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Ecological Psychoacoustics: Introduction and History

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Some might argue that the title of this book, *Ecological Psychoacoustics*, is itself an oxymoron. Many psychoacoustic investigations lack any semblance of ecological validity, and most ecological investigations of audition bear little likeness to traditional psychoacoustics. However, detecting and recognizing a sound are the result of a complex interaction of physics, physiology, sensation, perception, and cognition. The process involves an interaction of the listener with the environment. Identifying a familiar voice, for example, involves complex vibrations of the sound source, compression and rarefaction of a medium; reflecting and filtering of the signal by objects in the environment, the head, torso, and pinnae; transduction of the mechanical energy into an electrochemical signal in the nervous system; and the activation of an entire network of correlated physiological mechanisms from cochlea to cortex. This entire process finally results in some conscious recognition and identification of the familiar speaker. The range of approaches that have been used to study these processes varies as widely as the processes themselves. However, over the years a methodological dichotomy between approaches to studying hearing has emerged.

On the one hand, much of the research on how we hear the world has focused on the physics, physiology, and sensation that occur in this chain of events. Many psychoacousticians have focused their efforts on understanding the specific manner in which acoustical energy is transduced into an electrochemical signal in the nervous system. Central issues have included the manner in which frequency and intensity are coded, how sound sources are localized, and the thresholds of detection and discrimination. Often, the goal of this research was to better understand how the peripheral auditory system functions in order to develop

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better techniques to assist the hearing impaired. With the focus on lower level sensory processes and the functioning of the peripheral auditory system, both cognitive processes and perception–action cycles were thought to be somewhat out of the scope of investigation and were often treated as confounds. Thus, perhaps because such things could not be duplicated in a hearing aid, traditional psychoacousticians were faced with the unlikely prospect of dealing with cognition and perception–action cycles as somewhat of a nuisance. Few doubted that higher level cognition could influence responses in psychoacoustic experiments. The approach, therefore, was to develop experimental controls for cognitive effects. Researchers took great steps to ensure that listeners in their experiments were not "thinking" about their responses to sounds and used statistical methods such as signal detection theory to factor out decision criteria and other consequences of cognition.

The obvious advantage to studying the pieces of the auditory puzzle in this way is that one can gain a better understanding of how the hardware of the peripheral auditory system functions and perhaps develop more effective solutions for auditory pathology. Furthermore, the approach provides a more fine-grained analysis of the topic of interest while controlling for the effects of the other phenomena that are not of immediate concern. The disadvantage of this approach, perhaps, is that the stimuli (often pure tones and noise bursts) and listening conditions employed (headphones, sound-attenuating booths, and anechoic chambers) are often unrealistic, leaving the larger question of environmentally and ecologically important cognition, listening behaviors, and the linkage between perception and action relatively unexplored.

On the other hand, a more recent approach to studying audition has emerged. Influenced by Gibson's "ecological" approach to studying perception and bolstered by a greater acceptance of cognitive psychology, those who study auditory event perception and auditory cognition, as well as many music and speech researchers, have treated cognitive psychology and ecological psychology as tools rather than confounds. The goal of this line of research has typically been to understand the complex higher order processes that occur when a listener hears a sound or intricate acoustic pattern. Clearly, lower level sensory processing is a prerequisite for both auditory cognition and perception–action relationships. However, the focus of many of these investigations is often on what might be called "listening behavior." Identification, recognition, similarity scaling, and categorization are frequently employed methodologies. The results of these types of investigations often have implications that reach beyond simply perceiving music, speech, and auditory events. They may shed light on perception and action in other highly complex situations that involve overlearned stimuli. Those who study music performance, for example, may provide insight into other areas in which perception and the planning and execution of complex motor behaviors are intricately linked. The advantage of this approach is that it often comes closer to the listening experiences and behaviors that are encountered in everyday life. The disadvantage is that, because of either the conceptual complexity of the issues

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being investigated or the acoustic complexity of the stimuli, the level of precision and experimental control found in the work of traditional psychoacoustics is sometimes missing from the work of those who study auditory cognition. It should be noted that the fields of ecological and cognitive psychology are by no means synonymous. Vigorous debate, particularly over the issue of mental representation, still exists between the two fields. Yet, their common focus on listening behavior coupled with approaches by moderate researchers in both groups who are comfortable with the coexistence of perception–action linkage and mental representations has yielded a common line of research that stands in stark contrast to the approach of traditional psychoacoustics.

