide better evidence about the performance of a client's auditory system than other measures of streaming. Furthermore, a contralateral timing cue presented in a dichotic listening paradigm has been shown to improve masked thresholds of transient (i.e., temporally masked) stimuli (Puleo, & Pastore, 1980). This suggests that backward masking is related to limits of temporal resolution in the auditory system and would be affected by the neural timing deficits noted in aged, impaired, and other clinical populations.

In the development of a clinical test, attention must be given to the methodology that supports the data collection. As mentioned above, backward masking and other streaming and channel processing effects are subject to attention. The clinical test protocol must be robust enough to yield accurate data in the event of lapses of attention. Because data must be collected near threshold, moment-to-moment variation in absolute sensitivity of the system means that probabilistic psychometric techniques are likely to be most reliable. Psychometric functions describe a logistic ideal in which the accuracy of a behavioral response increases from chance performance to 100%. The function is hypothesized to grow exponentially from the minimum and then decay logarithmically up to the maximum. Psychometric functions reach asymptote near both the maximum and the minimum. Between these two bounds the function reflects the level at which some

fixed percent of correct responses was reached. Thus, there is an assumed probabilistic distribution that underlies each point within the psychometric curve.

Buss et al (2000) cast doubt on the *a priori* assumption that each observation is independent from the previous and succeeding observations. They questioned the underlying distribution that has been assumed to represent psychoacoustic properties, and in doing so made room for the application of auto correlation techniques to correct for statistical dependence. Buss, et al., endorsed the use of a G^2 statistic proposed by Allen, et al. (1998) in fitting curves to psychoacoustic data.

The variables to be manipulated in developing the clinical task are, *1)* the quality and duration of the signal and masker, *2)* the time between the signal and masker, *3)* the relative intensity of signal and masker, *4)* the absolute intensity of the signal, and *5)* the methodology. Much work has been done on manipulating these variables. However, the only extant studies to focus on the ease or "do-ability" of the task have approached the problem from the perspective of the method of presentation and collection (Amitay, et al., 2006; Buss, et al., 2000). No study to date has sought to establish the most efficacious signal type, quality, or duration, for use in a behavioral clinical test of backward masking.

Buss and colleagues (2000) explored the efficacy of the backward masking task by comparing two tracking procedures: the three-down-one-up adaptive staircase method proposed by Levitt (1971); and the Maximum Likelihood Estimation (MLE) promoted by Green (1993). Both the Levitt and MLE methods tracked threshold in a three alternative forced choice (3AFC) paradigm. Once threshold had been determined they used a method of constant stimuli to confirm it. The conclusion was that both tracking methods

produced comparable thresholds but that the Levitt allowed for more exposures to the stimuli at higher intensities so might be a better training tool for naïve listeners.

Most temporal masking studies track the relative level of the stimuli as a function of the inter-stimulus interval, but at least one early experiment reversed this paradigm by tracking the inter-stimulus interval as a function of the intensity of the stimuli (Deatherage & Evans, 1969)**.** This approach has methodological benefits in that the task is ostensibly easier for the participant, since the stimuli never change in level; however, because the masking function is more sensitive to changes in relative intensity than to time (except at very small inter-stimulus intervals) the ISI-tracking method does not reveal a dramatic enough family of curves to have clinical utility.

Method affects reliability and replication of results across subjects (Sparks, 1976). Commonly contrasted methods include: method of constant stimuli *vs* method of adjustment, forced choice *vs* adaptive, monaural *vs* binaural (Turner, et al., 1994; Leshowitz & Cudahy, 1973; Cudahy & Leshowitz, 1974; Watson, et al., 1976; Yost, et al., 1976).

Turner, et al., (1994) used two vetted psychoacoustic paradigms to measure the accuracy of subjects' judgments of just noticeable differences (JND) in stimulus intensity under forward and backward masking conditions. They reported that a forced choice paradigm revealed a mid-level "hump" in the JND whereas a method of adjustment did not. The mid-level "hump" describes an increase in the Weber fraction for temporally masked tones possibly related to adaptation of dominant nerve-fiber type recruitment (Carlyon & Beveridge, 1993; Plack & Viemeister, 1992; Zeng, et al., 1991). Turner's research group concluded that the two psychoacoustic paradigms might measure different

“quantities.” Furthermore, Yost, Berg, and Thomas (1976) compared four psychophysical paradigms and found that, especially in a backward masking condition, the procedure had an effect on the data. Thus, it is advisable to carefully consider the psychoacoustic paradigm that delivers the test in order to reliably measure the target quantity.

Amitay, and colleagues (2006) proposed a need to quickly and efficiently test subjects for psychoacoustic experiments without the confounding variable of rapid learning. Most adaptive learning happens within the first 500-1000 exposures (Hawkey, et al., 2004). They argued that researchers might miss crucial early-stage psychoacoustic events due to initial subject training programs that exceed the 500 trials in which the subjects neural system remains naïve. Four test paradigms were selected based on simulated predictions of efficacy. A three-alternative-forced-choice-oddball paradigm, plotted using a psychometric function, gave the most reliable data in backward masking conditions with naïve listeners. The goal addressed by Amitay, et al. (2006) aligns with the objective of the present author to develop a clinically applicable test of auditory processing through the study of backward masking. Patients in the clinic would have similar profiles to subjects in psychoacoustic studies; namely, they would be naïve to the task and most of the relevant diagnostic information would need to be gleaned in the first 100-500 trials beyond which it would be clinically unfeasible to extend testing.

In addition, the nature of the masking task plays a role. Paradigms in which subjects are required to detect the stimulus differ from those in which they must discriminate some acoustic feature between two or more stimuli, and again from those in which they must identify the stimulus in absolute terms. For example, Bland & Perrott

(1978) reported 200 ms as the threshold silent interval between stimulus and masker in a recognition task but only a 50 ms gap as the threshold in an equivalent detection task.

On a larger scale, that of design, Massaro (1975) contrasted subject performance on randomized blocks of backward masking trials compared within a session, with fixed blocks compared across sessions. He attributed the difference in the reliability of these two designs to the impact of memory. He advocated for a randomized within-session design so that variations in short-term auditory memory would not be a confounding variable.

Choice of stimulus in a temporal masking paradigm is essential. If a stimulus is too short or weak, the effects of temporal summation and observer uncertainty will contaminate results (Elliot, 1964); whereas, too long or intense a stimulus will generate either lateral suppression or sharpening of neural tuning curves (Moore, 1978; Lakey, 1976; LaRiviere, Winitz, & Herriman, 1975). Duration, frequency, phase, and temporal displacement of stimuli each have an effect on the magnitude and extent of the temporal masking function.

Duifhuis (1973) chose a Hamming window, which was modeled on the specifications of Blackman and Tuckey (1958)—later named in their honor. He chose this gating function because it minimizes the tonal artifacts noted when trapezoidal (sc. “linear rise-fall” envelopes) and rectangular (sc. “brick wall” envelopes) gating functions are fitted (Fasl, 1972). Such signals, spuriously generated by the initial and final movement of the speaker, limit frequency specificity and potentially confound isolation of masking effects.

There is reason to suspect a difference in neural response to various gating functions under temporal masking conditions because of electrophysiological data supplied by recent studies of objective pure-tone audiometry. Investigators have correlated the Blackman and linear rise-fall gating functions with differences in the amplitude and latencies of auditory brainstem response (ABR) to sinusoidal stimuli (Purdy, et al., 2002; John, et al., 2002). They have found notable differences in wave *V* responses (correlated with activity of the inferior colliculus) to the two gating functions.

During central processing, there are measurable differences in the effects of backward masking (also called interference) on speech versus non-speech sounds (Porter, 1975). Typical backward masking protocols use combinations of pure tones and/or Gaussian noise; however, Porter (1975) compared "chirps" and "bleats", both of which have speech-like characteristics. He found that speech-like signals were more vulnerable to backward masking in a dichotic condition. The dichotic condition guarantees the involvement of central processing (*sc.* language). Porter's finding suggests the chirp as a candidate in clinical testing of backward masking since the ultimate goal is to evaluate the effects of auditory processing disorders on the perception of speech. Hence, an idealized speech-like signal may serve to stimulate speech-processing centers while maintaining the controlled conditions necessary for reductive analysis.

Response time as a proxy for subject confidence: Hence ease of task

The present study examined and compared the efficacy and relative ease of three stimulus types in determining the backward masking function of naïve subjects. "Ease" was bootstrapped to reaction time (RT) with the assumption that quicker subject reaction correlated with greater confidence and hence more ease in the execution of the task. As

discussed above, “do-ability” is an essential ingredient in an effective clinical test. Reaction time has been explored as a proxy for subject confidence, with a directly proportional relationship between speed of response and the subject’s ease of decision. Reaction latencies have been employed in visual-perceptual studies and are considered valid indices of internal processes. Subject response time has been deemed more accurate than verbal report (Fehrer & Biederman, 1962; Fehrer & Raab, 1962). In an auditory test of suprathreshold masking using a method of constant stimuli, Lanson and colleagues (1973) reported that subject reaction time is a reliable index for the degree to which a signal is masked.

The current trend in temporal masking research as it relates to speech processing is folded into the investigation of auditory “glimpsing”. The glimpsing model attempts to reconcile the high degree of accuracy that skilled listeners have when attending to conversation at a social event even when many competing speech signals have degraded the signal that is physically reaching their ears. This is sometimes referred to as the “cocktail-party effect”. Competing streams blot-out essential spectral and temporal cues from the target stream so that the person who has received the degraded message must reconstruct the missing elements before it is possible to divine the intended meaning. Conversational partners are hypothesized to reconstruct the “glimpses” that they receive into a coherent speech stream by using temporal (prosodic) cues such as envelope. Skilled listeners are able to accomplish this because partial access to a sound stream can activate primed auditory memory so that phonemic and semantic restoration take place (Cooke, 2005). Trace evocation of entire memory networks is discussed in detail by McLachlan and Wilson (2010) in the object-attribute model of auditory streaming.

Temporal cues are necessary to generate distinct auditory streams (Grimault, et al., 2002). In fact, auditory fusion often occurs if the onset or timbre is similar (Bregman, 1990). Glimpsing research has revealed that the auditory system relies on temporal cues to reconstruct degraded meaning. Because backward masking introduces a high degree of temporal uncertainty (Hirch, 1957), the propagating effects of temporal masking and accompanying lapses of attention can undermine interrupted speech processing in the context of an auditory scene. Hence, elevated backward masking thresholds may compromise auditory streaming of speech in real world situations. This connection further endorses the use of backward masking testing as a probe into the function of the auditory system at large.

CHAPTER TWO

Statement of the Problem

Recent work has shed light on the role that auditory processing disorders (APD) have on the development of speech and language (McArthur & Bishop, 2001). Developmental disorders such as Stuttering and Specific Language Impairment (SLI) are closely tied to underlying auditory processing differences and difficulties (Hampton & Weber-Fox, 2008). Acquired speech and language disorders resulting from neural insult—as often happens in stroke, traumatic brain injury, toxic-metabolic conditions—have an auditory processing component (Bamiou, et al., 2006; Lew, et al., 2007; Finkelstein, et al., 1998). In designing a treatment plan for a speech or language disorder, diagnostic specificity is paramount. Because the advances in clinical understanding of the impact that an auditory processing disorder can have on the progressive development of speech, language, and literacy are relatively recent, children at risk for auditory processing disorders and the accompanying cascade of scholastic and interpersonal challenges often remain undiagnosed. Screening tools do not adequately address this dimension of language processing and children with APD are not often referred to an audiologist because their pure tone audiometry (PTA) hearing thresholds are within functional limits. A more precise understanding of the locus within the auditory pathway where degradation of speech signals takes place may enhance our understanding of the origin of many speech disorders and may lead to the development of more sophisticated and specific interventions.

Backward masking is considered to have both peripheral and central regimes with a strong connection to signal category and the effects of attention; it may manifest in a series of temporal regimes or physiological nodes at which the processes of auditory streaming lead to a fusion of distinct events and result in a misperception of the acoustic event (Osman & Raab, 1963; Moore & Welsh, 1970; Dolan & Trahiotis, 1970; Lynn & Small, 1977; Mclachlan & Wilson, 2010; Skoe, et al. 2013). Current research has reopened discussion about the active role of the brainstem in auditory processing and by extension, backward masking. Recent work has shown formerly unrecognized adaptive features of the brainstem, including timing, firing rate, and pattern selectivity in response to top down (i.e cortico-fugal) attentional directives (Skoe, et al., 2013). These adaptive changes may explain the learning effect that has been reported in backward masking experiments (Leshowitz & Cudahy, 1973; Sparks, 1976; Yost, et al., 1976), and support the need for a time effective test of backward masking that is not confounded by adaptation and rapid learning at the level of the brainstem (Skoe, et al., 2013).

Increased backward masking has been linked to APD in children and adults over age 60 (Buss, et al., 1999). Increases in thresholds under backward-masked conditions may correlate with a degraded ability to stream relevant acoustic data and result in communication breakdown and impaired phonemic restoration in noisy environments. Because of the relatively simple test paradigm for backward masking (similar to pure-tone audiometry), it is compelling to imagine a valid and reliable use of this paradigm as a screening tool for APD in at-risk populations. Yet, however simple the paradigm, the task of identifying a probe tone in close proximity to a masking signal at near absolute threshold levels proves to be cognitively and perceptually daunting. In naïve listeners,

unreliable responses and non-independence of observations commonly occur (Cobb, et al., 1993). Therefore, to aid the development of a user-friendly clinical test of the backward-masking function in naïve listeners, it is hypothesized that a more "acoustically marked" stimulus would increase client confidence without confounding the masking curves. Several variables may be manipulated in the process of finding a fitting stimulus, including: length, frequency, envelope, and timbre (i.e., harmonic complexity).

The purpose of the current study was to determine whether signal-type could influence the difficulty of a clinically postured test of the backward masking function. Three signal-types were chosen for inclusion in this study, 1) a linear-sweep (chirp), fitted with a 5-ms-linear rise and fall, 2) a 1000 Hz tone fitted with a Blackman gating function, 3) a 1000 Hz tone fitted with a 5-ms-linear rise and fall—alternately called a "trapezoidal" or "linear" envelope (Figures 3-5). The chirp was included because it has a synthetic similarity to vowel formant transitions (Porter, 1975), which are critical to speech perception; this similarity to a speech sound makes the chirp the most acoustically "marked" of the three signals. The 1000 Hz tone fitted with a Blackman gating function was included because it offers the greatest neural specificity; the Blackman envelope was engineered to optimize the onset and offset of a membrane (e.g., tympanic membrane, basilar membrane, or a speaker) so that it does not generate spurious signals (Blackman & Tuckey, 1958); neural specificity is desirable in the backward masking paradigm because it limits the interaction of neighboring neural groups and reduces the impact of lateral suppression. The 1000 Hz tone fitted with a 5-ms-linear rise and fall—alternately called a trapezoidal or linear envelope, has more neural specificity than the linear-sweep

(see Figures 11-14) and yields a 10-ms steady-state signal at full amplitude that makes this signal the least attenuated by temporal summation

These signal-types offer two natural comparisons: the signals fitted with the same gating function (Figures 3 and 4) are compared across the dimension of frequency, whereas the signals that share a frequency (Figures 4 and 5) are compared across the dimension of envelope. For the purpose of symmetry, signals 1 and 2 above (Figures 3 and 5) will be compared as part of a linear model but note that they vary in both envelope and frequency specificity.

