J Am Acad Audiol 24:572–589 (2013)

Review

Factors Influencing Tests of Auditory Processing: A Perspective on Current Issues and Relevant Concerns

DOI: 10.3766/jaaa.24.7.6

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Abstract

Background: Tests of auditory perception, such as those used in the assessment of central auditory processing disorders ([C]APDs), represent a domain in audiological assessment where measurement of this theoretical construct is often confounded by nonauditory abilities due to methodological shortcomings. These confounds include the effects of cognitive variables such as memory and attention and suboptimal testing paradigms, including the use of verbal reproduction as a form of response selection. We argue that these factors need to be controlled more carefully and/or modified so that their impact on tests of auditory and visual perception is only minimal.

Purpose: To advocate for a stronger theoretical framework than currently exists and to suggest better methodological strategies to improve assessment of auditory processing disorders (APDs). Emphasis is placed on adaptive forced-choice psychophysical methods and the use of matched tasks in multiple sensory modalities to achieve these goals. Together, this approach has potential to improve the construct validity of the diagnosis, enhance and develop theory, and evolve into a preferred method of testing.

Research Design: Examination of methods commonly used in studies of APDs. Where possible, currently used methodology is compared to contemporary psychophysical methods that emphasize computer-controlled forced-choice paradigms.

Results: In many cases, the procedures used in studies of APD introduce confounding factors that could be minimized if computer-controlled forced-choice psychophysical methods were utilized.

Conclusions: Ambiguities of interpretation, indeterminate diagnoses, and unwanted confounds can be avoided by minimizing memory and attentional demands on the input end and precluding the use of response-selection strategies that use complex motor processes on the output end. Advocated are the use of computer-controlled forced-choice psychophysical paradigms in combination with matched tasks in multiple sensory modalities to enhance the prospect of obtaining a valid diagnosis.

Key Words: Adaptive forced-choice psychophysical methods, auditory processing disorder, dissociation, double dissociation, forced-choice psychophysical methods, modality specificity, response selection

Abbreviations: APD = auditory processing disorder; ASHA = American Speech-Language-Hearing Association; (C)AP = (central) auditory processing; (C)APD = (central) auditory processing disorder; CNS = central nervous system; CPT = continuous performance test; ROC = receiver operating characteristics; UDTR = up-down transformed response

It has been suggested that the area of auditory processing disorders (APDs) lacks a strong theoretical foundation for implementing assessments, for interpreting and accounting for test results, and in predicting outcomes (e.g., Humes et al, 1992; McFarland and Cacace, 2009, 2012a; Watson and Kidd, 2009; Ferguson et al,

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2011). Indeed, this deficiency is a major impediment for advancing the field since the absence of an effective theory impacts directly on the accuracy of the diagnosis.

In this perspectives article, two general areas of interest are considered: (1) the application of modality specificity as a theoretical cornerstone for advancement, an investigative platform for discovery/innovation, and a diagnostic imperative, and (2) the use of computer-controlled forced-choice psychophysical methods as a way to structure test paradigms, control for confounding variables, eliminate floor and ceiling effects, and automate quantification of test results. It is argued that by incorporating these aforementioned features of test design, ambiguities of interpretation can be minimized and/or eliminated, indeterminate diagnoses can be averted, perceptual and cognitive processes can be delineated, and unwanted confounds can, in large part, be avoided.

BACKGROUND AND THEORY

In order to approach this topic with any degree of veracity and conviction, a useful definition is required. This represents a good starting point and serves as a theoretical and practical foundation to complement our perspective on this topic. We define *APD* as a modality-specific perceptual dysfunction that is not due to peripheral hearing loss (McFarland and Cacace, 1995a; Cacace and McFarland, 2005). This operational definition is preferred to others because it is explicit, straightforward, and simple; most importantly, there are no uncertainties in terms of *what is* and *what is not* an APD. It is derived from theoretical considerations and driven by hypotheses that can be evaluated by performing relevant tests so that factors that confound current assessment procedures can be minimized or eliminated.

Other definitions of *APD* have been proposed and some are briefly reviewed here. Based on the Bruton Consensus Conference, as summarized by Jerger and Musiek (2000), *APD* was broadly defined as a deficit in the processing of information that is specific to the auditory modality. The problem may be exacerbated in unfavorable acoustic environments and may be associated with difficulties in listening, speech understanding, language development, and learning. In its pure form, it is conceptualized as a deficit in the processing of auditory input. Consequently, this consensus conference emphasized and embraced the concept of modality specificity as an obligatory feature in the diagnosis of this disorder. Based on the position taken by the American Speech-Language-Hearing Association (ASHA) in a technical report on (central) auditory processing disorder (2005), *(central) auditory processing ([C]AP)* refers to the efficiency and effectiveness by which the central nervous system (CNS) utilizes auditory information. Narrowly defined, *(C)AP* refers to the perceptual processing of auditory information in the CNS and the neurobiologic activity that underlies that processing and gives rise to electrophysiological auditory potentials. *(C)AP* includes the auditory mechanisms that underlie the following abilities or skills: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination (e.g., temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals. While on face value, this definition also embraces the concept of modality specificity by referring directly to the perceptual processing of auditory information, the downside of this position is the lack of a strong theoretical foundation and the fact that it defines *APD* primarily on the basis of unimodal test performance. Abilities such as phonological awareness, attention to and memory for auditory information, auditory synthesis, comprehension and interpretation of auditorily presented information, and similar skills are considered higher order cognitive-communicative and/or language-related functions and, thus, are not included in this definition. *Guidelines for the Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder,* published by the American Academy of Audiology (Academy; 2010), builds on the definition given by ASHA (2005): "(C)APD refers to difficulties in the perceptual processing of auditory information in the central nervous system and the neurobiologic activity that underlies that processing and gives rise to the electrophysiologic auditory potentials." What is conspicuously absent from the Academy document is any discussion of a coherent theory.