The relationships and commonalities between these two broad subdivisions of hearing science (traditional psychoacoustics versus the cognitive–ecological approach) have been studied very little. Psychoacoustic journals typically published papers on sensory processes and auditory physiology. Auditory cognition and ecological acoustics papers were published in either perception and cognition journals or music and speech journals. When psychoacoustics began to emerge as its own discipline, the instrumentation of the day and dominant behaviorist paradigms in psychology were such that an integrated approach to studying auditory perception was not a realistic undertaking. Even within organizations dedicated to the study of acoustics (such as the Acoustical Society of America), music, speech, and psychoacoustic researchers had clear and formal divisions that continue to exist today. However, as the cognitive revolution began to take hold in psychology and technology began to develop at faster and faster rates, more comprehensive investigations of auditory function became possible. Advances in computer science, virtual environments, neurophysiology, and neuroimaging, coupled with emerging perspectives in evolutionary and ecological psychology, have now made it more plausible to begin to tie together lower level psychoacoustic work with perception–action relationships and higher level auditory cognition. Open-field ecological studies of auditory localization, for example, can now begin to draw on evidence from single-cell recording work to develop hypotheses further, and neuroimaging researchers can employ traditional psychophysical studies to identify structures responsible for processing classic psychoacoustic effects.

One of the goals of this book is to review some emerging work in psychoacoustics as well as work in auditory cognition and ecological psychology, highlighting the areas in which the lines of research intersect. The plan is to examine some of the complex interactions between these divergent areas of hearing science, tying together the occurrence of acoustic events, physiological responses of the auditory system, the perceptual and cognitive experience of the listener, and how this experience influences behavior, action, and subsequent perception. Where this is not possible, the goal is to address the potential reasons for the disparity or lack of convergence between the lines of research. Illuminating some of the converging evidence that is emerging from these traditionally divergent paths may yield a broader and perhaps more informative perspective on auditory

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function. Areas of inquiry that are useful in developing this perspective range from physics to physiology and from evolution to behavioral science.

Of course, the corresponding disadvantage of addressing the study of audition with such a global perspective is that at this time there is much that we do not know about each individual piece in the auditory puzzle. Thus, tying them all together is often an incomplete task. Perhaps more important when examining the big picture is the fine-grained analysis of each subarea becomes much coarser. Nevertheless, there are numerous exemplary sources that delve more thoroughly into fine detail of these areas and a few that attempt to tie them together. Thus, the approach of the book is to examine relationships that exist and provide a review of studies that incorporate environment, and cognition, as well as traditional psychoacoustics.

To gain some perspective on what we do and do not know about hearing, it is useful to begin by examining some of the historical forces that have driven psychoacoustic research. In the remainder of this introductory chapter, we first examine some of the influences that have shaped the questions that auditory researchers have traditionally asked. These forces include (but are certainly not limited to) the available technology and instrumentation of the time and the dominant theoretical perspectives that are in place when the research is conducted. Next, we examine briefly the role of evolution in shaping the form and function of the auditory system. Few would argue with the concept that the ability to hear has evolved. However, the evolution of the physiological structures that enable hearing is generally more widely accepted than the evolution of the behaviors that those structures support. We then discuss the distinctions between internal, external, and ecological validity, while examining the strengths and weaknesses of approaches that emphasize each. Finally, we further explore the distinction between research in psychoacoustics and research in auditory cognition.

HISTORICAL PERSPECTIVE

THE AVAILABLE TECHNOLOGY

In some ways, the traditional psychoacoustic research has mirrored the old joke about the bar patron who has had too much to drink and is on his hands and knees beneath a streetlight looking for his car keys. A police officer happens by and asks, “Well, where did you lose them?”

“Across the street” is the reply.

“Then why not look over there?”

“Because the light is better here.”