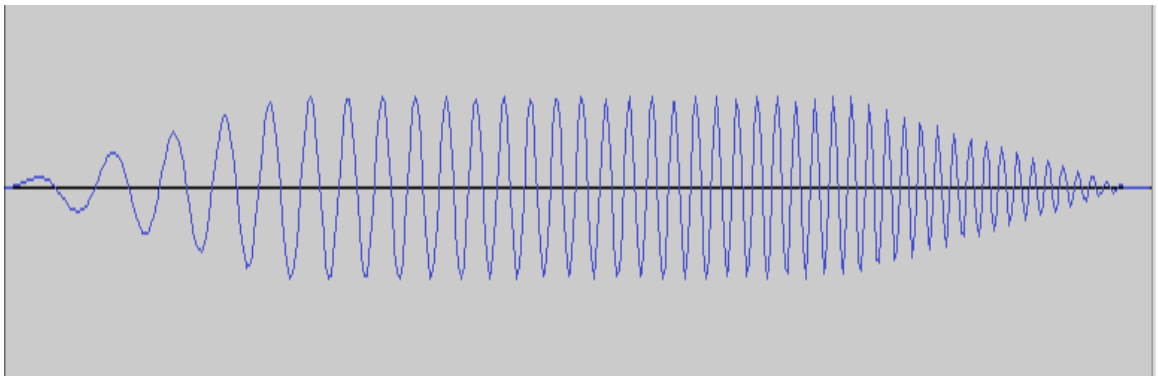

Fig. 3: 20-ms Linear-sweep "Chirp" (500 Hz-4000 Hz) with a 5ms-linear rise and fall

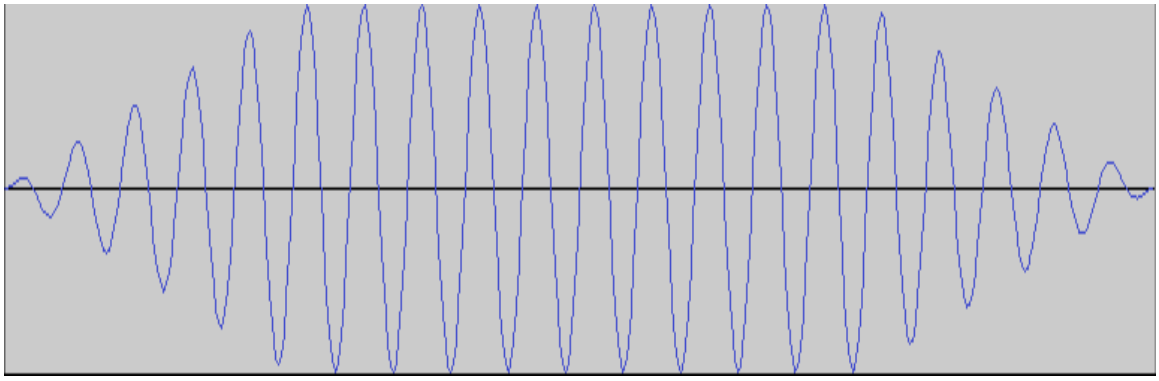

Fig. 4: 20-ms, 1000 Hz sine-wave with 5-ms-linear rise and fall

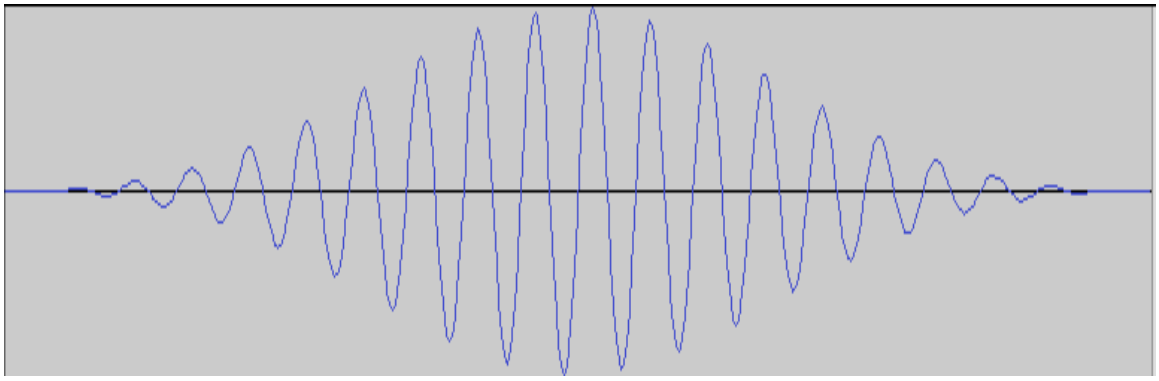

Fig. 5: 20-ms, 1000 Hz sine-wave with a Blackman gating function

In pursuing the following research questions, response time (RT) will be considered an index of "ease-of-task". Response time, though an epiphenomenon, has been robustly shown to correlate to participant confidence (Lanson, et al., 1973). Taken one step further, confidence can be correlated with a perceptual "ease-of-task" for the observer (participant). The easier the task is felt to be, the more confidence the participant reveals through his response time. Therefore, response time is taken as a proxy for ease-of-task with short response latencies corresponding to quicker decision making and thus greater ease than long response latencies.

Question #1

Does stimulus type influence the backward masking function?

The backward masking curve describes threshold as a function of ISI. If this relationship in the data is mapped by linear regression, are there statistically significant differences in the slope and intercept of the regression lines when the data are considered by signal type? First the complete data will be analyzed with linear regression to look for a masking trend and ensure that the backward masking function is present. The data will

then be sorted by signal-type and a separate linear regression will be calculated for each of the three types. The differences between the four resulting regression lines will be analyzed for significance.

Question #2

Does signal-type influence the ease-of-task in a backward-masking detection paradigm targeting naïve listeners with normal hearing?

Response time (s) will be described as a function of intensity (dB) and the data will be sorted by signal-type. Separate linear regressions will be calculated for each signal-type and the differences in coefficients including intercept and slope will be compared for significance.

Question #3

Is the effect of signal-type on response time conditioned by ISI?

This is an important consideration because an apparent effect of signal-type on RT may be confounded by a lurking variable such as ISI. In order to test the linear independence of these two variables, a multivariate linear regression with interaction terms will be calculated to look for significance in the interaction between “ISI” and “Signal-type”. Furthermore, a “complete” multivariate linear model of the impact of ISI, Signal-type, Intensity on Response time with interaction terms (ISI:Signal-type) will be compared to a “reduced” multivariate linear model of the same relationship but without interaction. The comparison will be made using an “incremental F-test”. This test measures how likely it is that two or more terms in a linear model act equally but distinctly on the response variable and by extension how unlikely they are to be collinear.

Question #4

If signal-type influences participant confidence as measured by reaction time, what signal -type results in the greatest participant confidence?

The results of the four linear regressions to be derived under question #2 will be analyzed and the signal-type that shows the lowest y-intercept with the least slope will be considered the easiest for participants to distinguish from the masking noise; and hence it will be considered the best candidate for a clinical test of the backward masking functions. Recall that the y-intercept represents the collective RT at ISI=0 (noise directly follows the offset of the probe signal). RT is correlated with participant confidence and hence ease of task.

The hypothesis is that a more acoustically marked signal will make it easier for subjects to distinguish the tone from the noise in a backward masking paradigm that utilizes a method-of-adjustment. The term “marked” is used here to describe a signal that presents with a distinct timbre. The linear-sweep was chosen to serve as the “marked” stimulus. It is perceived as a chirp or water droplet-like sound, similar to the vowel formant transitions that mark speech.

CHAPTER THREE

Methodology

This research was approved by the University of Montana Institutional Review Board (IRB # 229-15). See Appendix B.

Participants

All participants had normal hearing at octave frequencies between 0.5 and 8.0 kHz for pure tones presented at 20 dB HL (American National Standards Institute, 1996). Seven participants enrolled in this study. The participants ranged in age from 18-34 and included both males (N=2) and females (N=7). All participants volunteered their time for the study; no compensation was provided for their participation in the study.

Participants were given an explanation of the research and as a probe to determine their understanding of the task the audiometric threshold at 1000 Hz was compared to a BM task. Participants whose pure tone thresholds varied significantly from masked thresholds of ISIs of 128 milliseconds were considered to not understand the task and were excluded from the study. Nine participants were screened and two did not meet the inclusion criteria (see Table 1). A total of seven participants were included in the study (N=7).

Table 1

Participant demographics

Participant	Age	Gender	PTA-threshold (dB)
1	20	F	0
2	21	F	7.5
3	33	M	1
4	20	F	-5
5*	20	F	8
6	21	F	-2
7	30	M	15
8	19	F	5
9*	30	F	0

Note. *= did not meet inclusion criteria

Apparatus

The core of the apparatus was constructed using a Cirus Logic CS3310 stereo digital volume control (see Figure 6). The Integrated Circuit (IC) has two independent channels, laser-trimmed 0.5 dB steps and a dynamic range of 127 dB. Control of this IC was through a 16 bit serial interface. A separate circuit was utilized to toggle a flip-flop (74LS73) when the hand-switch was pressed. These circuits were transferred to a printed circuit card and the surface mount components were soldered to the board. The control program for the experiments including the driver for the CS3310 IC was controlled by a Windows based computer (Dell, XXX) running Windows XP ©. The control program was written in Quickbasic 64 (QB64). A flowchart of the program is shown in Figures 7a, 7b and the program code itself may be found in Appendix A. The two separately attenuated signals for the target (tone) and the noise were fed to a two-channel mixer and presented monaurally through a TDH-39 earphone with an MX41-AR cushion. Participant responses were printed on a screen (e.g., Figure 8) and recorded to a text file.

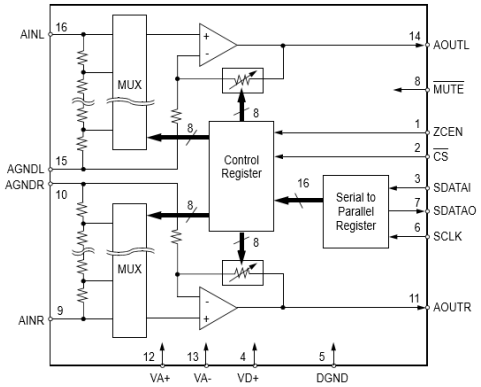

Fig. 6: Schematic of the Integrated Circuit used to build the test apparatus

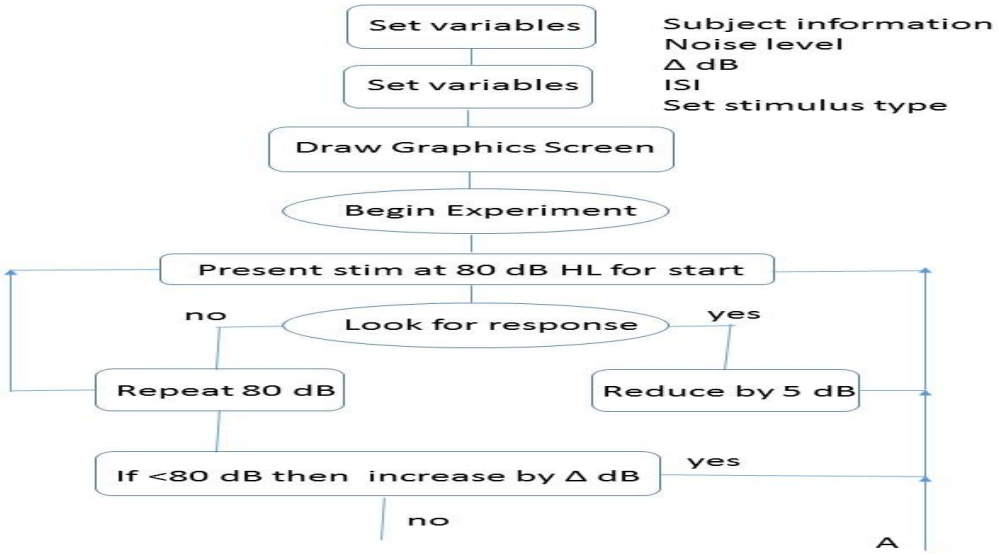

Fig. 7a: Functional flow chart of the control program

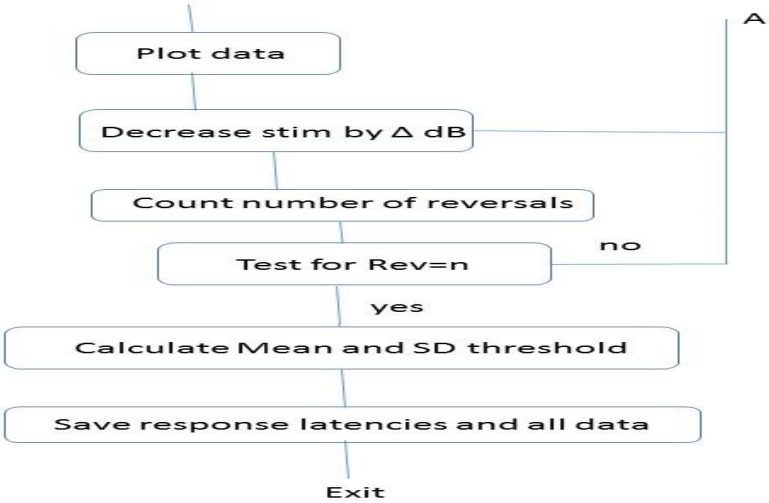

Fig. 7b: Functional flow chart of the control program (cont.)

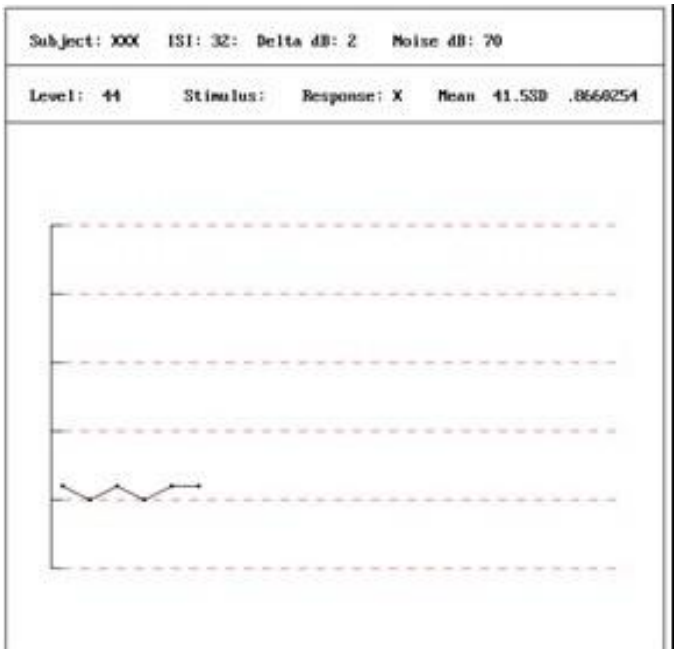

Fig. 8: Sample screen showing intensity reversals with calculated mean and SD

Stimuli

Three signal types, Blackman envelope, Linear rise-fall, and a "Chirp" (linear-sweep gated with a linear rise-fall) were constructed to serve as stimuli. The stimuli were constructed in Cool Edit (Syntrillium, 1996). The final stimuli were two-channel WAV files with one channel containing the target (tone) stimulus and the second channel containing the inter-stimulus interval (ISI) followed by the noise. The interstimulus interval (ISI)—a silence placed between the offset of the probe tone and the onset of the masking noise— ranged from 2-128 milliseconds in powers of 2. The two channels were aligned so that the onset of the masker always followed the offset of the target (tone) in time (Figure 9).

Fig. 9: Wave form of the stimulus (probe signal, ISI, masking noise)

All rise and fall times (envelope) were generated outside of Cool Edit using a QB64 routine. The target stimuli were a 20-ms 1,000 Hz sine wave fitted with either a linear 5-ms-linear rise and fall envelope or a Blackman gating function, and a 20-ms linear-sweep from 500 Hz to 4,000 Hz fitted with a linear rise-fall (also a 5-ms rise and 5-ms fall). A 50-ms Gaussian noise (linear rise-fall of 50 msec) served as the masker (Figure 10).

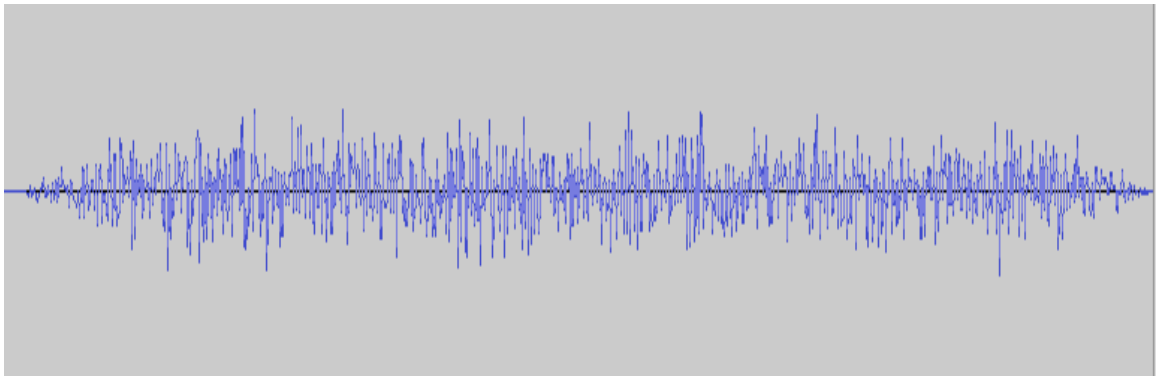

Fig. 10: 50-ms Gaussian Noise with 5-ms-linear rise and fall

The Fourier analysis for each of the stimuli is shown in Figures 11-14.