It is also noteworthy that some authors have chosen not to endorse an explicit definition of APD but rather to focus on a specific area such as listening difficulties in the presence of background noise, which might occur in environments where spatially distinct noise patterns could degrade auditory-related perceptual abilities. Dillon et al (2012) suggest that simulating these conditions and using sentence material as stimuli could be a useful diagnostic strategy for assessing APDs. However, a distinct limitation of this approach is the absence of a clear definition and acknowledgment that processing deficits associated with this paradigm are not limited to auditory-perceptual abilities but could result from more generalized disorders of attention, higher-level language, and/or cognitive abilities.

While definitions and "opinions" may differ on how to approach this topic, what is crystal clear is the fact that perception in general and auditory perception in particular are theoretical constructs. A theoretical construct is an explanatory variable that is *not* directly observable; it represents "some postulated attribute of people, assumed to be reflected in test performance" (e.g., Cronbach and Meehl, 1955). In the domain of psychology, examples of theoretical constructs include intelligence, motivation, personality, emotions, moods, and so on. In physics, atoms, gravity, black holes, the Higgs particle, and so forth are considered theoretical constructs. In biology, genes, evolution, taxonomies, et cetera are examples of theoretical constructs. In each of the scientific disciplines noted above, theoretical constructs are used to explain different phenomena pertinent to each of these fields of interest. In the field of audiology, the APD is also a theoretical construct; as such, it is *not* directly observable. We cannot see (observe) an APD; we cannot touch one, smell one, taste one, and so on. Consequently, when recent documents refer to auditory processing as constituting observable behaviors, it creates a quagmire and misrepresents how to conceptualize, identify, and diagnose an APD.[1]

For example, the ASHA report on CAPD states: "Typically, screening questionnaires, checklists, and related measures probe auditory behaviors related to academic achievement, listening skills, and communication" (2005). It further states: "The operational definition of (C)APD serves as a guide to the types and categories of auditory skills and behaviors that should be assessed during a central auditory diagnostic evaluation" (2005). In the Academy guidelines (2010), there are many citations referring to CAPD as a "behavior." Moreover, in a recent study characterizing the accuracy of central auditory test batteries in individuals with brain lesions, Musiek et al (2011) describe "negative auditory behaviors," which include misinterpretation of acoustical information, frequently asking for speech to be repeated, difficulty hearing in background noise, and so forth as being manifest in this population (Musiek et al, 2011, p. 357, reference note 1). Taken together, the view that there are "auditory behaviors" suggests a one-to-one correspondence between auditory processing, APDs, and the tests that measure these phenomena. But as Hood and Berlin (1992) point out, auditory perception cannot be measured directly; therefore, the alternative term *auditory processing* has been advocated. However, auditory processing cannot be measured directly either, and this term still requires further explication to be useful.

The distinction between observable behaviors and theoretical constructs is an important one. As noted by Smith (2005), the notion that tests are indices of unobservable hypothetical constructs was quite foreign to thinking in the field of individual differences prior to Cronbach and Meehl (1955). At that time, the prevailing view held that it was pure speculation to claim that a test measured anything over and above the criterion on which it was validated. In contrast, Cronbach and Meehl (1955) maintained that test validation was part of the process of theory construction and that the validity of a test was related to the validity of the theory from which it was derived. In a corresponding development, Campbell and Fisk (1959) emphasized the importance of using different methods to measure hypothetical traits. This approach is referred to as the "multitrait-multimethod technique." In this framework, multiple tests measuring multiple traits are compared in order to evaluate the evidence to determine whether a given test significantly correlates with those measures with which it is theorized to be related to (convergent validity) but does not correlate with measures in which theory suggests it should not (divergent validity). Multiple tests of each trait are deemed necessary, since no single test is considered to be a pure index of the construct being assessed. In this regard, consider a matrix of correlations between multiple tests of auditory function and multiple tests of visual function. Evidence for the convergent validity of tests of auditory processing would be provided to the extent that they were all intercorrelated. In theory and based on the concept of modality specificity (McFarland and Cacace, 1995a), evidence of divergent validity would be provided to the extent to which *auditory* test scores are not highly correlated with performances on *visual* tests. If successful, such an approach will help to provide evidence for the construct validation of the APD. While such evidence is crucial to this field, currently, its substantiation is lacking. Indeed, much more effort will be necessary in order for this concept to be realized (McFarland and Cacace, 2012a).

Let us consider whether auditory processing is an observable behavior or a theoretical construct, since confusion exists on this basic tenet of codification. If auditory processing is an observable behavior, then we can detect it by observation of a single behavior. In contrast, if it is a theoretical construct, we must infer the existence of an APD from a consistent pattern of test results across different times and situations. Consider the following scenario that might play out in a classroom situation. Suppose we suspect an APD in a child who misunderstands what was said in a classroom where materials under discussion were math related. It would be rash to reach any conclusion about this child's processing skill based solely on one specific event such as difficulty understanding oral instructions for performing a mathematical calculation. Observation of this one behavior would not be sufficient for a diagnosis, as alternative possibilities can be postulated. He or she might have been fatigued due to lack of sleep; the child could be unmotivated to answer; or for that matter, the child might have problems performing mathematical operations, rather than processing of auditory-based materials. We would also want to verify whether there were problems with additional sorts of material that involved other domains of knowledge. This would serve to eliminate the possibility that problems with mathematics, rather than speech perception per se, were at issue. Furthermore, we might also want to evaluate this child's ability to follow written instructions, so as to further demonstrate specificity to the auditory modality.