Early on in the history of modern psychacoustics, the difficulty in generating complex, controlled, dynamic stimuli limited many investigations of auditory function to studies of static sine wave tones or bursts of noise. In the 1930s and 1940s the scientific study of psychacoustics began to expand rapidly with the use

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of such stimuli. The widespread commercialization of the electronic vacuum tube made it possible not only to present these kinds of sounds with great control but also to amplify and measure the physiological responses in the auditory system (Wever & Bray, 1936a, 1936b, 1937). At the beginning of their classic text on the psychology and physiology of hearing, Stevens and Davis (1938) remarked that the development of the vacuum tube removed the principal impediment to the study of acoustics: the ability to produce sounds of any frequency, intensity, and complexity. No longer did researchers need to rely on tuning forks, sirens, and reeds to produce acoustic stimuli. The desired frequency and intensity could now be presented with electric signal generators, amplifiers, and loudspeakers. However, Stevens and Davis could not have known that the remarkable development that removed such a major impediment would also constrain psychoacoustic research for some time to come. Even with the advances of the day in electronics, it was still somewhat of a task to present listeners with simple static acoustic stimuli. More realistic sounds that exhibited dynamic changes in frequency, intensity, and spectrum were even more difficult to generate and were rarely used in experiments. Thus, most psychoacoustic experiments were conducted with static sine wave tones or complexes and in some cases bursts of noise. Although these types of sounds are rarely encountered in a natural listening environment, the limited instrumentation of the day dictated that these were the only types of experiments that could be performed under controlled conditions. Thus, researchers "looked where the light was better" and for the most part examined the perception of single-source, unchanging pure tones and noise.

The results of many of these studies have since become widely accepted classical models of auditory perception. The obvious problem is that they are based largely on sounds that rarely occur in a natural listening environment. Prior to the widespread use of the vacuum tube, realistic, complex sounds were generated manually. However, the level of precision and experimental control often suffered. Early electronics offered greater control but at the cost of dynamic complexity. Advances in computer technology have given researchers the best of both worlds, enabling the presentation of complex, dynamic stimuli under highly controlled conditions.

This more recent work is beginning to show that that under many circumstances, the perception of dynamic, ecologically valid stimuli is not predicted well by the results of many traditional stimuli experiments using static stimuli. If one accepts the position that our perceptual abilities have evolved specifically to deal with the stimuli that occur in a natural environment, perhaps it is not surprising that there are differences in processing naturally occurring stimuli and those that are more artificial. In this respect, auditory researchers are clearly not alone. Differences between static and dynamic perception have been shown not only in audition (Canévet & Scharf, 1990; Iverson, 1995; Neuhoff & McBeath, 1996; Perrott & Musicant, 1981; Spitzer & Semple, 1993) but also in vision (Kleiss, 1995; Muise, LeBlanc, Blanchard, & de Warnaffe, 1993; Spillmann & Kurtenbach, 1992; Verstraten, Fredericksen, van Wezel, Lankheet, & Van de Grind,

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1996), haptics (Menier, Forget, & Lambert, 1996; Rochat & Wraga, 1997), and categorization (Arterberry & Bornstein, 2002). The growing consensus among many perception researchers is that using the results of static-stimuli experiments to make broad generalizations about dynamic perception is often an untenable proposition.

DOMINANT PSYCHOLOGICAL PARADIGMS

Another historical influence on the development of psychoacoustic research was the dominant theoretical perspective in psychology of the day. The classical conditioning work of Pavlov and Watson in the early part of the 20th century gave way to operant conditioning and the rise of radical behaviorism. According to the behaviorist approach, the reinforcing consequences of behavior are the causes of subsequent behavior. One of the strengths of this approach was that it posited no internal cognitive mechanisms in explaining behavior. Previous approaches such as those of James and Freud required the use of ill-defined and unobservable phenomena. James and Freud both posited that instincts were the driving forces behind behavior. Freud suggested that a few instincts (primarily having to do with sexuality) were responsible for behavior. James suggested that there were many instincts that drove behavior. Many in the scientific community bristled at the proposals because of the obvious problem of operationally defining or observing an "instinct."

Part of the strength of behaviorism was that operational definitions were easy to come by. Behavior and reinforcers could be easily observed and quantified. The approach did not need to appeal to any internal mechanisms to explain behavior. As the behaviorist movement grew, it became less and less fashionable for researchers to examine internal mechanisms such as thought processes, prior knowledge, expectations, or beliefs. Thus, psychoacoustic research of the time was conducted under the dominance of a theoretical perspective in psychology that essentially renounced any type of cognitive or internal process as a means of explaining behavior. Although many psychoacousticians were keenly aware that cognition influenced behavior and action in response to an acoustic signal, it was more common to control for this influence and factor it out than to study the phenomenon to investigate its relationship with sensation and physiology.