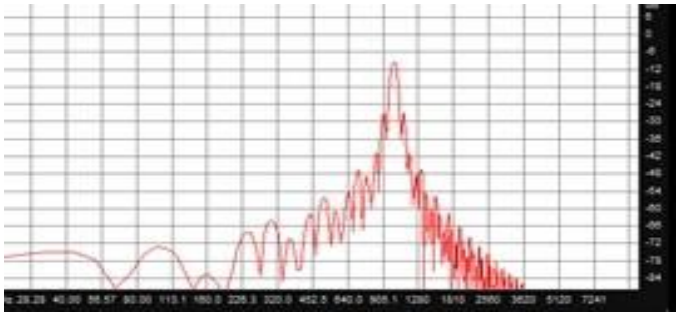

Fig. 11: Linear rise fall

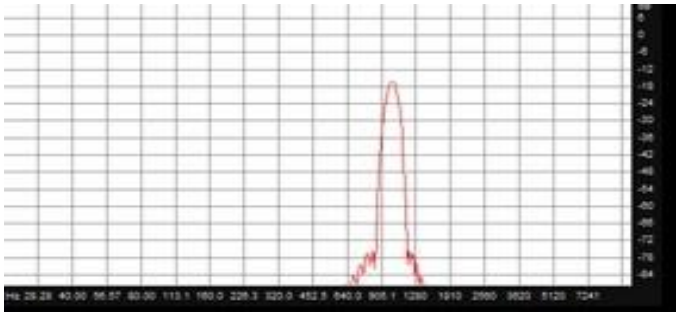

Fig. 12: Blackman

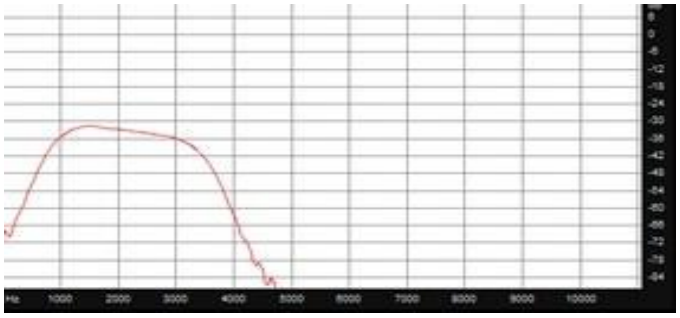

Fig. 13: Linear-Sweep

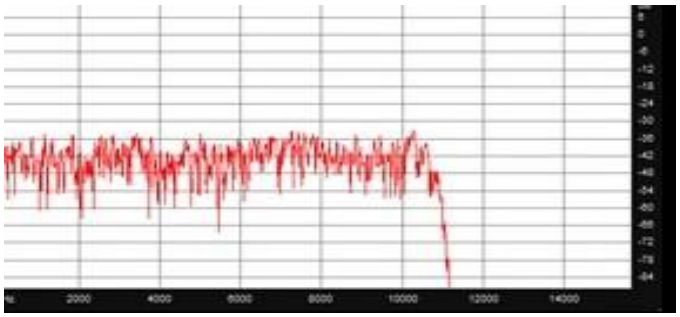

Fig. 14: Gaussian Noise with linear rise-fall

Procedure

The clinical inspiration for this study came from Cobb and colleagues (1993) investigation into the effects of age on the backward masking function. The clinical posture of the experimental paradigm used here explains the procedural use of a "method-of-adjustment". This method echoes the clinical tests of hearing used by audiologists. It is preferred because it allows the participant to learn the task at the easier conditions (i.e., louder and less masked) without extensive training. In this way, the examiner can have increased confidence that the participant is performing the task and that the test has validity.

The participant was verbally instructed to press the button on a hand-held switch when the tone was heard. Threshold was tracked using the method-of-adjustment. Correct responses attenuated the level of the target by 5 dB until no response was

obtained. At that point attenuation increment and decrement occurred at 2 dB. The points of inflection, where a descending pattern changed to an ascending one, were termed reversals— 4-6 reversals determined threshold. The participants attended to the stimuli monaurally through the left ear and responded by pressing the hand-switch. Response times, ISI, and presented intensities were saved by the control program as text files. The experiment was monitored in real time. Participants were free to take breaks when they felt fatigue or if they noticed reduced attention to the task. A run of the response time (RT) protocol ranged from 45-60min including breaks.

Data Analysis

The data are recorded in text files that include participant demographics, signal-type, intensity (dB), ISI, Response (yes=1, no=0), response times for each trial, threshold for each ISI, and standard deviation of the reversals. The text files were imported into an Excel worksheet, organized in a four columns with the headers: Participant, ISI, Signal-type, Intensity, Response time. A second Excel worksheet was constructed with the headers: Threshold, ISI, Response time, Participant, Standard Deviation. These data were then read into "R", a statistical software package. "R"-Code was written for simple linear regression, multivariate linear regression, multivariate linear regression with interaction terms, incremental F-test, Durbin-Watson test for autocorrelation, and transformations of the individual data (see epilogue). Graphs were produced by the Quartz package within "R". Summary statistics including diagnostics of the basic assumptions for linear modeling (i.e., normality, independence, constant variance, zero expectation for the average errors) were also produced in "R"

CHAPTER FOUR
Results

Aggregate data (all participant responses combined) was used to compare 1) inter-stimulus interval (ISI) to threshold, 2) intensity to response time—regressed according to signal type, and 3) intensity to response time—regressed according to ISI. The aggregate data was then used to construct a multivariate model of the response time in relation to three other dimensions that were tracked in this study (i.e., intensity, ISI, and signal type). Diagnostic tests were run to ensure basic assumptions for valid statistical testing. An incremental F-test was then conducted to rule out conditioning of the impact of Signal-type on RT by ISI; so that these potential interaction terms did not secretly confound the model's tests of significance.

Question #1

Does stimulus type influence the backward masking function?

A linear regression of the effect of ISI on threshold reveals a significant masking trend ($p<0.005$) across subjects but lack statistical power to reveal significant differences in masking trends between signal types (see Figure 15; Table 2).

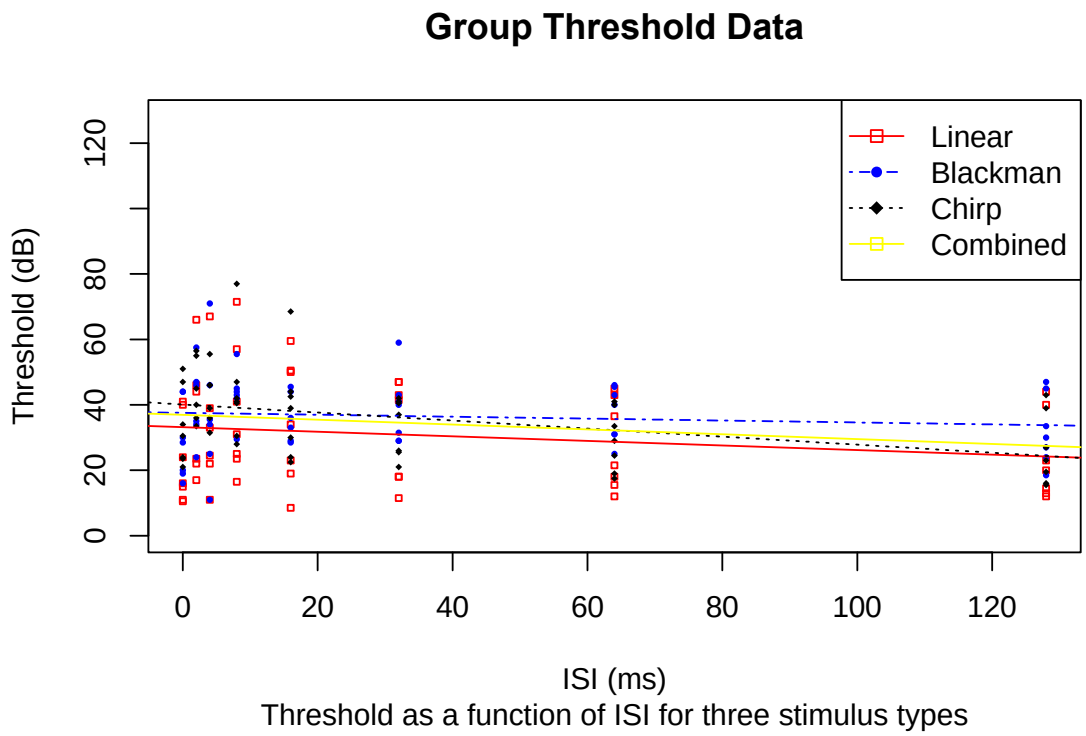

Fig. 15: Threshold data by signal-type and combined

The model has limited explanatory power (R^2=0.04). This is likely due to the limited number of participants (n=7), variations in absolute sensitivity, and the confounding variable of attention that was not controlled for in the method. The adjusted R^2 reported here is sensitive to outliers. The data were not cleaned prior to this analysis and a systematic removal of responses that lie ≥2 SD outside the expected value may significantly increase the explanatory power of the model. The linear regression of ISI on threshold presents a residual distribution that is close to normal (Figures 16 and 17). The regression of threshold data by signal type did not provide sufficient evidence to discard the null-hypothesis that— there is not a difference in the backward masking function among the three signal types. The existence of a masking trend across signal-type and including all participants may be interpreted to indicate that all signal-types have similar

masking curves. Thus, each signal-type displayed validity as a probe in the clinically postured test of backward masking that was used in this study.

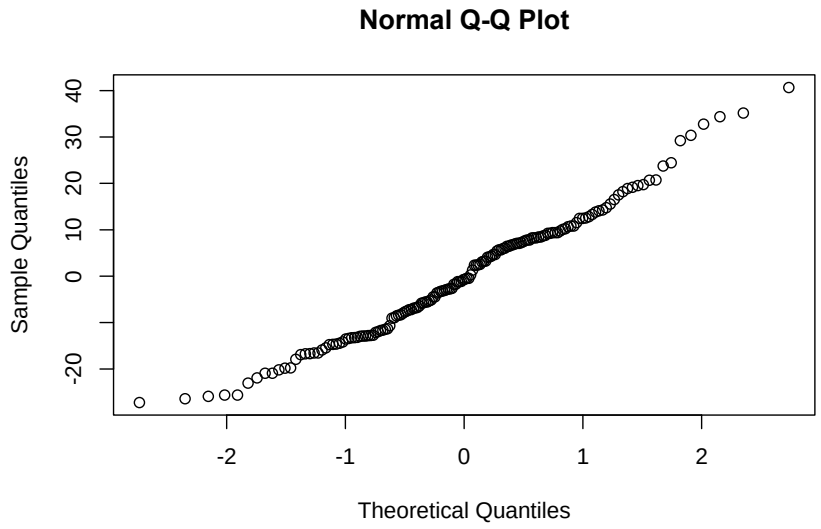

Fig. 16: Graph of the Residuals Relative to a Theoretical Norm

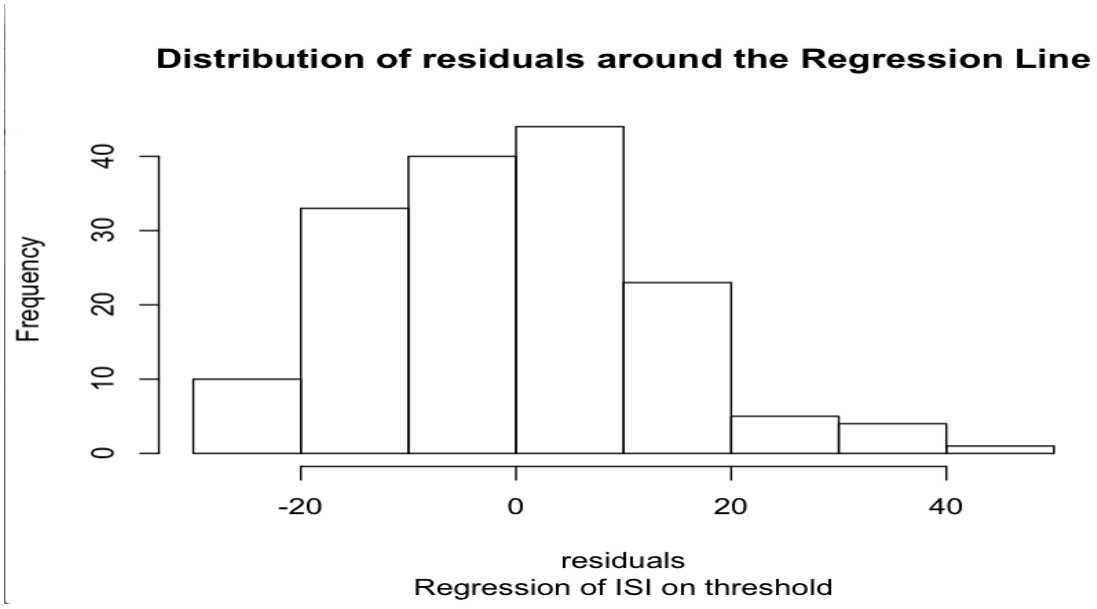

Fig. 17: Distribution of residuals for linear regression of ISI on threshold

Table 2

Linear regression of Interstimulus Interval (ISI) on threshold

	Coefficients:			
	Estimate	Std. Error	t-value	
Intercept	36.918	1.376	26.823***	
ISI	-0.0739	0.0257	-2.873**	
Residual Std. Error		Adj. R^2	F-statistic	DF
13.69		0.044†	8.253**	1 and 158

Note. †=Adjusted R^2 is strongly affected by outliers
Note. **= p≤0.01, ***=p≤0.001

Question #2

Does signal-type influence the ease-of-task in a backward-masking detection paradigm targeting naïve listeners with normal hearing?

The aggregate data, when regressed by signal-type, shows a statistically promising trend. The "chirp" and Blackman signals follow parallel courses with y-intercepts noticeably above the trapezoidal signal (see Figure 18). A multivariate linear model of these data incorporating the impact of Signal-type, ISI, and stimulus intensity on RT reveals significant differences in the intercepts and slopes of the regression lines when analyzed with respect to signal-type (Table 3). Empirically, these differences can be seen in graphical form (Figure 18). There is sufficient evidence to reject the null-hypothesis that —Signal-type does not affect response time/ease-of-task. There is then evidence to conclude that Signal-type does affect RT and hence ease-of-task.

The simple regression of the data with respect to signal-type has little explanatory power (chirp: $R^2 = 0.13$, Blackman: $R^2=0.08$, Linear: $R^2=0.06$). This is principally due to the leverage of the outliers. However, another probable reason for the low explanatory power of the model when considered by signal-type alone is the existence of at least one lurking variable, namely, ISI.

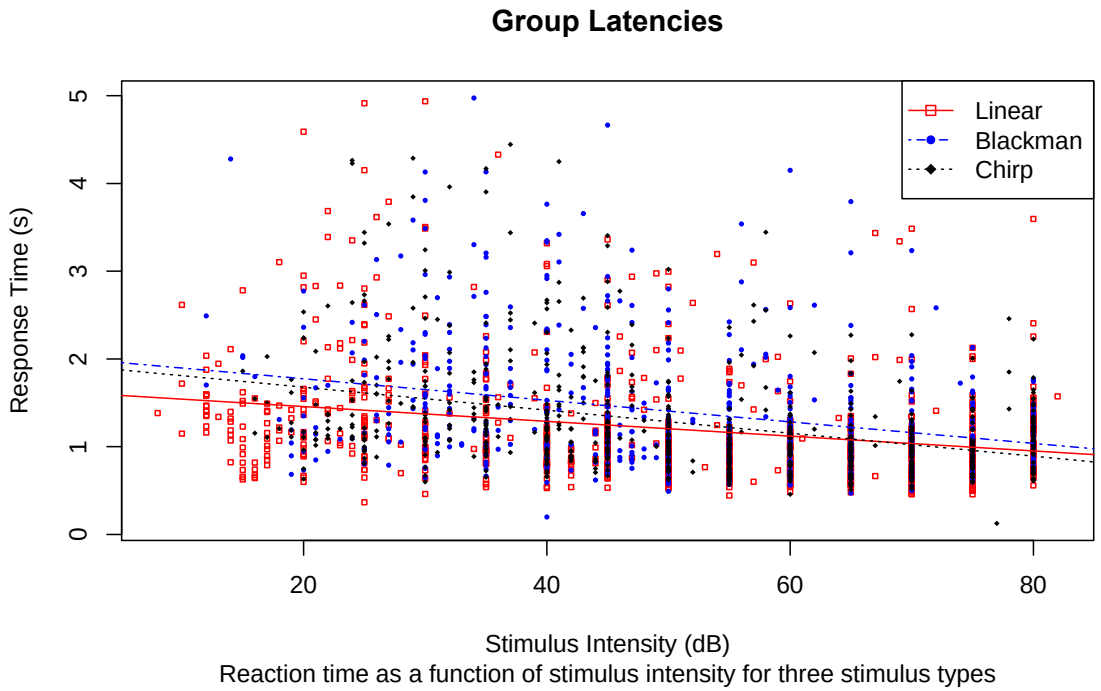

Fig. 18: Response times by signal type, $p \leq 0.000001$, $0.06 \leq R^2 \leq 0.13$

Question #3

Is the effect of signal-type on response time conditioned by ISI?

When the data is sorted by ISI category, a linear regression of stimulus intensity on RT reveals another striking series of trends (Figure 19) this time displaying slightly better explanatory power ($0.07<R^2<0.21$). This is to be expected since ISI is always strong contributing factor in backward masking experiments. The *y*-intercepts of the

regression lines reveal a pattern of increased response time with decreased ISI. This suggests that as ISI decreases, subject confidence also decreases which implies an increase in the difficulty of the task. This finding agrees with the basic assumption that tone-masker proximity is strongly correlated with effective masking. Furthermore, the inverse relationship between ISI and response time (RT) gives confidence that the data may be a representative sample of the population of all subject RT behaviors under backward masking conditions. These results are encouraging; however a system as complex as a behavioral test of perception is bound to have interaction terms that confound the interpretation of statistical significance as various factors vie for influence within the model.