Based on the arguments presented herein and in contrast to explicit statements made in the ASHA (2005) report, the Academy (2010) guidelines, and other publications, we conclude that an APD is *not* a behavior; rather, it is an abstract construct that describes a particular disposition (i.e., a tendency to have difficulty processing auditory stimuli). Secondly, individuals can be characterized by more than one disposition, for example, one dealing with auditory abilities and another dealing with mathematical abilities, and so forth. Thus, it is reasonable to assume that any observed behavior reflects the combination of several hypothetical dispositions, of which difficulty processing acoustic information could be one. Whereas the recognition that human perceptual abilities are theoretical constructs rather than observable behaviors may complicate the process of test construction, it also increases substantially the generalizability of the findings that would help to discriminate APDs from other disorders. Furthermore, the view that an APD is a theoretical construct leads to the proposition that APD be construed as a "hypothetical disposition" (e.g., McFarland and Cacace, 2009). With this reasoning, we can frame the assessment of APDs as a form of hypothesis testing, where the goal is to delineate modality-specific perceptual dysfunctions from supramodal or polysensory dysfunctions. From this perspective, diagnosis of an APD is not synonymous with poor performance on one, two, or more unimodal auditory tests, as current orthodoxy advocates and/or as some authors contemplate (Wilson and Arnott, 2013); rather, APD should be inferred from a pattern of test results that is consistent with theoretical expectations. Tenets underlying the concept of modality specificity provide such a theoretical framework. Alternatively, if there is no coherent theory, then diagnostic criteria as currently applied are not meaningful. In the context of the unimodal testing approach, Wilson and Arnott (2013) recommend abandoning the use of *(C)APD* as a global label; however, if one assumes modality specificity as a criterion for diagnosis, then this position is premature and would require modification.

Another area of inquiry in the domain of auditory processing relates to electrophysiological assessment as a component in the evaluation process. Some argue that using electrophysiological methods could potentially avoid some of the pitfalls that are apparent when behavioral tasks are used in the assessment process. While this observation may in part be true, biophysical issues involved in electrophysiological assessment are by their very nature inherently complex, particularly with respect to thalamic and cortical responses, and therefore may not necessarily simplify diagnosis as one might hope. Furthermore, to cover this area properly and to do justice to this topic, a more in-depth and separate article would be necessary. Therefore, for brevity and because we wish to keep the current article focused, we will make just a few general comments. First, consider the fact that electrical potentials detected by surface electrodes on the scalp record the superposition of all active sources in the brain and depending on the geometry of active cell populations and the electrical current fields that they produce, some potentials may not even be detectable at the level of the scalp (e.g., Lorente de Nó, 1947; Nunez, 1981). Thus, the biophysics of the scalp EEG is very complicated and the interpretation of the results is not always straightforward. Furthermore, there is no guarantee that the generators producing these potentials are all associated with modality-specific brain structures. However, there are exceptions. With electrocochleography (ECoG) and the auditory brainstem response (ABR), available evidence supports the assertion that the generators of these potentials are primarily associated with auditory processes within the inner ear and auditory specific brainstem structures. Amazingly, with ECoG and ABRs only a minimal number of electrode channels are required to obtain a valid response. However, when longer latency potentials are considered, such as those in the middle and/or longer latency time frame, which reflect thalamic and cortical activity, the evidence is not so clear (Cacace and McFarland, 2009). It appears that a larger number of recording channels (electrodes) are required in order to obtain a representative sample of responses that match well known theoretical models (e.g., Scherg and von Cramon, 1986, 1990), including vertex and temporal components (Wolpaw and Penry, 1975; Cacace et al, 1990; Cacace and McFarland, 2009) that often go undiscussed.

Thus, while keeping these issues in mind, if electrophysiological measures are applied as part of the assessment protocol, then it is instructive to ask, what tests should be used? Starting from the periphery and following a logical progression to the cortex, we can consider measures that include ECoG, ABRs, middle latency, and longer latency cortical responses. Electrocochleography can be used to assess modality-specific sensory and neural components arising from the inner ear and auditory nerve and aid in differential diagnosis of auditory-related disorders, like Ménière's disease (Margolis et al, 1992; Levine et al, 1998). The ABRs have been and continue to be an important tool in the diagnostic armamentarium not only for threshold assessment for clicks and frequency specific tone bursts (Sininger and Hyde, 2009) but for evaluating retrocochlear dysfunction (e.g., Don et al, 2005, 2012; Burkard and Don, 2007). Alternatively, Billiet and Bellis (2011) suggest using speech evoked (sABRs) as part of the test battery for diagnosing CAPD in children. While in theory this test might be of interest, issues related to the reliability (Hornickel et al, 2012) cast doubt on whether sABRs are justified at present for use in the diagnosis of CAPD in the clinic (Hornickel et al, 2012; McFarland and Cacace, 2012b). Cortical evoked potentials, including mismatch negativity (MMN) and P300, are other prospective strategies that may be considered within a test battery, although their inclusion is both complicated and questionable. While MMN may be of theoretical interest, available research has shown that expected responses are *not* consistently seen in individuals, as data represented in research papers are often reported as "grand means" (see Dalebout and Fox, 2001). This later concern has been echoed by Näätänen and colleagues (2012); they state, "Needless to say, a lot of work is still needed to bring the MMN methodology to clinics as a tool of everyday patient work in which reliable measurements have to be carried out at the level of individual patients..., but studies as those reviewed in the foregoing have shown that this goal is both valuable and probably also attainable" (p. 444). Whether MMN materializes for clinical use remains to be determined. Part of the reason for this uncertainty concerns large individual difference to different stimulus paradigms and the inherently poor signal-to-noise ratio that exists for certain classes of stimuli (Cacace and McFarland, 2003).