Finally, it should be noted that the study of audition was and is an interdisciplinary endeavor involving physicists, engineers, physiologists, biologists, and psychologists, to name only a few. The direction that auditory research took as the result of World War II probably did little to draw more psychologists into hearing research (Schubert, 1978). Much of the work became focused on the physics of the signal and the physiological response of the peripheral auditory system. Students in psychology found that in order to study the psychology of audition, they were often presented with the daunting task of first tackling the physics and physiology (Schubert, 1978). Thus, the limitations in technology and

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the general avoidance of anything cognitive coupled with growing avoidance of audition by psychologists resulted in many investigations of auditory function that, although rigorous and well defined, often brushed only the surface of true listening behavior.

EVOLUTION AND AUDITION

The ability to acquire and process acoustic information about the environment has no doubt evolved because it provides a selective advantage. The abilities to localize sound sources, communicate with conspecifics, and heed auditory warnings are all crucial to survival. In the biological sciences it is generally accepted that physiological structures often evolve because they provide advantages that allow more successful survival and reproduction. What is no less true, but is less emphasized, is that the behaviors that are supported by these physiological structures are also products of evolution. So, for example, if one agrees that the complex shape of the outer ear has evolved because it provides a selective advantage in source localization, one must also concede that the behavior of localizing a sound source using input from the acoustic filtering performed by the pinnae has also evolved. Although the evolution of specific behaviors is met with skepticism by some, the point was not lost on Charles Darwin. In 1859 he predicted that the impact of evolutionary theory would reshape how we thought about behavior:

> In the distant future I see open fields for far more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation. (Darwin, 1859, p. 449).

The impact of evolutionary theory on the behavioral sciences clearly has not lived up to Darwin's prediction. Cognitive scientist Steven Pinker (a strong proponent of evolution in the study of cognitive science) has summed up the current status of evolutionary theory in psychology in this way:

> . . . the study of the mind is still mostly Darwin-free. Evolution is said to be irrelevant, sinful, or fit only for speculation over a beer at the end of the day. (Pinker, 1997, pp. 22–23).

Nonetheless, evolutionary theory has clearly influenced the thinking of a growing number of psychologists. The interaction between behavioral and biological scientists has recently flowered with the explosion of the neurosciences. Still, the dominant trend among those who study human audition has been to focus on psychoacoustic questions per se, leaving the often "wooly" evolutionary origins of the psychoacoustic phenomena unaddressed. It is interesting to note that this is in contrast to much of the bioacoustic research on animals, where the role of evolution in shaping the auditory system and listening behaviors of organisms is often stressed.

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ECOLOGICAL, EXTERNAL, AND INTERNAL VALIDITY

In any type of experimental setting, the validity of the findings is crucial to interpreting the results and drawing reasonable conclusions about the data. There are various types of validity, most of which have been extensively outlined by Campbell and Stanley (1963). The focus of traditional psychoacoustic research has been on internal validity, assuring that the experimental manipulations or independent variables are really responsible for any changes in the dependent variable. Typically, researchers have gone to great lengths to assure that experiments are conducted in a quite controlled environment, that stimuli are presented in precisely the same manner on every trial, and that a small number of well-practiced participants receive a large number of trials. All of these precautions are requisites from the standpoint of maintaining the internal validity of the research and the practicality of actually conducting the experiments. For example, the practice of using a small number of listeners with a large number of trials has the several advantages. First, the resources required to recruit and compensate participants are minimal. It is certainly easier to convince 2 or 3 graduate students to sit in a sound booth for 45 minutes and press a key in response to a sound than it is to entice 30 undergraduates to do the same. Second, because of the small number of participants, extraneous variability due to individual differences is minimized. Finally, presenting a large number of trials to well-practiced listeners minimizes the effects of learning and practice on the results.

However, when it comes to drawing reasonable conclusions about the data, a telescopic focus on internal validity to the exclusion of other types of validity can be as detrimental as ignoring internal validity altogether. External validity is the degree to which the results of an experiment would apply in other settings with other populations. For example, how might an auditory effect discovered by conducting an experiment in a sound booth hold up in a concert hall or a living room? The experimental control afforded by the booth increases internal validity at the cost of external validity. The small number of participants typical of many psychoacoustic experiments can also reduce external validity. How might the findings of a study conducted with authors and graduate assistants differ from one conducted with naïve listeners? If the critical question is one that involves using psychophysics to make inferences about the physiology of the peripheral auditory system, these questions become less of a concern. However, if one is interested in listening behavior, how listeners perceive and use acoustic information to guide action, then these questions are crucial.