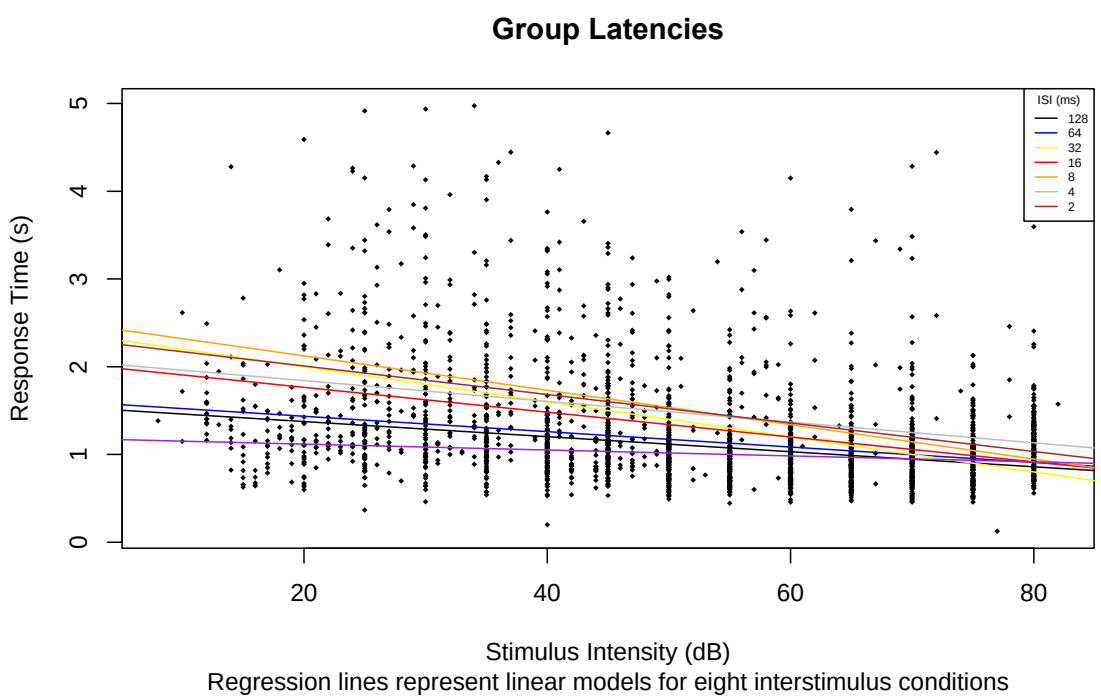

Fig. 19: Response times by ISI, $p \leq 0.0001$, $0.07 \leq R^2 \leq 0.21$

Because an interaction between ISI and Signal-type may exist the multivariate analysis must include interaction terms. The dimensions measured in this study that are

candidates for influence within the model are: RT, ISI, intensity of stimulus (dB), and Signal-type. The multivariate linear model used to test for interaction terms compared the effect of all the interactions between Signal-type and ISI on RT and added the individual effects of intensity level, Signal-type and ISI on RT. A model that compared all the interactions of all three terms was constructed and subsequently abandoned because it did not report any differences from the model described above that accounted for only the interactions between ISI and Signal-type. This step was empirically supported because intensity (the independent variable in Figures 18 and 19) has a well-documented relationship to both Signal-type (cf. duration of signal, frequency, etc.) and ISI, so that the relationship between these two factors was considered most relevant. Analysis of Variance (ANOVA) on this interaction model revealed that the effect of signal-type on RT is not conditioned by the effect of ISI on RT, and *vice versa* ($p<0.45$, i.e. not significant; see appendix A for details). This means that ISI and signal-type operate independently on subject RT and it is appropriate to consider Signal-type *per se.* An incremental F-test compared the relative contribution of Signal-type and ISI to the model; significant differences were found ($F=4.065$, 3 and 2096 DF, $p<0.0068$) further indicating that the impact of Signal-type on RT is not conditioned by ISI (nor *vice versa*) and that they contribute equally within the model to the prediction of RT (see appendix A for details).

Question #4

If signal-type influences participant confidence as measured by reaction time, what signal -type results in the greatest participant confidence?

The results from question #1 suggest that Signal-type does impact RT so it is natural to ask which Signal-type, of those tested, resulted in the lowest RTs overall. In preparing the data for multivariate analysis, a minor change was deemed appropriate; all RTs gathered at 80dB HL for the stimulus were removed from the data set, on the grounds that the position of 80dB as the initial presentation level conditioned it to serve as a training tone (as happens in a pure-tone clinical test of hearing) and introduced a systematic bias into the response time data. Baselines for the comparisons made within the multivariate model are the tone alone (i.e., the tone without a masker) and the Blackman envelope. However, using a different baseline will not change the inherent relationship between the constituents.

The distribution of the residuals is not strictly normal (see Figure 20), but the large number of observations (>2,000) included in the statistical analysis relieves the need for strict normality in the data. The assumptions of independence, constant variance, and zero expectation were tested and vetted.

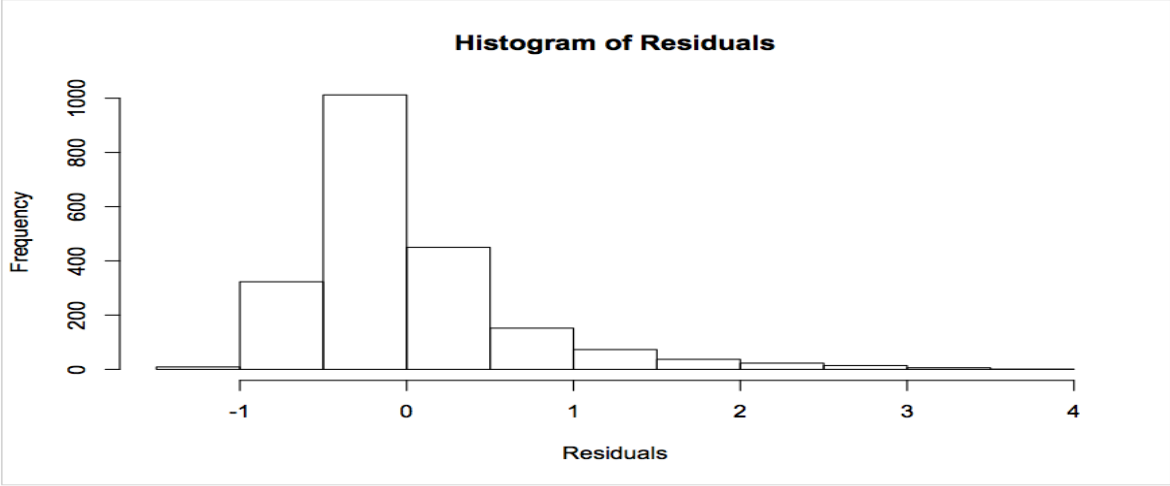

Fig. 20: Showing the slight right-skewness of the data for a linear model of (RT~dB)

Table 3

Multivariate linear regression of Intensity, Signal-type and Interstimulus-Interval on Response Time (s)

	Coefficients:		
	Estimate	Std. Error	t-value
Intercept	1.766	0.057	30.754***
Chirp†	-0.133	0.035	-3.816***
Linear†	-0.233	0.034	-6.767***
2 ms ISI††	0.574	0.057	10.137***
4 ms ISI††	0.552	0.057	9.68***
8 ms ISI††	0.578	0.056	10.243***
16 ms ISI††	0.393	0.054	7.269***
32 ms ISI††	0.452	0.054	8.36***
64 ms ISI††	0.219	0.053	4.137***
128 ms ISI††	0.14	0.052	2.7**
Intensity(dB)	-0.0142	0.0009	-17.09***

Residual Std. E	Adj. R^2	F-stat	DF
0.6152	0.1937	47.58****	10 and 1929

Note. **= p≤0.01, ***p≤0.001, *****p≤0.00001
Note. † = the Blackman envelope is used here as the baseline
Note. ††= the tone alone is used here as the baseline

The multivariate model overall boasts strong significance ($p<2*10^{(-16)}$) with more explanatory power (R^2=0.194) than the previous bivariate models. The reported influence of the signal types is independent from the influence of the ISI and the influence of both the chirp and trapezoidal signals are significantly different from the Blackman (p<0.00014). The trapezoidal signal contributes -0.233 *s* to the y-intercept (RT) relative to the Blackman, -0.10 *s* less than the Chirp. Thus, the trapezoidal signal is associated with faster RT. Note that the contribution of the ISIs follows a predictable pattern—smaller ISI has a larger effect on the RT. For example, ISI=2 increases the RT, relative to the control condition (i.e., no masker), by 0.574*s*, whereas ISI=128 increases RT by only

0.14*s*. This makes sense in that smaller ISI means that the signal and masker are closer together increasing the effect of temporal masking. The effect of intensity likewise follows expectation. The model predicts that an increase in stimulus intensity of 1 dB will result in a decrease of 0.014*s* in RT. Because the trapezoidal signal is associated with significantly faster RT, it may be correlated to greater participant confidence and thus greater ease-of-task.

CHAPTER FIVE
Discussion

The results of this study suggest that there are significant differences in the effect of the three signal types that were tested on subject response time (RT). The greatest difference was between the 1000 Hz signal with a trapezoidal (linear rise-fall) gating function and the signal fitted with a Blackman function. The trapezoidal function yielded, on average, faster response times that either the Blackman or the chirp. The RTs to the chirp were slightly faster than those to the Blackman signal. Faster response times correlate to greater subject confidence and imply greater perceptual ease of task execution. Therefore, the trapezoidal envelope on a 20-ms, 1000 Hz tone was the easiest signal-type for subjects to distinguish from the masking noise.

For a listener who is naïve to the task of a backward masking protocol, the most familiar and therefore efficacious signal might be a linguistically familiar unit such as a consonant-vowel (CV) syllable. A simple confusion matrix could reveal backward masking patterns and would require little subject training. However, the masking of a consonant by a following vowel does not isolate the temporal aspect of backward masking and requires an assumption that the psychoacoustic filter during the task be quite broad. Consider that vowels have a relatively low frequency steady-state fundamental with formant transitions, whereas consonants have high frequency noise bursts and chirps. A syllable-based paradigm for backward masking would present a harmonic complex rather than a pure tone and thus would incorporate more levels of processing (including semantic). It would also introduce the confounding influence of frequency on the backward masking function. The motor component necessary for the subject to

reproduce what he heard in a backward masking test using a syllabic probe may also exclude cases of stroke, cerebral palsy, and young children. With this in mind the advantages of a simple neurally specific signal become clear. First, a neurally specific probe is easier to control and thus easier to norm on a wide population, and second, greater neural specificity would increase its diagnostic potential. On this note, the linear sweep (chirp)—used as one of the stimulus types in the current study—lacks neural specificity; however, it achieves a compromise by imitating some of the spectral characteristics of speech (such as formant transitions) while retaining a controlled bandwidth, envelope, and duration.

Interestingly, the Blackman and chirp stimuli are not significantly different from each other in terms of group response time, despite differing across two dimensions. However, they do have one similarity, to wit, neither has more than a single cycle at a particular wavelength at full amplitude. The Blackman signal achieves peak amplitude for at most one cycle because the envelope is sinusoidal (therefore has a single maximum). The chirp continuously changes wavelength across the 20-ms duration. The signal with trapezoidal-envelope may be easier to hear because it has a longer steady-state portion. In other words the trapezoidal signal has a greater number of cycles of a single frequency at full amplitude (Figures 3-5) than either the chirp or the Blackman signal. The trapezoidal gating function on a 1000 Hz tone has more energy at a single frequency and must therefore provide greater temporal resolution—mitigating the effects of temporal masking.

The effects of subject learning cannot be eliminated from the model. Learning in psychoacoustic experiments is estimated to extend to between 500 and 1000 trials

(Amitay, et al., 2006). The subjects in the current study participated in roughly 480 trials, which is within the 500-1000 trial learning period reported in literature. Importantly, the study reported by Amitay and colleagues (2006) sought to establish a method that would capture the early learning effects, as they are more instructive about auditory processing than the later, "trained", responses. In a clinical test, the objective is to witness the auditory system as it processes a new a challenging auditory scene (i.e, controlled masked stimuli). What is more, a patient in a clinic will not be trained on a masking paradigm. Thus a learning effect will necessarily be present in any clinical test of hearing.

A learning effect can be seen in the aggregate data for RT between 80-75dB. The subject first hears the tone accompanied by a masker at 80dB, this level of presentation makes this the easiest trial for subjects to distinguish target from masker; however, across all subjects the reaction time at 80dB was longer than that at 75dB. This is clearly an effect of subject training which amounts to a learning effect. Thus, neural "priming" which allows the subject to assume a mental posture that accommodates the task, may explain some of the learning effect. This *in situ* training is built into the experimental method. In designing the test protocol care was taken to model the procedure as closely as possible on a standard test of hearing. Pure-tone audiometry has a long history of clinical utility. The methods that have been vetted by audiologists used higher intensity tones in a descending method of adjustment to "train" patients on what the target stimulus sounds like and how to attend to it. Although this method introduces a systematic bias in the form of an order effect into the data, it is justified by the clinical posture of the procedure and its purpose as an eventual clinical tool. Some amount of training is necessary. The method of adjustment gave the subjects more practice at the easier

conditions to yield better results on the difficult conditions. This increases the validity of the experiment, which is to say: subjects are being tested on what the test is ostensibly about.

Two subjects who participated in the study but failed to meet the inclusion criteria (i.e., thresholds to tone alone and tone-plus-masker at 128 ISI did not match) are non-the-less interesting case studies in how the test paradigm might present for persons with APD

Developing an appropriate signal to serve as a stimulus type marks the beginning of the process for creating a useful diagnostic test for APD using a backward masking paradigm. The next phase will be to refine the method and the parsimony of the test protocol. Further research should include subjects with known APDs and subjects from a broader age range. Young and older patients present with different masking functions and may respond differently to the test procedure.

Epilogue

Preliminary results from a single "typical" participant, reveal a pattern best fitted by a hyperbolic function (Figure 21). These data control for dB level and signal-type and suggest a statistically significant difference between the curves for each signal type ($p<10^{(-16)}$) with relatively strong explanatory power ($R^2=0.67$). While this data set is small, the distribution is normal and the lines can be fitted with confidence. These exploratory results indicate that the true interaction of response time to ISI is non-linear and that future investigation with tighter controls may tease out this relationship.

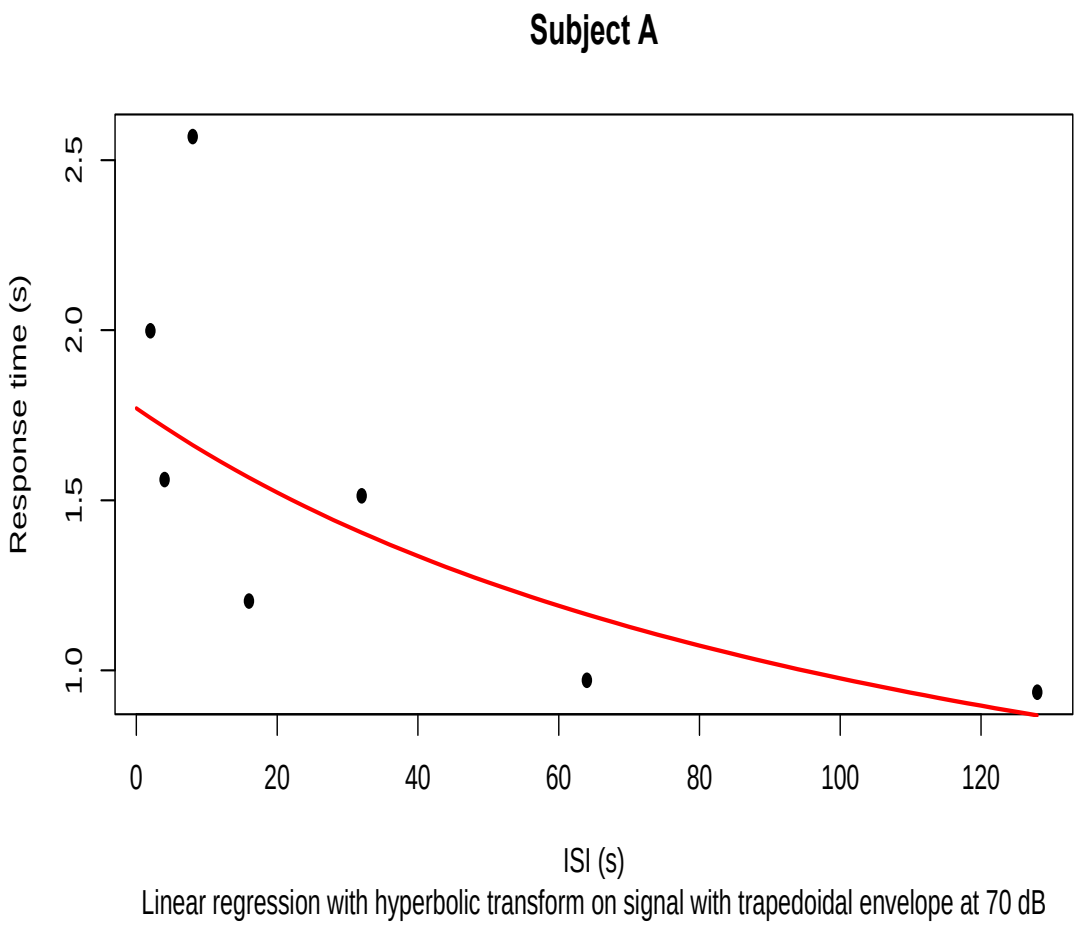

Fig. 21: Individual response times for one signal type at 70 dB HL

CHAPTER SIX
Summary

The current study sought to establish whether Signal-type affected the ease-of-task, indexed by participant response time. The results justify a conclusion that signal-type is a significant factor in subject response time and hence, ease-of-task. Moreover, the contribution of signal type to response time is not confounded by any potential interaction terms, such as inter-stimulus interval. The signal-type that yielded the quickest response times across all subjects, ISIs, and intensity levels was the 20-ms, 1000 Hz sine-wave fitted with a trapezoidal gating function. Because the trapezoidal envelope on a 20-ms 1000 Hz sine-wave yielded the fasted response times it was concluded to be the easiest for subjects to attend to and to distinguish from the noise masker, enhancing its utility as a probe in a clinical test of auditory processing disorders.