In a similar oddball type paradigm, but one requiring considerable attentional resources and active discriminatory involvement during the task, evidence suggests that standard time domain signal processing (averaging) underestimates the true cognitive response and that more sophisticated data collection procedures and analysis procedures are required to interpret these results accurately (e.g., McFarland and Cacace, 2004; Cacace and McFarland, 2007). This includes incorporating the assessment of EEG oscillations (event-related synchronizations and desynchronizations) (see Buzsáki, 2006), frequency domain analysis, and evaluating both time-locked and unlocked components that are reactive to the stimulus (McFarland and Cacace, 2004). While this more sophisticated approach has seen only limited use in the hearing sciences, in the cognitive sciences, it is being exploited more thoroughly to understand various neural processes including those associated with the acquisition of new cognitive skills (Romero et al, 2008). Lastly and importantly, consideration must also be given to the fact that the concept of modality specificity pertains directly to electrophysiological procedures just as it does to behavioral methodologies. This later observation has been echoed, and to some extent extended, by Tillery (2009) by noting that "an abnormality of the CANS determined through electrophysiological measures does not provide specific information as to the type of (C)APD or auditory behaviors that can be expected based on the results obtained" (p. 634). In relation to APDs, electrophysiological assessment remains to be explored in a more comprehensive and meaningful way as it offers a rich area for future research.

Modality Specificity

Teuber (1955) introduced the concept of modality specificity to the neuropsychology literature; Thompson et al (1963) applied the concept to the neurophysiology literature; and Mountcastle (1997) used modality specificity as a way of defining characteristics of sensory cortex in the brain. Humes et al (1992) were the first to discuss modality specificity within the context of CAPD/APD and McFarland and Cacace (1995a) and Cacace and McFarland (1998, 2005) developed the logical arguments for applying modality specificity as a defining characteristic of CAPD/APD.

Some researchers and clinicians agree with the necessity of defining auditory perceptual disorders as being modality specific (e.g., Friel-Patti, 1999) while others do not (e.g., Musiek et al, 2005). Likewise, "consensus statements" do not agree on this issue. The Bruton Consensus Conference, as summarized by Jerger and Musiek (2000), concluded that "there is a pressing need for analogous behavioral and/or electrophysiological test procedures in a non-auditory modality (e.g., vision)" (p. 472). In contrast, the ASHA (2005) report and the recent Academy (2010) guidelines are deficient in this context and fail to even discuss this issue.

The concept of modality specificity is fundamental to the diagnosis of an APD. As the name implies and as the definition indicates, an APD is a perceptual dysfunction in the processing of "acoustic" information. If the basic tenet of demonstrating specificity to the auditory modality cannot be met, then the diagnosis cannot be made; it is indeterminate. Consequently, it follows that multimodal testing (i.e., use of matched tasks in multiple sensory modalities) becomes a necessary component in the evaluation process. However, it is important to point out that *modality specificity* is a relative term; it is not an "absolute" entity as construed by some. An instructive example illustrating the perplexity of issues surrounding this concept can be found in the work of Bellis et al (2008).

Bellis and colleagues (2008) compared performances on small samples of normal adults, normal children, and children with CAPD, using a dichotic digits test and its visual analog. In this study, normal children performed significantly better than children with purported CAPD.[2] However, it is unclear how their data on dichotic and dichoptic digit test performance support the CAPD diagnosis. To illustrate this concern, graphical data from Bellis et al (2008) are shown in Figure 1. The top graph (Fig. 1A; taken from their table 1, p. 283) shows the performances of normal children on auditory and visual versions of the dichotic/dichoptic digits test; the bottom graph (Fig. 1B; taken from their table 2, p. 285) shows the performances of children with CAPD