Campbell and Stanley (1963) have proposed that the ideal design is one in which both internal and external validity are maximized, thereby yielding tightly controlled designs from which real-world conclusions can be drawn. However, others have suggested that the relative importance of internal versus external validity depends on the questions and goals of the investigation. In defending external "invalidity," Mook (1983) has suggested that the terms "validity" and

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"invalidity" connote inherent value judgments and that in some cases experiments that lack external validity are quite valuable and informative. For example, if the goal of the investigation is to determine the limits of the perceptual system under ideal conditions, a tightly controlled experimental environment is critical, even if this environment never exists outside the laboratory. The insights gained from such experiments can lead to a greater understanding of perceptual systems even though the laboratory conditions may never match those experienced in the real world. On the other hand, if the goal is to examine how auditory phenomena generalize across situations and populations, an investigation with greater external validity is clearly called for.

A final validity issue is that of ecological validity, essentially how the results of an experiment might apply in an environment in which similar conditions might be encountered. The precise meaning of ecological validity has been the subject of considerable debate. However, Schmuckler (2001) has suggested a dimensional analysis that specifies ecological validity as the extent to which the laboratory setting, stimuli, and task of the participant are representative of those experienced in everyday life. For example, almost any experiment that uses isolated sine wave tones has suspect ecological validity because isolated pure sine waves almost never occur in a natural listening environment.

It is interesting to note that before the widespread development of reliable electronic signal generating instrumentation, many ecologically valid psychoacoustic experiments were conducted with "real-world" stimuli. For example, after a conversation about the generality of Weber's law, Fechner and Volkman fashioned a makeshift apparatus to examine the validity of Weber's law in loudness perception.

> After Volkman had carried out his photometric experiments, I spoke to him about the great importance of a general validation of Weber's Law. He improvised on the spot the following apparatus for a preliminary proof of the law applied to loudness, which was built the same day at a cost hardly worth mentioning.
>
> It consists simply of a free-swinging hammer, which knocks against a plate made of some substance that either does or does not give off a tone. A strong knitting needle served as the axis for this pendulum. . . . The sound produced is understandably stronger or weaker, physically speaking if the hammer is made heavier or lighter, if it is allowed to drop from a greater or lesser height against the plate, or if one stands closer or further away from the apparatus. (Fechner, 1966, p. 147).

The pendulum apparatus was used by Fechner, Volkman, and many others to investigate loudness perception and even to investigate auditory pathology (Fechner, 1966, p. 149). This illustrates the somewhat ironic and circular historical course that ecological validity has taken in psychoacoustic investigations. Fechner used real sounds with rich harmonic structure that were heard binaurally in a natural listening environment. It is difficult to imagine an experimental setting with better ecological validity. The drawback of the methodology was a certain lack of precision (or internal validity). Releasing the pendulum from exactly the same point from trial to trial was problematic. Producing sounds of fractional

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intensity by releasing the pendulum from correspondingly lower heights was compounded by differences in friction at the axis and even differences in air resistance. The characteristics of the room and the listener could also affect the results.

When it became practical to present acoustic signals electronically through headphones, the internal validity of psychoacoustic experiments was increased dramatically. The intensity of tones could be produced reliably from trial to trial. Fractional intensities could be presented accurately. The drawback now, however, was that the types of sounds that could easily be presented electronically rarely if ever occurred in a natural listening environment. However, the rise of behaviorism with its emphasis on rigorous operational definitions and the backlash against the ill-defined Freudian psychology probably convinced psychoacoustic researchers that the precision and convenience of the available electronics outweighed the drawbacks. Advances in computer technology have now given researchers the best of both worlds. Realistic, harmonically rich, dynamic stimuli can now be presented with great precision.

It is clearly not the case that any one type of validity is somehow more valuable than any other. A variety of experimental approaches and techniques are required to gain a better understanding of auditory function and listening behavior. Different approaches should emphasize different types of validity. If convergent evidence from these different approaches can be obtained, we can have greater confidence in the theories and models derived from them.