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APPENDIX A

Name of Principal Investigator Robert David Sears
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University of Montana

Assorted Tables and Computational Scripts:

Multivariate model with term interactions

```
lm(formula = RT2 ~ Signal2 * ISI3 + dB2)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.2316 -0.3842 -0.1257  0.1982  3.2959 

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)    
(Intercept)       1.7366845  0.0740336  23.458  < 2e-16 ***
Signal2C         -0.0607112  0.0923858  -0.657 0.511165    
Signal2L         -0.2069776  0.0890650  -2.324 0.020235 *  
ISI32             0.5110006  0.0969197   5.272 1.50e-07 ***
ISI34             0.5728626  0.0975549   5.872 5.06e-09 ***
ISI38             0.6041445  0.0994722   6.074 1.51e-09 ***
ISI316            0.4246909  0.0968011   4.387 1.21e-05 ***
ISI332            0.6137549  0.0957789   6.408 1.85e-10 ***
ISI364            0.3189747  0.0943444   3.381 0.000737 ***
ISI3128           0.1237757  0.0909996   1.360 0.173933    
dB2              -0.0142128  0.0008326 -17.071  < 2e-16 ***
Signal2C:ISI32    0.0429804  0.1396861   0.308 0.758349    
Signal2L:ISI32    0.1430553  0.1360929   1.051 0.293318    
Signal2C:ISI34   -0.1062353  0.1418805  -0.749 0.454090    
Signal2L:ISI34    0.0327810  0.1366381   0.240 0.810425    
Signal2C:ISI38   -0.0623145  0.1406251  -0.443 0.657725    
Signal2L:ISI38   -0.0203579  0.1363945  -0.149 0.881366    
Signal2C:ISI316  -0.1009228  0.1353505  -0.746 0.455976    
Signal2L:ISI316  -0.0004607  0.1319770  -0.003 0.997215    
Signal2C:ISI332  -0.2853861  0.1342569  -2.126 0.033658 *  
Signal2L:ISI332  -0.1845250  0.1322787  -1.395 0.163186    
Signal2C:ISI364  -0.1042061  0.1324166  -0.787 0.431405    
Signal2L:ISI364  -0.1865851  0.1298536  -1.437 0.150913    
Signal2C:ISI3128  0.0172853  0.1295528   0.133 0.893873    
Signal2L:ISI3128  0.0259272  0.1265131   0.205 0.837643    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6152 on 1915 degrees of freedom
Multiple R-squared:  0.2037,	Adjusted R-squared:  0.1937 
F-statistic: 20.41 on 24 and 1915 DF,  p-value: < 2.2e-16
```

Analysis of Variance (ANOVA) evaluating the conditioning of signal type by ISI and *vice versa*: note $p < 0.45$, highly insignificant.

```
> anova(full3)
Analysis of Variance Table

Response: RT2
               Df Sum Sq Mean Sq  F value    Pr(>F)
Signal2         2  10.37   5.183  13.6931 1.245e-06 ***
ISI3            7  59.14   8.449  22.3242 < 2.2e-16 ***
dB2             1 110.58 110.576 292.1591 < 2.2e-16 ***
Signal2:ISI3   14   5.30   0.378   0.9997    0.4505
Residuals    1915 724.78   0.378
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
```

Multivariate Model without term interactions

```
Call:
lm(formula = RT2 ~ Signal2 + ISI3 + dB2)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.2047 -0.3825 -0.1226  0.1988  3.2971 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.765796   0.057416  30.754  < 2e-16 ***
Signal2C    -0.132828   0.034813  -3.816  0.00014 ***
Signal2L    -0.232639   0.034376  -6.767 1.73e-11 ***
ISI32        0.574203   0.056643  10.137  < 2e-16 ***
ISI34        0.551925   0.057016   9.680  < 2e-16 ***
ISI38        0.577951   0.056421  10.243  < 2e-16 ***
ISI316       0.392827   0.054045   7.269 5.25e-13 ***
ISI332       0.452181   0.054120   8.355  < 2e-16 ***
ISI364       0.219688   0.053104   4.137 3.67e-05 ***
ISI3128      0.140770   0.052103   2.702  0.00696 **  
dB2         -0.014170   0.000829 -17.093  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6152 on 1929 degrees of freedom
Multiple R-squared:  0.1979,	Adjusted R-squared:  0.1937 
F-statistic: 47.58 on 10 and 1929 DF,  p-value: < 2.2e-16
```

"Complete" multivariate model: used to formulate the "Incremental F-test"

```
Call:
lm(formula = RT ~ dB * Signal)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.3305 -0.4051 -0.1512  0.1994  3.5637 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  2.0193820  0.0796360  25.358  < 2e-16 ***
dB          -0.0122717  0.0014431  -8.504  < 2e-16 ***
SignalC     -0.0789526  0.1091192  -0.724   0.4694    
SignalL     -0.3933725  0.1003140  -3.921 9.09e-05 ***
dB:SignalC  -0.0008365  0.0019852  -0.421   0.6735    
dB:SignalL   0.0038484  0.0018491   2.081   0.0375 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6334 on 2094 degrees of freedom
Multiple R-squared:  0.1033,	Adjusted R-squared:  0.1012 
F-statistic: 48.24 on 5 and 2094 DF,  p-value: < 2.2e-16

> anova(com.f)
Analysis of Variance Table

Response: RT
            Df Sum Sq Mean Sq  F value    Pr(>F)    
dB           1  79.42  79.418 197.9607 < 2.2e-16 ***
Signal       2  14.10   7.050  17.5723 2.703e-08 ***
dB:Signal    2   3.26   1.628   4.0584   0.01741 *  
Residuals 2094 840.07   0.401                       
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
```

"Reduced" multivariate model: used to formulate the "Incremental F-test"

```
Call:
lm(formula = RT ~ dB + Signal)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.3133 -0.4054 -0.1536  0.1924  3.5173 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.9472055  0.0465938  41.791  < 2e-16 ***
dB          -0.0108966  0.0007535 -14.461  < 2e-16 ***
SignalC     -0.1213638  0.0344270  -3.525 0.000432 ***
SignalL     -0.2005652  0.0340247  -5.895 4.36e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6343 on 2096 degrees of freedom
Multiple R-squared:  0.09982,	Adjusted R-squared:  0.09853 
F-statistic: 77.48 on 3 and 2096 DF,  p-value: < 2.2e-16

> anova(com.red)
Analysis of Variance Table

Response: RT
            Df Sum Sq Mean Sq F value    Pr(>F)    
dB           1  79.42  79.418 197.385 < 2.2e-16 ***
Signal       2  14.10   7.050  17.521 2.842e-08 ***
Residuals 2096 843.33   0.402                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Incremental F-test

F = ((SSE(reduced)-SSE(complete))/2)/(MSE(complete))
F = ((843.33-840.07)/2)/0.401
F = 4.064838
DF = 3 and 2096
p = 0.00685

Statistical Summaries of regression by signal type

Linear model of Intensity (dB) on Response Time (s)						
Signal type	Linear envelope					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-1.0484	-0.3956		-0.1496	0.1637	3.5637	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	1.626	0.061	26.592	$<2e^{-16}$	***	
Intensity	-0.00842	0.0012	-7.268	$<9.2e^{-13}$	***	
Resid. S.E	0.6349 on 739 degrees of freedom					
Adj. R^2	0.06545					
F-stat	52.83 on 1 and 739 DF			p-value: $9.28e^{-13}$		

Linear model of Intensity (dB) on Response Time (s)						
Signal type	Blackman envelope					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-1.0484	-1.3305		-0.4528	-0.1544	3.3719	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.019	0.085	23.754	$<2e^{-16}$	***	
Intensity	-0.012	0.0012	-7.97	$<7.2e^{-15}$	***	
Resid. S.E	0.6761 on 661 degrees of freedom					
Adj. R^2	0.0862					
F-stat	63.46 on 1 and 661 DF			p-value: $7.17e^{-15}$		

Linear model of Intensity (dB) on Response Time (s)						
Signal type	Linear Sweep with Linear envelope					
Residuals:						
Min.	1Q.	Median	3Q.	Max.		
-1.0463	-0.3618	-0.1504	0.1724	2.9896		
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	1.94	0.069	28.02	$<2e^{-16}$	***	
Intensity	-0.013	0.0013	-10.36	$<2e^{-16}$	***	
Resid. S.E	0.588 on 694 degrees of freedom					
Adj. R^2	0.1326					
F-stat	107.3 on 1 and 694 DF			p-value: $2.2e^{-16}$		

Statistical Summaries of regressions by ISI

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	128 ms					
Residuals:						
Min.	1Q.	Median	3Q.	Max.		
-0.735	-0.309	-0.072	0.15	2.99		
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	1.547	0.073	21.321	$<2e^{-16}$	***	
Intensity	-0.00858	0.0014	-6.092	$<3.4e^{-9}$	***	
Resid. S.E	0.4829 on 302 degrees of freedom					
Adj. R^2	0.1065					
F-stat	37.11 on 1 and 302 DF			p-value: $3.4e^{-9}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	64 ms					
Residuals:						
Min.	1Q.	Median	3Q.	Max.		
-0.8537	-0.343	-0.154	0.115	2.827		
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	1.61	0.092	17.457	$<2e^{-16}$	***	
Intensity	-0.00876	0.0017	-5.05	$<3.4e^{-9}$	***	
Resid. S.E	0.5474 on 282 degrees of freedom					
Adj. R^2	0.0796					
F-stat	25.47 on 1 and 282 DF			p-value: $8.1e^{-7}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	32 ms					
Residuals:						
Min.	1Q.	Median	3Q.	Max.		
-1.084	-0.479	-0.106	0.319	3.166		
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.398	0.128	18.75	$<2e^{-16}$	***	
Intensity	-0.0199	0.0023	-8.57	$<8.6e^{-16}$	***	
Resid. S.E	0.6654 on 265 degrees of freedom					
Adj. R^2	0.2141					
F-stat	73.45 on 1 and 265 DF			p-value: $8.7e^{-16}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	16 ms					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-1.328	-0.413		-0.174	0.263	3.407	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.049	0.119	17.265	$<2e^{-16}$	***	
Intensity	-0.014	0.002	-6.506	$<3.8e^{-10}$	***	
Resid. S.E	0.638 on 265 degrees of freedom					
Adj. R^2	0.135					
F-stat	42.33 on 1 and 265 DF			p-value: $3.8e^{-10}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	8 ms					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-1.102	-0.44		-0.156	0.244	2.55	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.516	0.156	16.144	$<2e^{-16}$	***	
Intensity	-0.019	0.003	-7.123	$<1.3e^{-11}$	***	
Resid. S.E	0.6786 on 230 degrees of freedom					
Adj. R^2	0.1772					
F-stat	50.74 on 1 and 230 DF			p-value: $1.3e^{-11}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	4 ms					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-0.989	-0.477		-0.183	0.24	3.214	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.079	0.148	14.066	$<2e^{-16}$	***	
Intensity	-0.0118	0.003	-4.413	$<1.6e^{-5}$	***	
Resid. S.E	0.7404 on 219 degrees of freedom					
Adj. R^2	0.077					
F-stat	19.47 on 1 and 219 DF			p-value: $1.6e^{-5}$		

Linear model of Intensity (dB) on Response Time (s)						
InterStimulus interval	2 ms					
Residuals:						
Min.	1Q.		Median	3Q.	Max.	
-1.105	-0.466		-0.182	0.281	3.092	
Coefficients:						
	Estimate	Std. Error	t-value	Pr(>|t|)		
Intercept	2.332	0.159	14.63	$<2e^{-16}$	***	
Intensity	-0.016	0.003	-5.81	$<2.1e^{-8}$	***	
Resid. S.E	0.715 on 227 degrees of freedom					
Adj. R^2	0.126					
F-stat	33.76 on 1 and 227 DF			p-value: $2.1e^{-8}$		

Comparison of correlations between all coefficients:

```
Generalized least squares fit by REML
  Model: RT2 ~ Signal2 + ISI3 + dB2
  Data: NULL
       AIC      BIC    logLik
  3692.973 3759.751 -1834.487

Coefficients:
                 Value  Std.Error    t-value p-value
(Intercept)  1.7657963 0.05741604  30.754404   0e+00
Signal2C    -0.1328280 0.03481247  -3.815529   1e-04
Signal2L    -0.2326389 0.03437621  -6.767438   0e+00
ISI32        0.5742027 0.05664305  10.137214   0e+00
ISI34        0.5519250 0.05701624   9.680135   0e+00
ISI38        0.5779507 0.05642143  10.243462   0e+00
ISI316       0.3928265 0.05404470   7.268549   0e+00
ISI332       0.4521809 0.05411955   8.355222   0e+00
ISI364       0.2196884 0.05310402   4.136945   0e+00
ISI3128      0.1407701 0.05210324   2.701754   7e-03
dB2         -0.0141696 0.00082899 -17.092680   0e+00

 Correlation:
          (Intr) Sgnl2C Sgnl2L ISI32  ISI34  ISI38  ISI316 ISI332 ISI364 ISI312
Signal2C -0.307
Signal2L -0.369  0.521
ISI32    -0.357 -0.007 -0.007
ISI34    -0.382 -0.002 -0.006  0.432
ISI38    -0.353 -0.020 -0.024  0.440  0.433
ISI316   -0.395 -0.031 -0.028  0.455  0.450  0.457
ISI332   -0.392 -0.030 -0.017  0.455  0.450  0.457  0.475
ISI364   -0.423 -0.030 -0.018  0.460  0.456  0.463  0.482  0.482
ISI3128  -0.459 -0.019 -0.008  0.466  0.463  0.468  0.489  0.488  0.498
dB2      -0.681  0.017  0.093 -0.096 -0.056 -0.095 -0.057 -0.063 -0.028  0.006

Standardized residuals:
       Min         Q1        Med         Q3        Max
-1.9582823 -0.6217020 -0.1992317  0.3230694  5.3594302

Residual standard error: 0.6152042
Degrees of freedom: 1940 total; 1929 residual
```

Durbin-Watson test for autocorrelation:

```
> full2 <- lm(RT2~Signal2+ISI3+dB2)
> summary(full2)

Call:
lm(formula = RT2 ~ Signal2 + ISI3 + dB2)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.2047 -0.3825 -0.1226  0.1988  3.2971 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.765796   0.057416  30.754  < 2e-16 ***
Signal2C    -0.132828   0.034813  -3.816  0.00014 ***
Signal2L    -0.232639   0.034376  -6.767 1.73e-11 ***
ISI32        0.574203   0.056643  10.137  < 2e-16 ***
ISI34        0.551925   0.057016   9.680  < 2e-16 ***
ISI38        0.577951   0.056421  10.243  < 2e-16 ***
ISI316       0.392827   0.054045   7.269 5.25e-13 ***
ISI332       0.452181   0.054120   8.355  < 2e-16 ***
ISI364       0.219688   0.053104   4.137 3.67e-05 ***
ISI3128      0.140770   0.052103   2.702  0.00696 ** 
dB2         -0.014170   0.000829 -17.093  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6152 on 1929 degrees of freedom
Multiple R-squared:  0.1979,	Adjusted R-squared:  0.1937 
F-statistic: 47.58 on 10 and 1929 DF,  p-value: < 2.2e-16

> dwtest(full2)

	Durbin-Watson test

data:  full2
DW = 1.1053, p-value < 2.2e-16
alternative hypothesis: true autocorrelation is greater than 0
```

GLS model accounting for order of stimuli presentation:

```
Generalized least squares fit by REML
  Model: RT2 ~ Signal2 + ISI3 + dB2
  Data: comdat.new1
       AIC      BIC    logLik
  3689.793 3762.135 -1831.896

Correlation Structure: AR(1)
 Formula: ~1 | index
 Parameter estimate(s):
        Phi
-0.05911021

Coefficients:
                Value  Std.Error    t-value p-value
(Intercept)  1.7688923 0.05668053  31.208111  0.0000
Signal2C    -0.1391624 0.03413364  -4.076985  0.0000
Signal2L    -0.2370495 0.03334514  -7.108969  0.0000
ISI32        0.5734479 0.05618646  10.206158  0.0000
ISI34        0.5540549 0.05661403   9.786531  0.0000
ISI38        0.5776051 0.05594437  10.324634  0.0000
ISI316       0.3953482 0.05353219   7.385243  0.0000
ISI332       0.4594370 0.05345387   8.595018  0.0000
ISI364       0.2215676 0.05237028   4.230789  0.0000
ISI3128      0.1393917 0.05136386   2.713808  0.0067
dB2         -0.0141975 0.00082402 -17.229581  0.0000