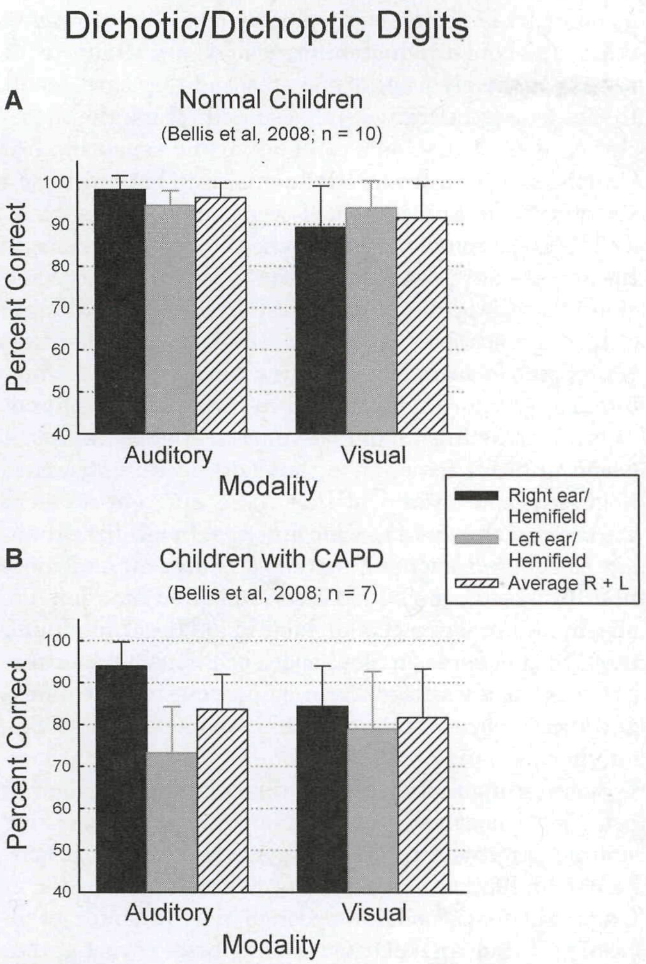

Figure 1. Vertical bar graphs (means and standard deviations) representing dichotic (auditory) and dichoptic (visual) digit data, replotted from Bellis et al (2008, table 1, p. 283; table 2, p. 285). We added the average values for left and right ears/hemifields. *A*: data from normal hearing children; *B*: data for children diagnosed with CAPD.

on the same tasks. In the CAPD group, children performed poorer on the dichoptic-digits paradigm (visual version of the dichotic-digits task) than on the actual auditory-based dichotic-digits task. As can be seen in Figure 1B, the performance deficits on these tasks were *not* specific to the auditory sensory modality, indicating that a more generalized cognitive deficit was operating under these conditions. The obvious conclusion that can be derived from these data are that some, if not all, of the children prediagnosed with CAPD have problems that are *not* modality specific and, therefore, are *not* of a perceptual nature. However, rather than questioning the legitimacy of their CAPD diagnosis, Bellis et al (2008) chose to question the proposition that perceptual deficits are modality specific.

In this context, given the lack of specificity in test performance, it is difficult to understand how the diagnosis of CAPD is ascertained. Seemingly, their justification was based on the interpretation that modality specificity is an all-inclusive phenomena; they state that their results "do not support the concept of complete modality-specificity in children diagnosed with CAPD"; they further assert that their findings are consistent with the position "that complete modularity of central auditory function is neurophysiologically untenable" (Musiek et al, 2005). However, this statement represents a misinterpretation of the historical facts because up until this time, no one has ever used the term *complete modality specificity* as a descriptor of this effect. Instead, it has been stated that it is sufficient to demonstrate "relative" modality specificity where the point of emphasis is the realization that if an auditory-perceptual disorder is manifest, then it should involve the auditory modality to a disproportionate degree (McFarland and Cacace, 1995a).

This notion of *relative modality specificity,* defined as performance deficits involving the auditory modality to a disproportionate degree (McFarland and Cacace, 1995a), is related to the notion of incremental validity (Hunsley, 2003). *Incremental validity* refers to the performance of a measure relative to other measures. In the case of APD, incremental validity relates to the extent to which APD tests add to our ability to predict variance in performance that is not accounted for by tests of other constructs. Thus, if testing suggests that an individual will have the same degree of difficulty processing certain types of information regardless of the sensory modality it is presented in, then the concept of APD does not add anything new or additional in this particular case. However, if testing suggests that an individual will have more difficulty when this information is presented in the auditory modality than in other sensory modalities, then the diagnosis of APD enhances our ability to predict performance. Thus, by the criterion of incremental validity, an APD test must be shown to add additional information above and beyond what can be deduced from other tests and that, taken together, can be accounted for by a more global disorder (e.g., attention deficit disorder). Therefore, test results must show relative modality specificity to support the diagnosis of APD.

We contend that if performance deficits in perceptual testing are manifest in multiple sensory modalities, then an explicit APD diagnosis is a dubious interpretation. Part of this conundrum, particularly with respect to Bellis et al (2008), can be traced to the inclusive criteria that relates to the practice of diagnosing children with APD using auditory tests alone. Indeed, the unimodal approach to testing is suboptimal since it raises distinct questions concerning whether these children actually have an APD. Clearly, the failure of Bellis and colleagues to demonstrate modality specificity in their test results is more likely related to limitations of established tests than with problems associated with modality specificity.

In line with the concept of modality specificity, we argue that perceptual disorders should be modality specific. Modality-specific disorders are in contrast to "supramodal" cognitive disorders such as those related to attention, memory, or polysensory language disorders where modality specific effects would not be expected. In fact, modality specificity is both necessary and sufficient to make the diagnosis of APD. The importance of this requisite relates to the fact that disorders of attention, language, or reading (i.e., those entities that are visual in nature) can present as modality specific, supramodal, or polysensory dysfunctions (see Bedi et al, 1994; Cacace et al, 2000; Dawes et al, 2009; Dawes and Bishop, 2010; Marinelli et al, 2011 as relevant examples). To underscore this point, we use attentional processes as an example and use continuous performance tests (CPTs) as an outcome measure. In this regard, Bedi and colleagues (1994) demonstrated that attention deficits (distractibility) in school-aged children can be modality specific. They found that visual distractibility was correlated with teacher ratings of behavior but not with cognitive or academic achievement measures. In contrast, auditory distractibility was correlated with cognitive functioning and reading scores but not with the CPT measure of inattention or teacher ratings of behavior. Thus, making explicit comparisons between performances on tests that use stimuli from different sensory modalities clarifies the nature of what these tests measure. With respect to the issue of attention/distractibility, the psychological community has been applying the concept of modality specificity with greater rigor, realizing that a unimodal framework in this type of evaluation process is unduly simplistic and fundamentally limited in scope. The Integrated Visual and Auditory Continuous Performance Test (IVA+Plus, BrainTrain, Richmond, VA) attempts to resolve these inadequacies by providing a much more comprehensive examination tool. It also adds credence to the view that in many areas of cognitive, psychological, and neural sciences, modality specificity is considered a useful and important construct (McFarland and Cacace, 2009).