PSYCHOACOUSTICS VERSUS AUDITORY COGNITION

Traditional psychoacoustic research has focused on the sensory impressions of an acoustic stimulus and determining the physiological structures that mediate these experiences. In comparison, the cognitive and ecological components of auditory perception have been studied somewhat less and are often treated by psychoacousticians as extraneous variables that need to be controlled. The classic technique that exemplifies this approach is signal detection theory. Essentially, the goal of signal detection theory is to separate a listener's sensitivity to a stimulus from the listener's decision criterion for responding. The goal is to separate the lower level physiological and sensory characteristics of a response from the higher order cognitive influence on deciding how to respond to the stimulus. Clearly, this is a necessary technique if we are to fully understand auditory processing. However, this type of approach alone is not *sufficient*.

The relationship of sensory and physiological investigations to ecological and cognitive investigations should be one of synergy. Physiological discoveries of structures that are implicated in specific auditory functions give rise to specific predictions about perception and listening behavior. Thus, psychological investigations can test the limits of the relationship between the structure and the func-

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tion. Conversely, discoveries in perception and listening behavior can provide direction for physiological investigations of the structures that mediate the behavior. The relationship is synergistic because advances in one area spur research in the other.

However, at best there has been relatively little dialogue between traditional psychoacousticians and the researchers who do study nonspeech auditory cognition. At worst, there is a clear rift between the two types of researchers. The extreme traditional view is that if a phenomenon does not have a readily identifiable physiological structure that mediates it, the effect is somehow less important. After presenting a finding about a particular listening behavior at a recent professional meeting, a psychologist was asked by a more physiologically inclined colleague, "Yes, but what cells or tissues are responsible for the effect?" The psychologist sheepishly responded that he did not know. The physiologist nodded, as if this lack of a known neural basis for the effect somehow diminished the results of the experiment. On the contrary, psychological findings that flow well from what we currently know about the physiology of the auditory system are often less interesting than those that are surprising. It is the phenomena that lack a clear physiological explanation that illustrate what we do not know about physiology and drive physiological investigations. A complete understanding of auditory function will require cooperation between physiology and psychology. It will require more than just a description of cellular form and function from cochlea to cortex. Although this level of cellular analysis is necessary, it is not sufficient. Physiology is the basis for perception, cognition and behavior. It is interesting to note that in vision, the synergistic relationship between research in physiology, psychophysics, and cognition is widely accepted and advocated by such notable figures as Nobel Laureate David Hubel (Livingstone & Hubel, 1988).

This is not to say that relationships between physiology and perception as well as the study of complex real-world auditory phenomena have been ignored, only that further development of this integrative approach might yield greater understanding. This idea was pointed out in an address by the eminent psychoacoustician Reinier Plomp. His comments were given at the March 1999 meeting of the Acoustical Society of America in a session honoring the Plomp's lifetime of achievement and contributions to the field.

> The exceptional honor of this session gives me the opportunity to introduce some questions usually not discussed in conference papers. My point of departure is that the function of our hearing is to inform us as reliably as possible about the world of sounds around us. It is the task of hearing research to find the laws involved. In carrying out this task, we are permanently confronted with several temptations. Their common origin is the scientific rule to keep the number of variables as small as possible. In this way, parts get more attention than structure. Hence, many essential aspects of everyday sounds had to wait surprisingly long before they got proper scientific attention. (Plomp, 1999, p. 1239)

Hearing usually takes place in the presence of complex stimuli in complex acoustic environments. The neural mechanisms and processes responsible extend

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beyond the peripheral auditory system and in some cases beyond the auditory system itself. For example, the auditory researcher would be hard pressed to explain things such as the McGurk effect (McGurk & MacDonald, 1976), where visual speech can influence what is heard, or the visual effect of vocal effort on loudness (Rosenblum & Fowler, 1991) using only physiological structures solely devoted to audition. It is understanding the complex interaction of acoustics, physiology, sensation, perception, cognition, and behavior that is the puzzle of audition.

SUMMARY

Auditory perception and cognition are the result of complex physical, physiological, and cognitive factors. However, the cognitive characteristics and perception–action relationships of early psychoacoustic research were limited by the technology of the day, the dominant theoretical perspectives in psychology, and perhaps reluctance on the part of psychologists to engage in the more cumbersome physical and physiological modeling of acoustic signals and responses. Thus, influential models of auditory processing were developed using sounds that are not frequently encountered in a natural listening environment. Although this approach was useful in developing models of the function of the peripheral auditory system, it was less so in developing models of auditory cognition and behavior. However, technical innovations and paradigmatic shifts in psychology have spawned more ecologically valid investigations of complex auditory perception–action relationships and auditory cognition. These efforts complement more traditional psychoacoustic research in furthering our understanding of audition.

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