 Correlation:
         (Intr) Sgnl2C Sgnl2L ISI32  ISI34  ISI38  ISI316 ISI332 ISI364 ISI312
Signal2C -0.306
Signal2L -0.372  0.533
ISI32    -0.354 -0.010  0.005
ISI34    -0.382 -0.003  0.005  0.425
ISI38    -0.351 -0.021 -0.016  0.429  0.429
ISI316   -0.391 -0.034 -0.023  0.448  0.441  0.450
ISI332   -0.387 -0.033 -0.015  0.444  0.445  0.448  0.467
ISI364   -0.421 -0.031 -0.015  0.452  0.450  0.457  0.475  0.473
ISI3128  -0.458 -0.017 -0.004  0.459  0.457  0.465  0.486  0.484  0.493
dB2      -0.686  0.021  0.092 -0.095 -0.054 -0.095 -0.057 -0.064 -0.027  0.006

Standardized residuals:
       Min         Q1        Med         Q3        Max
-1.9591109 -0.6221961 -0.2000980  0.3237584  5.3518470

Residual standard error: 0.6152037
Degrees of freedom: 1940 total; 1929 residual
```

GSL model accounting for order of stimuli presentation using compound symmetry:

```
Generalized least squares fit by REML
  Model: RT2 ~ Signal2 + ISI3 + dB2
  Data: comdat.new1
       AIC      BIC    logLik
  3679.343 3751.685 -1826.671

Correlation Structure: Compound symmetry
 Formula: ~1 | index
 Parameter estimate(s):
        Rho
-0.05112461

Coefficients:
                 Value  Std.Error   t-value p-value
(Intercept)  1.7657765 0.05481731  32.21202  0.0000
Signal2C    -0.1349604 0.03339249  -4.04164  0.0001
Signal2L    -0.2408231 0.03093252  -7.78543  0.0000
ISI32        0.5763902 0.05468984  10.53926  0.0000
ISI34        0.5468616 0.05504734   9.93439  0.0000
ISI38        0.5682716 0.05502156  10.32816  0.0000
ISI316       0.3966899 0.05179578   7.65873  0.0000
ISI332       0.4536410 0.05150829   8.80715  0.0000
ISI364       0.2172183 0.05008268   4.33719  0.0000
ISI3128      0.1366079 0.04914766   2.77954  0.0055
dB2         -0.0140551 0.00081527 -17.23976  0.0000

 Correlation:
         (Intr) Sgnl2C Sgnl2L ISI32  ISI34  ISI38  ISI316 ISI332 ISI364 ISI312
Signal2C -0.290
Signal2L -0.371  0.557
ISI32    -0.343 -0.012  0.032
ISI34    -0.367 -0.008  0.025  0.397
ISI38    -0.339 -0.032 -0.007  0.409  0.398
ISI316   -0.369 -0.051 -0.030  0.421  0.411  0.420
ISI332   -0.369 -0.043 -0.017  0.422  0.422  0.426  0.433
ISI364   -0.409 -0.038 -0.017  0.425  0.426  0.446  0.451  0.439
ISI3128  -0.452 -0.018 -0.001  0.445  0.432  0.455  0.478  0.473  0.471
dB2      -0.707  0.018  0.085 -0.088 -0.048 -0.087 -0.052 -0.058 -0.016  0.013

Standardized residuals:
       Min         Q1        Med         Q3        Max
-1.9563059 -0.6224083 -0.2024790  0.3188994  5.3480182

Residual standard error: 0.6150703
Degrees of freedom: 1940 total; 1929 residual
```

Coefficients estimated with 95% confidence intervals:

```
Approximate 95% confidence intervals

 Coefficients:
                  lower       est.       upper
(Intercept)  1.65826905  1.7657765  1.87328388
Signal2C    -0.20044953 -0.1349604 -0.06947118
Signal2L    -0.30148780 -0.2408231 -0.18015840
ISI32        0.46913275  0.5763902  0.68364757
ISI34        0.43890302  0.5468616  0.65482012
ISI38        0.46036360  0.5682716  0.67617958
ISI316       0.29510826  0.3966899  0.49827147
ISI332       0.35262327  0.4536410  0.55465882
ISI364       0.11899643  0.2172183  0.31544020
ISI3128      0.04021973  0.1366079  0.23299597
dB2         -0.01565401 -0.0140551 -0.01245619
attr(,"label")
[1] "Coefficients:"
```

```
 Correlation structure:
          lower        est.       upper
Rho -0.07023555 -0.05112461 -0.02871441
attr(,"label")
[1] "Correlation structure:"

 Residual standard error:
    lower      est.     upper
0.5958471 0.6150703 0.6349137
```

Code for the Control Program

```
REM D0 = sdata (2) 378 pin 2 red
REM D1 = CS (3) 378 pin 3 orange
REM D2 = Clock (4) 378 pin 4 pink
REM D3 = Reset Switch (5) 378 pin 5 yellow
REM Select as input (bit 4) 379 pin 13 blue violet-white
REM Ground pin 25 black

REM these are the variables that are used
DIM bitval$(16)
REM 0-7 is right and 8-15 is left

DIM present(200)
DIM levels(200)
DIM reversal(100)
DIM scale(30)
DIM lat(200)
j = 0
x = 60
sinecal = 7
noisecal = 1

noiselevel1 = 70
deldb = 2

sinelevel = 80
trials = 0
enough = 6
volset = .25
directionold$ = "softer"
directioncurrent$ = "softer"
DECLARE DYNAMIC LIBRARY "inpout32"
   FUNCTION Inp32% (BYVAL PortAddress AS INTEGER)
   SUB Out32 (BYVAL PortAddress AS INTEGER, BYVAL Value AS INTEGER)
END DECLARE

pcount = 1000
REM Output port &h378
baseadd = &H378
Out32 baseadd, 0

start:
SCREEN 0
CLS
PRINT
PRINT
PRINT

PRINT "        * * * * * Backward Masking * * * * *"
PRINT
```

```
PRINT
PRINT "          SUBJECT INFORMATION (1)"
PRINT "          SET NOISE LEVEL in HL (2) -SKIP"
PRINT "          SET Delta dB (3)-SKIP;"
PRINT "          SET ISI (4)"
PRINT "          BEGIN EXPERIMENT (5)"
REM PRINT "          CALIBRATION (6)"
PRINT

PRINT "          ";: INPUT keyval$
IF keyval$ = "1" THEN GOTO SUBJECTINFO
IF keyval$ = "2" THEN GOTO NOISELEVEL
IF keyval$ = "3" THEN GOTO DELTADB
IF keyval$ = "4" THEN GOTO ISISET
IF keyval$ = "5" THEN GOTO BEGINEXP
GOTO start

SUBJECTINFO:
CLS
PRINT
PRINT
PRINT
PRINT "     Subject Information"
PRINT
PRINT "Subject ID (two initials, eg ss: ";
INPUT subjectid$
PRINT
PRINT "Today's date: ";
INPUT todaysdate$
PRINT
PRINT "Name: ";
INPUT name1$
PRINT

subid$ = "Robert\" + subjectid$ + ".txt"
GOTO start

NOISELEVEL:
CLS
PRINT
PRINT "Noise Level (dB HL - Max=70): ";
INPUT noiselevel1
REM HARD FIX OF NOISE LEVEL
GOTO start

DELTADB:
CLS
PRINT
PRINT "Threshold Delta Value (0, 1, 2 or 4 dB): ";
INPUT deldb
GOTO start
```

```
ISISET:
CLS
PRINT
PRINT "Enter PTA"
REM PRINT "Enter isi=(0,10,20,30,40,50,60,70,80,90,100 msec) "
REM PRINT "Enter isi=(0,2,4,8,16,32 msec)"
PRINT
REM PRINT "Enter cal"
REM PRINT "Enter stim"
PRINT "Enter 20 msec Linear Risefall tone alone (r20)"
PRINT "Enter 20 msec Linear Risefall+isi  (2;,4;,8;,16;,32;,64;,128; msec)"
PRINT
PRINT "Enter 20 msec Blackman Risefall alone (b20)"
PRINT "Enter 20 msec Blackman Risefall+isi  (2:,4:,8:,16:,32:,64:,128: msec)"
REM PRINT "Enter 30 msec Risefall (r30)"
REM PRINT "Enter 30 msec RiseFall isi=(2a,4a,8a,16a,32a,100a)"
PRINT
PRINT "Enter 20 msec Chirp alone (c20)"
PRINT "Enter 20 msec Chirp+isi  (2c,4c,8c,16c,32c,64c,128c)"
PRINT
REM PRINT "Enter 20 msec Linear risefall+20msec noise  (2n,4n,6n,8n,10n,12n,14n,16n,18n,20n,22n,24n"
REM PRINT "                    26n,28n,30n,32n,34n,36n,38n,40n,64n,128n)"


INPUT isival$
GOTO start

BEGINEXP:
IF isival$ = "0" THEN stimfile$ = "stim 0 msec isi.wav"
IF isival$ = "10" THEN stimfile$ = "stim 10 msec isi.wav"
IF isival$ = "20" THEN stimfile$ = "stim 20 msec isi.wav"
IF isival$ = "30" THEN stimfile$ = "stim 30 msec isi.wav"
IF isival$ = "40" THEN stimfile$ = "stim 40 msec isi.wav"
IF isival$ = "50" THEN stimfile$ = "stim 50 msec isi.wav"
IF isival$ = "60" THEN stimfile$ = "stim 60 msec isi.wav"
IF isival$ = "70" THEN stimfile$ = "stim 70 msec isi.wav"
IF isival$ = "80" THEN stimfile$ = "stim 80 msec isi.wav"
IF isival$ = "90" THEN stimfile$ = "stim 90 msec isi.wav"
IF isival$ = "100" THEN stimfile$ = "stim 100 msec isi.wav"

IF isival$ = "cal" THEN stimfile$ = "cal.wav"
IF isival$ = "stim" THEN stimfile$ = "stim.wav"
IF isival$ = "r20" THEN stimfile$ = "risefall20.wav"
IF isival$ = "r30" THEN stimfile$ = "risefall30.wav"

IF isival$ = "2" THEN stimfile$ = "stim 2 msec isi.wav"
IF isival$ = "4" THEN stimfile$ = "stim 4 msec isi.wav"
IF isival$ = "8" THEN stimfile$ = "stim 8 msec isi.wav"
IF isival$ = "16" THEN stimfile$ = "stim 16 msec isi.wav"
IF isival$ = "32" THEN stimfile$ = "stim 32 msec isi.wav"

IF isival$ = "2;" THEN stimfile$ = "20stim2isi.wav"
```

```
IF isival$ = "4;" THEN stimfile$ = "20stim4isi.wav"
IF isival$ = "8;" THEN stimfile$ = "20stim8isi.wav"
IF isival$ = "16;" THEN stimfile$ = "20stim16isi.wav"
IF isival$ = "32;" THEN stimfile$ = "20stim32isi.wav"
IF isival$ = "64;" THEN stimfile$ = "20stim64isi.wav"
IF isival$ = "128;" THEN stimfile$ = "20stim128isi.wav"

IF isival$ = "b20" THEN stimfile$ = "blackrisefall20.wav"
IF isival$ = "2:" THEN stimfile$ = "20black2isi.wav"
IF isival$ = "4:" THEN stimfile$ = "20black4isi.wav"
IF isival$ = "8:" THEN stimfile$ = "20black8isi.wav"
IF isival$ = "16:" THEN stimfile$ = "20black16isi.wav"
IF isival$ = "32:" THEN stimfile$ = "20black32isi.wav"
IF isival$ = "64:" THEN stimfile$ = "20black64isi.wav"
IF isival$ = "128:" THEN stimfile$ = "20black128isi.wav"

IF isival$ = "PTA" THEN stimfile$ = "risefall500msec.wav"

IF isival$ = "2a" THEN stimfile$ = "30stim2isi.wav"
IF isival$ = "4a" THEN stimfile$ = "30stim4isi.wav"
IF isival$ = "8a" THEN stimfile$ = "30stim8isi.wav"
IF isival$ = "16a" THEN stimfile$ = "30stim16isi.wav"
IF isival$ = "32a" THEN stimfile$ = "30stim32isi.wav"
IF isival$ = "100a" THEN stimfile$ = "30stim100isi.wav"

IF isival$ = "c20" THEN stimfile$ = "chirp.wav"
IF isival$ = "2c" THEN stimfile$ = "chirp2.wav"
IF isival$ = "4c" THEN stimfile$ = "chirp4.wav"
IF isival$ = "6c" THEN stimfile$ = "chirp6.wav"
IF isival$ = "8c" THEN stimfile$ = "chirp8.wav"
IF isival$ = "10c" THEN stimfile$ = "chirp10.wav"
IF isival$ = "12c" THEN stimfile$ = "chirp12.wav"
IF isival$ = "14c" THEN stimfile$ = "chirp14.wav"
IF isival$ = "16c" THEN stimfile$ = "chirp16.wav"
IF isival$ = "18c" THEN stimfile$ = "chirp18.wav"
IF isival$ = "20c" THEN stimfile$ = "chirp20.wav"
IF isival$ = "22c" THEN stimfile$ = "chirp22.wav"
IF isival$ = "24c" THEN stimfile$ = "chirp24.wav"
IF isival$ = "26c" THEN stimfile$ = "chirp26.wav"
IF isival$ = "28c" THEN stimfile$ = "chirp28.wav"
IF isival$ = "30c" THEN stimfile$ = "chirp30.wav"
IF isival$ = "32c" THEN stimfile$ = "chirp32.wav"
IF isival$ = "34c" THEN stimfile$ = "chirp34.wav"
IF isival$ = "36c" THEN stimfile$ = "chirp36.wav"
IF isival$ = "38c" THEN stimfile$ = "chirp38.wav"
IF isival$ = "40c" THEN stimfile$ = "chirp40.wav"
IF isival$ = "64c" THEN stimfile$ = "chirp64.wav"
IF isival$ = "128c" THEN stimfile$ = "chirp128.wav"

IF isival$ = "0n" THEN stimfile$ = "20stim20noise0.wav"
IF isival$ = "2n" THEN stimfile$ = "20stim20noise2.wav"
IF isival$ = "4n" THEN stimfile$ = "20stim20noise4.wav"
```

```
IF isival$ = "6n" THEN stimfile$ = "20stim20noise6.wav"
IF isival$ = "8n" THEN stimfile$ = "20stim20noise8.wav"
IF isival$ = "10n" THEN stimfile$ = "20stim20noise10.wav"
IF isival$ = "12n" THEN stimfile$ = "20stim20noise12.wav"
IF isival$ = "14n" THEN stimfile$ = "20stim20noise14.wav"
IF isival$ = "16n" THEN stimfile$ = "20stim20noise16.wav"
IF isival$ = "18n" THEN stimfile$ = "20stim20noise18.wav"
IF isival$ = "20n" THEN stimfile$ = "20stim20noise20.wav"
IF isival$ = "22n" THEN stimfile$ = "20stim20noise22.wav"
IF isival$ = "24n" THEN stimfile$ = "20stim20noise24.wav"
IF isival$ = "26n" THEN stimfile$ = "20stim20noise26.wav"
IF isival$ = "28n" THEN stimfile$ = "20stim20noise28.wav"
IF isival$ = "30n" THEN stimfile$ = "20stim20noise30.wav"
IF isival$ = "32n" THEN stimfile$ = "20stim20noise32.wav"
IF isival$ = "34n" THEN stimfile$ = "20stim20noise34.wav"
IF isival$ = "36n" THEN stimfile$ = "20stim20noise36.wav"
IF isival$ = "38n" THEN stimfile$ = "20stim20noise38.wav"
IF isival$ = "40n" THEN stimfile$ = "20stim20noise40.wav"
IF isival$ = "64n" THEN stimfile$ = "20stim20noise64.wav"
IF isival$ = "128n" THEN stimfile$ = "20stim20noise128.wav"


path0$ = "c:\documents and settings\administrator\desktop\qb 64\qb64\subject stim\" + stimfile$

w = 600
h = 600
SCREEN _NEWIMAGE(w, h, 256)

begin:
GOSUB screengrid
begin1:
IF revnum = enough THEN GOTO QUIT
trials = trials + 1
GOSUB setcals
GOSUB setatt
GOSUB armswitch
GOSUB playstim
GOSUB resdelay
GOSUB chhandsw
IF press = 1 THEN directioncurrent$ = "softer"
IF press = 0 THEN directioncurrent$ = "louder"
present(trials) = press
levels(trials) = sinelevel
IF stimsoft2flag = 0 AND directionold$ = "softer" AND directioncurrent$ = "softer" THEN GOSUB stimsofter: GOTO begin1
IF stimsoft2flag = 1 AND directionold$ = "softer" AND directioncurrent$ = "softer" THEN GOSUB stimsofter2: GOTO begin1
IF directionold$ = "softer" AND directioncurrent$ = "louder" THEN GOSUB stimlouder: GOSUB plot: GOTO begin1
IF directionold$ = "louder" AND directioncurrent$ = "louder" THEN GOSUB stimlouder: GOTO begin1
IF directionold$ = "louder" AND directioncurrent$ = "softer" THEN GOSUB stimsofter2: GOSUB plot: GOTO begin1