By using matched tasks in multiple sensory modalities, dissociations and double dissociations that have functional value can be evaluated. Dissociations provide a mechanism by which investigators can make useful distinctions about function and, therefore, can aid in diagnosis (see Cacace and McFarland, 2012). A practical distinction used daily in clinical audiology is the dissociation between conductive and sensorineural hearing loss, accomplished by comparing the difference between pure-tone air- and bone-conduction thresholds at various frequencies. Here the distinction is simple and obvious. If hearing loss is manifest by pure-tone audiometry, and if large differences exist between air- and bone-conduction thresholds (bone-conduction thresholds being better [more sensitive] than air-conduction thresholds), then a conductive hearing loss is highly probable. However, if air- and bone-conduction thresholds are similar with respect to the presence of elevated auditory thresholds, then a sensorineural loss is assumed. Thus, the dissociation is made between conductive and sensorineural hearing loss, and this distinction aids in both differential diagnosis and potential treatment options. However, a more complex distinction, and one applicable to the assessment of auditory processing, auditory specializations, and the diagnosis of APD, fall under the rubric of the "double dissociation." To establish a double dissociation, the following logic applies: consider that if symptom A appears with a lesion in brain structure X, but not in brain structure Y, and if symptom B appears with a lesion in brain structure Y, but not in brain structure X, then it can be argued that those different areas of the brain each have a specific function. In localized damage to the brain, when function A is present and function B is absent in a single individual, and function A is absent and function B is present in another individual, then the presence of a "double dissociation" can be interpreted as meaning that the two functions involve different mechanisms and operate independently of one another.

Successful use of the double dissociation paradigm in behavioral studies has solidified how scientists view sensory information processing in the brain. A prominent exposition of this idea is based on the work of Ungerleider and Mishkin (1982) and Mishkin et al (1983). Through novel experiments, these investigators showed how dorsal and ventral pathways in the visual modality form two dissociable processing streams. These processing specializations form the basis of assigning meaning to an object (determining *what* it is) and of localizing objects in space (determining *where* it is). The establishment of parallel "what" and "where" streams of information processing in the visual system have been extended to the cortical organization of the auditory system (see Rauschecker and Tian, 2000). As part of the validation process to extend this conceptualization to the auditory modality, Lomber and Malhotra (2008) used a cooling technique to temporarily deactivate anterior and posterior auditory cortical fields in the cat. By comparing two separate behavioral tasks for each auditory cortical field deactivation, these investigators demonstrated a "double dissociation" between auditory object recognition and auditory localization abilities. Figure 2 provides a highly schematized representation of these experimental results in a single animal. In the figure, it can be seen that deactivating the anterior auditory field significantly affected (substantially reduced) object recognition performance but not localization abilities, whereas posterior auditory field deactivation resulted in normal object recognition performance but significantly affected (reduced) localization abilities. In both experimental conditions, actual