END

REM Quit and Save
```

```
QUIT:
OPEN subid$ FOR OUTPUT AS #1
PRINT #1, "Name", name1$
PRINT #1, "Date", todaysdate$
PRINT #1, "Stimfile", stimfile$
FOR j = enough TO 3 STEP -1
   total = reversal(j) + total
   ss = (reversal(j) * reversal(j)) + ss
NEXT j
meansinelevel = total / (enough - 2)
sumsq = (total * total) / (enough - 2)
sd = SQR((ss - sumsq) / (enough - 2))

LOCATE 6, 50: PRINT "Mean "; meansinelevel
LOCATE 6, 60: PRINT "SD "; sd
FOR j = 1 TO trials
   PRINT #1, present(j), levels(j), lat(j)
NEXT j
FOR j = 1 TO revnum
   PRINT #1, reversal(j)
NEXT j
PRINT #1, "Mean", meansinelevel
PRINT #1, "SD", sd
CLOSE #1
END
REM GOTO start

END

REM *************************
REM These are the Subroutines
REM *************************

REM Sreen Grid
screengrid:
LINE (10, 10)-(10, 590)
LINE (10, 590)-(590, 590)
LINE (590, 590)-(590, 10)
LINE (590, 10)-(10, 10)

LINE (10, 60)-(590, 60)
LINE (10, 110)-(590, 110)

LOCATE 3, 5: PRINT "Subject:";
LOCATE 3, 14: PRINT subjectid$;
LOCATE 3, 20: PRINT "ISI:";
LOCATE 3, 25: PRINT isival$;
LOCATE 3, 30: PRINT "Delta dB:";
LOCATE 3, 39: PRINT deldb;
LOCATE 3, 45: PRINT "Noise dB:";
LOCATE 3, 54: PRINT noiselevel1;
```

```
LOCATE 6, 5: PRINT "Level: ";
LOCATE 6, 12: PRINT "     ";

LOCATE 6, 22: PRINT "Stimulus: ";
LOCATE 6, 35: PRINT "Response: ";

LINE (50, 200)-(50, 500)
LINE (50, 200)-(60, 200)
LINE (50, 260)-(60, 260)
LINE (50, 320)-(60, 320)
LINE (50, 380)-(60, 380)
LINE (50, 440)-(60, 440)
LINE (50, 500)-(60, 500)

LINE (60, 200)-(550, 200), 3, , &HFF00
LINE (60, 260)-(550, 260), 3, , &HFF00
LINE (60, 320)-(550, 320), 3, , &HFF00
LINE (60, 380)-(550, 380), 3, , &HFF00
LINE (60, 440)-(550, 440), 3, , &HFF00
LINE (60, 500)-(550, 500), 3, , &HFF00
RETURN

REM Play Stim
playstim:
h& = _SNDOPEN(path0$, "sync, vol")
_SNDVOL h&, volset
_SNDPLAY h&
REM _SNDPLAYFILE path0$
LOCATE 6, 32: PRINT "X";

maxdel = 500000
FOR del3 = 1 TO maxdel
   IF Inp32(&H379) = 120 THEN lat(trials) = del3: GOTO cont100
NEXT del3

cont100:
FOR del4 = 1 TO ((maxdel + 1) - del3)
NEXT del4
LOCATE 6, 12: PRINT "   ";
LOCATE 6, 12: PRINT sinelevel
LOCATE 6, 32: PRINT " ";
RETURN


REM Set Cal Level for Noise and Sine
setcals:
noiseatt = (70 - noiselevel1) + noisecal
IF sinelevel < -5 THEN END
sineatt = (80 - sinelevel) + sinecal
RETURN

REM Set Stimulus louder
```

```
stimlouder:
sinelevel = sinelevel + deldb
directionold$ = "louder"
RETURN

REM Set Stimulus softer
stimsofter:
sinelevel = sinelevel - 5
directionold$ = "softer"
RETURN

REM Set Stimulus softer
stimsofter2:
stimsoft2flag = 1
sinelevel = sinelevel - deldb
directionold$ = "softer"
RETURN

REM Arm Switch
armswitch:
REM reset
Out32 &H378, 8
FOR del = 1 TO 10000
NEXT del
Out32 &H378, 0
FOR del = 1 TO 10000
NEXT del
Out32 &H378, 8
FOR del = 1 TO 10000
NEXT del
RETURN

REM Plots data value and increments X
plot:
scaling = scaling + 1
scaley = INT(500 - (60 * (sinelevel - 30) / 10))
revnum = revnum + 1
reversal(revnum) = sinelevel
scale(scaling) = scaley

PSET (x, scaley)
PSET (x + 1, scaley)
PSET (x - 1, scaley)
PSET (x, scaley + 1)
PSET (x + 1, scaley + 1)
PSET (x - 1, scaley + 1)
PSET (x, scaley - 1)
PSET (x + 1, scaley - 1)
PSET (x - 1, scaley - 1)
x = x + 24

REM line plotter
```

```
IF scaling = 2 THEN LINE (60, scale(1))-(84, scale(2))
IF scaling = 3 THEN LINE (84, scale(2))-(108, scale(3))
IF scaling = 4 THEN LINE (108, scale(3))-(132, scale(4))
IF scaling = 5 THEN LINE (132, scale(4))-(156, scale(5))
IF scaling = 6 THEN LINE (156, scale(5))-(180, scale(6))
IF scaling = 7 THEN LINE (180, scale(6))-(204, scale(7))
IF scaling = 8 THEN LINE (204, scale(7))-(228, scale(8))
IF scaling = 9 THEN LINE (228, scale(8))-(252, scale(9))
IF scaling = 10 THEN LINE (252, scale(9))-(276, scale(10))
IF scaling = 11 THEN LINE (276, scale(10))-(300, scale(11))
IF scaling = 12 THEN LINE (300, scale(11))-(324, scale(12))
RETURN

REM Check Handswitch
chhandsw:
LOCATE 6, 45: PRINT " ";
press = 0
a = Inp32(&H379)
IF a = 120 THEN press = 1
IF a = 104 THEN press = 0
IF press = 1 THEN LOCATE 6, 45: PRINT "X";
RETURN

REM Set Attenuators
setatt:
Out32 baseadd, 2
REM right=sine and left=noise
REM codert = (192 - (2 * sineatt))
REM codelt = (192 - (2 * noiseatt))

codelt = (192 - (2 * sineatt))
codert = (192 - (2 * noiseatt))

setatten:
REM to change decimal number into a binary number
n = codert
FOR j = 0 TO 7
   r = n MOD 2
   n = INT(n / 2)
   bitval$(j) = STR$(r)
NEXT j
REM to change decimal number into a binary number
n = codelt
FOR j = 8 TO 15
   r = n MOD 2
   n = INT(n / 2)
   bitval$(j) = STR$(r)
NEXT j

REM Send the data to the attenuator chip
Out32 baseadd, 0 'rem sets the CS low
```

```
FOR j = 15 TO 0 STEP -1
   IF RIGHT$(bitval$(j), 1) = "1" THEN Out32 baseadd, 1
   IF RIGHT$(bitval$(j), 1) = "1" THEN Out32 baseadd, 5: GOTO cont1
   Out32 baseadd, 4 'rem sets the clock high
   cont1:
   FOR del = 1 TO pcount
   NEXT del

   Out32 baseadd, 0

   FOR del = 1 TO pcount
   NEXT del
NEXT j
Out32 baseadd, 2
RETURN

REM Response Delay
resdelay:
rnum = RND
IF rnum < .25 THEN count = 2000
IF rnum >= .25 AND rnum < .5 THEN count = 3000
IF rnum >= .5 AND rnum < .75 THEN count = 4000
IF rnum >= .75 THEN count = 5000

FOR h = 1 TO count
   FOR i = 1 TO 50000
   NEXT i
NEXT h
RETURN
```

APPENDIX B

Name of Principal Investigator	Robert David Sears
Department	Communicative Science and Disorders University of Montana

Documents:

See next page.

Institutional Review Board Approval (IRB):

UNIVERSITY OF MONTANA

INSTITUTIONAL REVIEW BOARD
for the Protection of Human Subjects in Research
FWA 00000078
Research & Creative Scholarship
University Hall 116
University of Montana
Missoula, MT 59812
Phone 406-243-6672 | Fax 406-243-6330

Date: October 13, 2015

To: Dr. Al Yonovitz, Communicative Sciences and Disorders
Robert Sears, Communicative Sciences and Disorders

From: Paula A. Baker, IRB Chair, Manager

RE: IRB #229-15: "Backward Masking Across the Lifespan"

Your IRB proposal cited above has been **APPROVED** under **expedited review** by the Institutional Review Board in accordance with the Code of Federal Regulations, Part 46, section 110. Expedited approval refers to research activities that (1) present no more than minimal risk to human subjects, and (2) fit within the following category, as it applies to your study, for expedited review as authorized by 45 CFR 46.110 and 21 CFR 56.110:

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)
Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

All consent forms used for this project must be date-stamped and signed by the IRB. Use the PDF sent with this approval notice as a "master" from which to make copies.

Amendments: Any changes to the originally-approved protocol must be reviewed and approved by the IRB ***before*** being made (unless extremely minor). Requests must be submitted using Form RA-110.

Unanticipated or Adverse Events: You are required to timely notify the IRB if any unanticipated or adverse events occur during the study, if you experience an increased risk to the participants, or if you have participants withdraw from the study or register complaints about the study. Use Form RA-111.

Continuation: Federal and University of Montana IRB policy requires you to file an annual Continuation Report (Form RA-109) for expedited studies. You must file the report within 30 days prior to the expiration date, which is **October 12, 2016**. *Tip: Put a reminder on your calendar now.* A study that has expired is no longer in compliance with federal or University IRB policy, and all project work must cease immediately.

Study Completion or Closure: Finally, you are also required to file a Closure Report (Form RA-109) when the study is completed or if the study is abandoned. See the directions on the form.

Please contact the IRB office with any questions at (406) 243-6672 or email irb@umontana.edu.

Form RA-108
(Rev. 09/15)

Institutional Review Board
OCT 13 2015
University of Montana

THE UNIVERSITY OF MONTANA-MISSOULA
Institutional Review Board (IRB)
for the Protection of Human Subjects in Research
APPLICATION FOR IRB REVIEW

IRB Protocol No.: 229-15

At the University of Montana (UM), the Institutional Review Board (IRB) is the institutional review body responsible for oversight of all research activities involving human subjects as outlined in the U.S. Department of Health and Human Services' Office of Human Research Protection and the National Institutes of Health, Inclusion of Children Policy Implementation.

Instructions: A separate application must be submitted for each project. IRB proposals are approved for no longer than one year and must be continued annually (unless Exempt). Faculty and students may email the completed form as a Word document to *IRB@umontana.edu*, or submit a hardcopy (no staples) to the Office of the Vice President for Research in University Hall 116. Student applications must be accompanied by email authorization by the supervising faculty member or a signed hard copy. *All fields must be completed. If an item does not apply to this project, write in: N/A.* Questions? Call the IRB office at 243-6672.

1. Administrative Information

Project Title: Backward Masking Across the Lifespan	
Principal Investigator: Robert Sears	UM Position: Grad Student
Department: Comm. Sciences and Disorders	Office location: CHC 044
Work Phone: 406 243 2408 * AL	Cell Phone: 406 396 8960

2. Human Subjects Protection Training *(All researchers, including faculty supervisors for student projects, must have completed a self-study course on protection of human research subjects* ***within the last three years*** *and be able to supply the "Certificate(s) of Completion" upon request. If you need to add rows for more people, use the Additional Researchers Addendum.*

All Research Team Members (list yourself first)	PI	CO-PI	Faculty Supervisor	Research Assistant	DATE COMPLETED IRB-approved Course mm/dd/yyyy
Name: Robert Sears Email:	☐	☒ ✓	☐	☐	02/12/2015
Name: Sarah Schied Email:	☐	☐	☐	☒	03/06/2015
Name: Al Yonovitz Email:	☐	☒ ✓	☐	☐	03/16/2016 ?
Name: Email:	☐	☐	☐	☐	

3. Project Funding *(If federally funded, you must submit a copy of the abstract or Statement of Work.)*

Is grant application currently under review at a grant funding agency? ☐Yes *(If yes, cite sponsor on ICF if applicable)* ☐No			Has grant proposal received approval and funding? ☐Yes *(If yes, cite sponsor on ICF if applicable)* ☐No	
Agency	Grant No.	Start Date	End Date	PI on grant

For UM-IRB Use Only

IRB Determination:

____ Not Human Subjects Research
____ Approved by Exempt Review, Category # ____ *(see memo)*
X Approved by Expedited Review, Category # 4 *(see* **Note to PI***)*
____ Full IRB Determination
____ Approved *(see* **Note to PI***)*
____ Conditional Approval *(see memo)* - IRB Chair Signature/Date: _____
____ Conditions Met *(see* **Note to PI***)*
____ Resubmit Proposal *(see memo)*
____ Disapproved *(see memo)*

Note to PI: Non-exempt studies are approved for one year only. Use any attached IRB-approved forms (signed/dated) as "masters" when preparing copies. If continuing beyond the expiration date, a continuation report must be submitted. Notify the IRB if any significant changes or unanticipated events occur. When the study is completed, a closure report must be submitted. Failure to follow these directions constitutes non-compliance with UM policy.

Risk Level: Minimal

Final Approval by IRB Chair/Manager: [signature] Date: 10/13/2015 Expires: 10/12/2016

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The University of Montana IRB
Expiration Date 10-12-2016
Date Approved 10-13-2015
Chair/Admin

SUBJECT INFORMATION AND INFORMED CONSENT

Title:

Backward Masking and Aging

Project Directors:

Robert Sears (CO-PI) , Sarah Schied Co-student Investigator, and Al Yonovitz, CO-PI) 32 Campus Drive, Department of Communicative Sciences and Disorders; (406) 243-2408

Al Yonovitz, Faculty Supervisor; 32 Campus Drive, Department of Communicative Sciences and Disorders; (406) 243-2408

Special instructions:

This consent form may contain words that are new to you. If you read any words that are not clear to you, please ask the person who gave you this form to explain them to you.

Purpose:

The purpose of this study is to investigate auditory processing using backward masking tests with adults. We seek to investigate the accuracy of our ability to hear a brief tonal sound that occurs just before a noise sound. None of the sounds are at a level that will be uncomfortable to you.

Procedures:

If you agree to take part in this research study, you will be seated in a sound-attenuated booth and headphones will be placed over your ears and adjusted until comfortable. You will first be given a hearing screening which will take approximately 10 minutes. Next, after placing earphones on you, you will hear a target tone. Your task is to press the hand button if you hear it and not press the button if you don't hear it. If you hear the tone, the sound will become softer and if you hear the tone the sound will get louder. This procedure will take approximately 20 minutes.

Risks/Discomforts:

There is no anticipated discomfort for participating in this study, so risk to participants is minimal.

Benefits:

You will receive a free hearing screening and gain the knowledge of your personal hearing thresholds. Participation may contribute to our knowledge of temporal masking may result in advances in the field of Communicative Sciences and Disorders.

Confidentiality:

Your records will be kept confidential and will not be released without your consent except as required by law. You will be assigned a code number. Only the principle investigators will have access to the link between the code number and the name of the subject. This code number will be kept in a locked file cabinet. Even the data assigned to a code number will be protected. At the end of the

experiment, including the publication, all identifying information will be destroyed. If the results of this study are written in a journal or presented at a meeting, your name will not be used.

Compensation for Injury:

In the event that you are injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by the negligence of the University or any of its employees, you may be entitled to reimbursement or compensation pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A., Title 2, Chapter 9. In the event of a claim for such injury, further information may be obtained from the University's Claims representative or University Legal Counsel. (Reviewed by University Legal Counsel, July 6, 1993)

Voluntary Participation/Withdrawal:

Your decision to take part in this study is entirely voluntary, and you may leave the study at any time for any reason.

Questions:

If you have any questions about the research before or after the study, contact:

Al Yonovitz 406-243 2408

Robert Sears 406 396 8960

If you have any questions regarding your rights as a research subject, you may contact the Chair of the IRB through the University of Montana Research Office at 243-6672.

Statement of Consent:

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions I may have will also be answered by a member of the research team. I voluntarily agree to take part in this study. I understand I will receive a copy of this consent form.

_____

Printed Name of Subject

_____ _____

Subject's Signature Date

The University of Montana IRB
Expiration Date 10-12-2016
Date Approved 10-13-2015
Chair/Admin

IRB application**:**

Form RA-108
(Rev. 09/15)

THE UNIVERSITY OF MONTANA-MISSOULA
Institutional Review Board (IRB)
for the Protection of Human Subjects in Research
APPLICATION FOR IRB REVIEW

IRB Protocol No.: _____

At the University of Montana (UM), the Institutional Review Board (IRB) is the institutional review body responsible for oversight of all research activities involving human subjects as outlined in the U.S. Department of Health and Human Services' Office of Human Research Protection and the National Institutes of Health, Inclusion of Children Policy Implementation.

Instructions: A separate application must be submitted for each project. IRB proposals are approved for no longer than one year and must be continued annually (unless Exempt). Faculty and students may email the completed form as a Word document to *IRB@umontana.edu*, or submit a hardcopy (no staples) to the Office of the Vice President for Research in University Hall 116. Student applications must be accompanied by email authorization by the supervising faculty member or a signed hard copy. *All fields must be completed. If an item does not apply to this project, write in: N/A.* Questions? Call the IRB office at 243-6672.

1. Administrative Information

Project Title: Backward Masking across the lifespan	
Principal Investigator: Robert Sears	UM Position: Grad Student
Department: Comm. Sciences and Disorders	Office location: CHC 044
Work Phone: 406 243 2408	Cell Phone: 406 396 8960

2. Human Subjects Protection Training *(All researchers, including faculty supervisors for student projects, must have completed a self-study course on protection of human research subjects* ***within the last three years*** *and be able to supply the "Certificate(s) of Completion" upon request. If you need to add rows for more people, use the Additional Researchers Addendum.*

All Research Team Members (list yourself first)	**PI**	**CO-PI**	**Faculty Supervisor**	**Research Assistant**	**DATE COMPLETED IRB-approved Course mm/dd/yyyy**
Name: Robert Sears Email:	☐	☒	☐	☐	02/12/2015
Name: Sarah Schied Email:	☐	☐	☐	☒	03/06/2015
Name: Al Yonovitz Email:	☐	☒	☐	☐	03/16/2016
Name: Email:	☐	☐	☐	☐	

3. Project Funding *(If federally funded, you must submit a copy of the abstract or Statement of Work.)*

Is grant application currently under review at a grant funding agency? ☐Yes *(If yes, cite sponsor on ICF if applicable)* ☐No	Has grant proposal received approval and funding? ☐Yes *(If yes, cite sponsor on ICF if applicable)* ☐No

Agency	Grant No.	Start Date	End Date	PI on grant

For UM-IRB Use Only

IRB Determination:

_____ Not Human Subjects Research
_____ Approved by Exempt Review, Category # _____ *(see memo)*
_____ Approved by Expedited Review, Category #_____ *(see* **Note to PI***)*
_____ Full IRB Determination
  _____ Approved *(see* **Note to PI***)*
  _____ Conditional Approval *(see memo)* - IRB Chair Signature/Date: _____
    _____ Conditions Met *(see* **Note to PI***)*
  _____ Resubmit Proposal *(see memo)*
  _____ Disapproved *(see memo)*

Risk Level: _____

Note to PI: Non-exempt studies are approved for one year only. Use any attached IRB-approved forms (signed/dated) as "masters" when preparing copies. If continuing beyond the expiration date, a continuation report must be submitted. Notify the IRB if any significant changes or unanticipated events occur. When the study is completed, a closure report must be submitted. Failure to follow these directions constitutes non-compliance with UM policy.

Final Approval by IRB Chair/Manager: _____ Date: _____ Expires: _____

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<In an effort to be environmentally responsible, please expand/reduce box size as needed.>

4. Purpose of the Research Project: Briefly summarize the overall intent of the study. Your target audience is a non-researcher. Include in your description a statement of the objectives and the potential benefit to the study subjects and/or the advancement of your field. **Generally included are literature related to the problem, hypotheses, and discussion of the problem's importance.** Expand box as needed.

Backward masking is a procedure to assess a listener's ability to detect a tone after that tone is followed by white-noise. Backward masking testing begins by presenting a tonal stimulus to a listener. Next, after an extremely brief silent interval (0-32 msec), the listener is presented a white-noise masking signal. The phenomenon that occurs is the white-noise signal that is heard last in the sequence, alters the listener's perception by masking and reducing the audibility of the initial tonal stimulus (Picket,1959). Some studies that examine backward masking tribute their findings to the timing of central auditory and temporal processing in the brain and brainstem (Gehr & Sommers, 1999; Gray & Holian, 1999; Marler & Champlain, 2005). Studying backward masking is relevant because the findings provide more information about a wide-range of populations. The results of a study examining the effects of backward masking on aging found that independent of hearing loss, older adults' displayed an increased amount of masking as compared to younger adults. The authors suggested that due to these findings, older adults have slower peripheral and central auditory recovery functions (Gehr & Sommers, 1999). Gray and Holian (1999) conducted a study that found significant results while exposing chicks to low-levels of lead and examining their responsiveness to backward masking tests. Since birds and humans develop hearing similarly, the authors suggested that this study was relevant for human children with reading disabilities, perceptual disorders, and dyslexia. Also, other studies contain data that also show the affects of backward masking on children with learning-language impairments (Wright et al., 1997; Marler & Champlin 2005). The data will be analyzed with regard to the masking function and amount of masking achieved for different silent intervals. The purpose of this study is to investigate auditory processing using backward masking tests with older adults. We seek to investigate the backward masking functions in adults and compare these results to standard clinically obtained speech discrimination measures.

4.1 What do you plan to do with the results? If not discussed above, include considerations such as whether this is a class project, a project to improve a program/school system, and/or if the results will be generalized to a larger population, contribute to the general field of knowledge, and/or be published/presented in any capacity.

The results of this study will provide data with regard to the This baseline data can be used for future studies that test backward masking and speech perception by comparing this baseline to populations with poor speech discrimination/intelligibility abilities, especially the older adult/aging population. The results will be presented and published at profesional meetings and journals.

Is this part of a thesis or dissertation? ☒No ☐Yes If yes and other than the PI's, then whose?

5. IRB Oversight

Is oversight required by other IRB(s) [e.g., tribal, hospital, other university] for this project? ☐Yes ☒ No

If yes, please identify IRB(s):

6. Subject Information:

6.1 Human Subjects *(identify, include age/gender)*:

Adults (male and female) of varying ages (50-80)

6.2 How many subjects will be included in the study? 10 M and 10 F

6.3 Are minors included *(under age 18, per Montana law)*? ☐ Yes ☒ No

If yes, specify age range: to

6.4 Are members of a physically, psychologically, or socially vulnerable population being specifically targeted?

☐Yes ☒ No

If yes, please explain why the subjects might be physically, psychologically or socially vulnerable:

6.5 Are there other special considerations regarding this population? ☐Yes ☒ No

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If yes, please explain:

6.6 Do subjects reside in a foreign country? ☐ Yes *Specify country:* _____ ☐ No
If yes, please fill out and attach Form RA-112, Foreign Site Study Appendix
(http://www.umt.edu/research/compliance/IRB/Docs/foreign.doc).

6.7 How will the subjects be selected or recruited? Include a bulleted list of inclusion/exclusion criteria. ***(Attach copies of all flyers, advertisements, etc,. that will be used in the recruitment process as these require UM-IRB approval)***

Subjects will be offered the opportunity to participate from a screening on October 17, 2015 offered by the Community Medical Center (see attached announcement and approval). They will be given a fact sheet and offered the opportunity to participate by calling the faculty CO-PI.

6.8 How will subjects be identified in your personal notes, work papers, or publications: *(may check more than one)*

☐ Identified by name and/or address or other
(Secure written [e.g., ICF] or verbal permission to identify; if risk exists, create a confidentiality plan.)

☒ Confidentiality Plan
(Identity of subjects linked to research, but not specific data [e.g., individuals identified in ICF but not included in publications]; identification key kept separate from data; or, data collected by third party [e.g., Select Survey, SurveyMonkey, etc.] and identifiers not received with data.)

☐ Never know participant's identity
(An ICF may be unnecessary [e.g. anonymous survey, paper or online] ***unless*** *project is sensitive or involves a vulnerable population.)*

6.9 Describe the means by which the human subject's personal privacy is to be protected, and the confidentiality of information maintained. If you are using a Confidentiality Plan (as checked above), include in your description a plan for the destruction of materials that could allow identification of individual subjects or the justification for preserving identifiers.

All subjects will be assigned a code number. Only the principle investigators will have access to the link between the code number and the name of the subject. This code number will be kept in a locked file cabinet. Even the data assigned to a code number will be protected. At the end of the experiment including the publication all identifying information will be destroyed.

6.9a Will subject(s) receive an explanation of the research – separate from the informed consent form (if applicable) – before and/or after the project? ☐ Yes *(attach copy and explain when given)* ☒ No

7. Information to be Compiled

7.1 Explain where the study will take place *(physical location not geographic). If permission is required to conduct the research at the location or to use any of the facilities, indicate those arrangements and attach copies of written permission.*

The study will take place in a sound attenuated booth of the Audiology lab in the DeWit Rite Care RiteCare Speech, Language, and Hearing Clinic.

7.2 Will you be working with infectious materials, ionizing radiation, or hazardous materials? Please specify. *(Do not include here standard biological samples, such as blood, buccal cells, or urine; specify those in #7.6.)*

No

7.3 Subject matter or kind(s) of information to be compiled from/about subjects:

Before performing the testing procedure, the subject's will be given a standard pure-tone, air-conduction hearing evaluation between the octave frequencies of 250-8000 Hz. Common speech discrimination testing will also occur. The results will be explained to the subject and they will also be offered recommendations for improved hearing.

7.4 Activities the subjects will perform and how the subjects will be used. Describe the instrumentation and procedures to be used and kinds of data or information to be gathered. **Provide enough detail** so the IRB will be able to evaluate the intrusion from the subject's perspective (expand box as needed):

Background

The generation of backward masking stimuli was based on Pickett's stimuli model of altering the ISI times and noise intensity level (Pickett, 1959). Band-limited, white-noise masker signals at 60, 70, and 80 dB were each added to the stimuli and positioned at 0, 10, 20, 30, 40, 50 msec after the consonants. The stimuli will be presented with a specially written computer program (QuickBASIC 45). The specially written computer program will presnt our specifically designed stimuli at 2, 4, 8, 16 and 32 msec ISI intervals.

Procedure

The participants will be tested in the audiology lab at the DeWit RiteCare Speech, Language, and Hearing Clinic and be instructed to sit in a sound-attenuated booth. The listeners will wear a set of comforatable earphones. After practice, they will press a handswitch when they detect the presence of the target tonal signal. After the subjects indicate that they are ready to begin the procedure, the backward masking stimuli will be presented to the listener via the headphones. The entire procedure should last approximately 20 minutes.

General Data Analysis

The subjects' responses to the stimuli will be analyzed by determining any relationship of the Backward Masking function with with age and speech discrimination measures.

7.5 Is information on any of the following included? *(check all that apply)*:

- ☐ Sexual behavior
- ☐ Alcohol use/abuse
- ☐ Drug use/abuse
- ☐ Illegal conduct
- ☐ Information about the subject that, if it became known outside the research, could reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability.

7.6 Means of obtaining the information *(check all that apply)*. **Attach questionnaire or survey instrument,** if used:

- ☒ Field/Laboratory observation
- ☐ Blood/Tissue/Urine/Feces/Semen/Saliva Sampling *(IBC Application must be submitted)*
- ☐ Medical records *(require HIPAA form)*
- ☒ Measurement of motions/actions
- ☐ Use of standard educational tests, etc.
- ☐ Other means *(specify)*:
- ☐ In-person interviews/survey
- ☐ Telephone interviews/survey
- ☐ On-site survey
- ☐ Mail survey
- ☐ Online survey *(attach Statement of Confidentiality)*
- ☐ Examine public documents, records, data, etc.
- ☐ Examine private documents, records, data, etc.

7.7 Will subjects be *(check all that apply)*:

☐ Videotaped ☐ Audio-taped ☐ Photographed ☐ N/A

(securing an additional signature is recommended on consent/assent/permission forms)

Explain how above media will be used, who will transcribe, and how/when destroyed:

7.8 Discuss the benefits (does not include payment for participation) of the research, if any, to the human subjects and to scientific knowledge *(if the subjects will not benefit from their participation, so state)*:

Subjects will receive a free hearing assessement, with recommendations and gain the knowledge of their personal hearing thresholds. They will benefit as group, by contributing to our knowledge of temporal masking.

7.9 Cite any payment for participation (payment is not considered a benefit). If grant funding is not indicated in item #2, please specify the source of the funding and in what form it is to be dispersed.

N/A

7.9a Outline, **in detail**, the risks and discomforts, if any, to which the human subjects will be exposed *(Such deleterious effects may be physical, psychological, professional, financial, legal, spiritual, or cultural. As a result, one can never guarantee that there are no risks – see "minimal." Some research involves violations of normal expectations, rather than risks or discomforts; such violations, if any, should be specified)*:

There are no anticipated risks or discomforts in this study. The risks are minimal.

7.9b Describe, **in detail**, the means taken to minimize each such deleterious effect or violation::

Breaks if needed.

8. Informed Consent

An informed consent form (ICF) is usually required, unless subjects remain anonymous or a waiver is otherwise justified below. *(Templates and examples of Informed Consent, Parental Permission, and Child's Assent Forms are available at http://www.umt.edu/research/compliance/IRB/forms.php).*

- A signed copy of the consent/assent/permission form **must be offered to all subjects**, including parents/guardians of subjects less than 18 years of age (minors).
- Use of minors
  - All minor subjects (under the age of 18) must have written parental or custodial permission (45 CFR 46.116(b)).
  - All minors from 10 to 18 years of age are required to give written assent (45 CFR 46.408(a)).
  - Assent by minor subjects: All minor subjects are to be given a clear and complete picture of the research they are being asked to engage in, together with its attendant risks and benefits, as their developmental status and competence will allow them to understand.
  - Minors less than 10 years of age and all individuals, regardless of age, with delayed cognitive functioning (or with communication skills that make expressive responses unreliable) will be denied involvement in any research that does not provide a benefit/risk advantage.
    - Good faith efforts must be made to assess the actual level of competence of minor subjects where there is doubt.
    - The Minor Assent Form must be written at a level that can be understood by the minor, and/or read to them at an age-appropriate level in order to secure verbal assent.
- Is a **written** informed consent form being used? ☐ Yes *(attach copy)* ☐ No *(justify below)*

  ➔ *Written consent means that physical signatures will be obtained on the informed consent forms.*

  To waive the requirement for written informed consent (45 CFR 46.117), describe your justification:
- Is a written parental permission form being used? ☐ Yes *(attach copy)* ☒ No

  (If yes, will likely require minor assent form)
- Is a written minor assent form being used? ☐ Yes *(attach copy)* ☒ No

  (If yes, will likely require parental permission form)

Principal Investigator's Statement

By signing below, the Principal Investigator agrees to comply with all requirements of the University of Montana-Missoula IRB, the U.S. Department of Health and Human Services Office of Human Research Protection Guidelines, and NIH Guidelines. The PI agrees to ensure all members of his/her team are familiar with the requirements and risks of this project, and will complete the Human Subject Protection Course available at http://www.umt.edu/research/compliance/IRB/hspcourse.php.

I certify that the statements made in this application are accurate and complete. I also agree to the following:

- I will not begin work on the procedures described in this protocol, including any subject recruitment or data collection, until I receive final notice of approval from the IRB.
- I agree to inform the IRB in writing of any adverse or unanticipated problems using the appropriate form. I further agree not to proceed with the project until the problems have been resolved.
- I will not make any changes to the protocol written herein without first submitting a written **Amendment Request** to the IRB using form RA-110, and I will not undertake such changes until the IRB has reviewed and approved them.
- It is my responsibility to ensure that every person working with the human subjects is appropriately trained.
- All consent forms and recruitment flyers must be approved and date-stamped by the IRB before they can be used. The forms will be provided back to the PI in PDF format with the IRB approval email. Copies must be made from the date-stamped version. All consent forms given to subjects must display the IRB approval date-stamp.

- I understand that it is my responsibility to file a **Continuation Report** before the project expiration date (does not apply to exempt projects). This is not the responsibility of the IRB office. *Tip: Set a reminder on your calendar as soon as you receive the date.* A project that has expired is no longer in compliance with UM or federal policy.
- I understand that I must file a **Closure Report** (RA-109) when the project is completed, abandoned, or otherwise qualifies for closure from continuing IRB review (does not apply to exempt projects).
- I will keep a copy of this protocol (including all consent forms, questionnaires, and recruitment flyers) and all subsequent correspondence with the IRB.
- I understand that failure to comply with UM and federal policy, including failure to promptly respond to IRB requests, constitutes **non-compliance** and may have serious consequences impacting my project and my standing at the University of Montana.

Signature of Principal Investigator: *Robert Sears, Sarah Schied* Date: 10/12/2015
(Type for electronic submission; sign for hard copy)

NOTE: Electronic submission of this form must be sent from your University of Montana email account.

Attention Students: If you are submitting your application by hard copy (paper), please have your faculty supervisor sign the statement below. If you are submitting your application electronically (by email), then you must have your faculty supervisor send a separate email to the IRB affirming the statements below.

As the student's **faculty supervisor** on this project, I confirm that:

1) I have read the IRB Application and attachments.
2) I agree that it accurately represents the planned research.
3) I will supervise this research project.

Faculty Supervisor: Al Yonovitz
(Type or print name)

Faculty Supervisor Signature: Date: 10/12/2015
(Sign for hard copy)

Department: CSD Phone: 406 243 2408

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