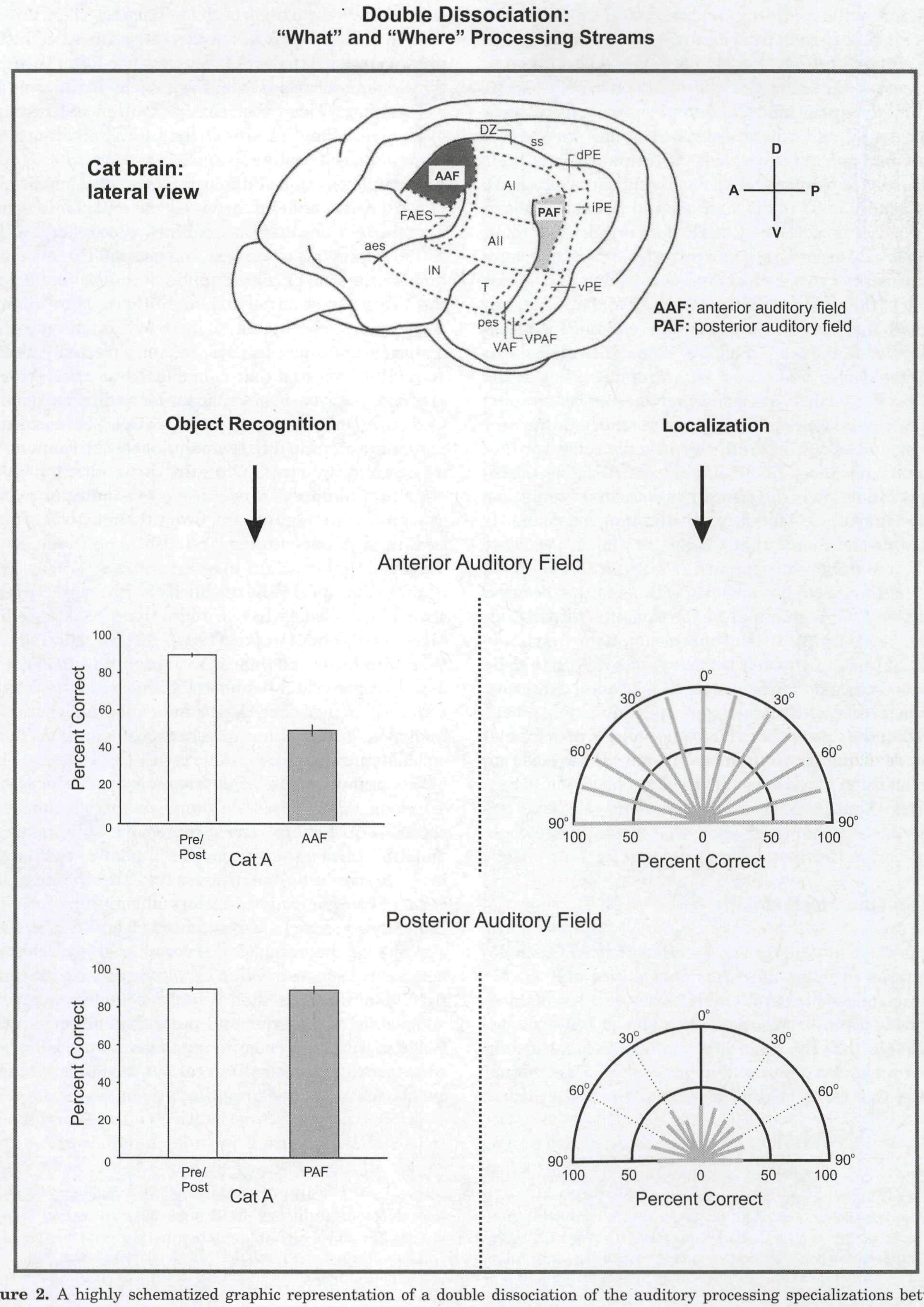

Figure 2. A highly schematized graphic representation of a double dissociation of the auditory processing specializations between "what" and "where" processing streams in cat auditory cortex taken from Lomber and Malhotra (2008). *Top*: lateral view of the cat brain with specific auditory areas labeled. AAF = anterior auditory field (dark gray); AI = primary auditory cortex; AII = second auditory cortex;

detection skills were unimpaired indicating that the experimental paradigm of localized cooling did not produce any generalized effects on behavioral performance.

Moreover, an example where demonstrable lesions to auditory areas affect auditory but not visual task performance, and where lesions to visual areas affect visual but not auditory task performance, has been demonstrated using matched nonverbal pattern recognition memory tasks in the auditory and visual modalities (e.g., Cacace et al, 1992). Clearly, for perceptual studies, the double dissociation can be a powerful approach because it demonstrates two distinct aspects of testing: (1) the *sensitivity* of the task and (2) the *specificity* of the deficit,[3] an approach that has been advocated for evaluating functional localization in the brain (Shallice, 1988). The rationale for using the double dissociation paradigm fits well with the concept of modality specificity and theoretical accounts of auditory-system modularity, particularly in the context of assessing for auditory-perceptual disorders (Polster and Rose, 1998). In contrast, because modularity of function is not typically assumed in conditions related to reading, language, or attention, assessing for double dissociations under these circumstances may not be as viable an approach (e.g., Van Orden et al, 2001), although well-known exceptions to this position exist (see Warrington and McCarthy, 1987; Karmiloff-Smith et al, 2003). It is of interest to note that some scientists have extended this concept even further by demonstrating a "triple dissociation" concordant with certain processes associated with reading (e.g., Pelli and Tillman, 2007). In this context, the presence of a "triple dissociation" can be interpreted as meaning that the three functions studied (parts, wholes, and context) contribute independently to reading rate. Interestingly, these authors also show that a relatively simple yet powerful additive model can account for these effects.

Multimodal Methodology

Musiek et al (2005) have asserted that while analogous tasks in different sensory modalities may enable detection of deficits in other modalities, it is not possible to equate stimuli across sensory systems. However, we emphasize that the main intent of multimodal testing is to control for abilities that are *not* of a perceptual nature; that is, to hold all aspects of the test constant other than the stimuli to be discriminated. Then, it is possible to evaluate whether performance varies with stimulus modality. If this is not the case, then it can be argued that other supramodal abilities may be influencing test performance. Thus, the point of multimodal testing is to have all other features of the task similar such that stimulus-specific effects can be assessed.

A simple example is apparent if we consider the pitch pattern test, which has been recommended as a component in test batteries of auditory processing (ASHA, 2005). The typical version consists of three-element binary patterns of high and low frequency tones, and the subject is required to encode these, store them in memory, attach linguistic labels to the individual frequencies, and reproduce the sequence verbally. Cacace et al (1992) showed that a double dissociation could be produced between memory spans for auditory sequential frequency (pitch) and visual sequential color patterns in patients with partial temporal lobe extirpations for intractable epilepsy. While in this context it is not clear that auditory frequency and visual color pattern sequences are "equivalent" (even though both types of stimuli can be described by having different wave lengths), these results illustrate that it is feasible to demonstrate modality specificity with these types of stimuli when used within an adaptive forced procedure. McFarland and Cacace (1997) further showed that there are large differences in recognition memory for auditory and visual sequences. Using a dual-task interference paradigm, the results indicated that there were both modality specific and general contributions to recognition memory performance with these sequences of binary stimuli. Thus, while frequency and color stimuli are clearly not equivalent, there well may be modality-specific contributions to sensory memory. Thus, frequency and color can be used as stimuli in tests to evaluate for modality specificity. Again, we reiterate that the intent here is to control for general factors affecting performance rather than to somehow equate for modality-specific effects.

While the profession of audiology has always embraced new technologies to advance testing paradigms, the time is right to take the next step in terms of implementing computer-based technology on a more wide scale basis, both to facilitate standard clinical assessments and to advance APD testing protocols. With respect to standard clinical assessments, the background, rationale, necessity, and

FAES = auditory field of the anterior ectosylvian sulcus; IN = insular region; iPE = intermediate ectosylvian area; PAF = posterior auditory field (light gray); T = temporal region; VAF = ventral auditory field; VPAF = ventral posterior auditory field; vPE = ventral posterior ectosylvian area; aes = anterior ectosylvian, pes = posterior ectosylvian; dPE = dorsal posterior ectosylvian area; ss = suprasylvian; A = anterior; D = dorsal; P = posterior; V = ventral; DZ = dorsal zone. Reversible lesions to anterior and posterior auditory fields show differential performance for object recognition (discrimination) and localization performance, demonstrating that "what" and "where" processing streams can be double dissociated. Vertical bar plots (left side of figure) represent performances on the object recognition task; polar plots (right side of figure) represent sound-localization performance. In these plots, the two concentric semicircles (solid lines) represent 50% and 100% response levels of performance. Detection abilities were unaffected by these experimental manipulations indicating that the experimental effect of cooling did not have generalized effects on behavioral performance.

validation of computerized audiological tools have been developed to a point where they are now being implemented clinically (see Margolis and Morgan, 2008; Margolis et al, 2010, 2011). In contrast, the use of computerized assessment of APD is *not* as well developed as it should be for clinical applications and usage. This is unfortunate given the clear advantages that putting experiments or clinical testing protocols under computer control can provide. The exemplar for using computers in the assessment of more complex audiological tasks has been advocated by Tyler (1982) almost three decades ago, and this framework now sets the stage for future developments.

Contemporary Psychophysical Methods

Applying Computer-Controlled Forced-Choice Recognition Paradigms

Under the rubric of contemporary psychophysical methods, establishing a unified structure for test administration using computer-controlled methodology covers a modest amount of territory in terms of test design, including controlling for decision processes and response bias, minimizing memory and attentional demands, limiting the use of complex motor processes in response selection, and automating the scoring of the results. We now address these issues and advocate for their use in the assessment of APDs in the clinic.

Forced-Choice Methods

Use of forced-choice psychophysical methods in clinical testing of APDs will allow for a known theoretical framework (Signal Detection Theory; SDT) to be applied as a way to control decision criteria and response bias during testing (Green and Swets, 1974; Kidd, 2002). Forced-choice psychophysical methods add an element of structure to test paradigms and provide a mechanism whereby simple and unambiguous instructions can be applied to a variety of tasks. An example illustrating the structure and temporal sequence of a typical forced-choice recognition procedure is depicted in Figure 3A.

These strategic factors in test design are most beneficial in the extreme age groups (i.e., young children and older adults), where tests of auditory processing are most often applied, where cognitive concerns could be an issue, and where pragmatics should be the operational principles that govern consideration of the strategies imposed. Furthermore, because placement of the relevant stimulus item is randomized and because the selection of the correct interval is as likely to occur in one interval as another, chance performance under these conditions will differ given the number of intervals selected and based on the examinee's criterion; consequently, "response bias" is virtually eliminated.

Adaptive Psychophysical Methods

Adaptive tracking procedures have a long and distinguished history in psychoacoustics, beginning with Zwislocki et al (1958) and subsequently being applied by many others (e.g., Levitt, 1971; Green, 1990). While controlling for response bias and decision processes are known benefits, adaptive forced-choice procedures offer other notable advantages, including: avoidance of floor and ceiling effects, providing the same level of difficulty across different tasks, and being very efficient in terms of converging on a threshold in a timely manner.

Adaptive forced-choice methods fall into four general categories: tracking (e.g., Zwislocki et al, 1958), staircase (e.g., Wetherill and Levitt, 1965; Levitt, 1971), parameter estimation by sequential testing (PEST) (e.g., Taylor and Creelman, 1967), and maximum likelihood (e.g., Pentland, 1980; Lieberman and Pentland, 1982; Watson and Pelli, 1983). While all methods have their own theoretical underpinnings, differences in usage can be attributed to preference and procedural issues. Features that all procedures have in common include the control of decision-making criteria and use of one's history of performance to change the dependent variable, using specific stepping rules to converge upon and stopping rules to estimate the threshold of interest. Consequently, correct responses and errors change the dependent variable in predictable ways. With adaptive tracking based on a staircase procedure (up-down transformed response [UDTR]; Wetherill and Levitt, 1965; Levitt, 1971), if a two-interval forced-choice (2IFC) and a 2-down 1-up tracking procedure are applied, it estimates the 70.7% point on the psychometric function; a 3-down 1-up procedure estimates the 79% correct point; and a 4-down 1-up procedure estimates the 84% correct point (Levitt, 1971). As they were initially applied, adaptive tracking and the UDTR typically use step sizes that remain constant over trials, although this can be modified without detriment, as noted in the next section. Parameter estimation by sequential testing is another procedure whereby initial step sizes are large and become progressively smaller over time as threshold convergence is approached. In this paradigm, the step size is typically reduced by half until a minimum predetermined step size is reached. In maximum-likelihood methods, the adaptive parameter of the signal on each trial is determined by a statistical estimation of the observer's threshold and by a given form of the psychometric function being estimated. The QUEST procedure developed by Watson and Pelli (1983) assumes a Weibull function; the procedure advocated by Pentland (1980) and Lieberman and Pentland (1982) assumes a logistic function. Thus, many choices are available to clinicians and scientists, and their application will depend on the examiner's expectations, theoretical viewpoints, and what he or she feels comfortable in implementing.

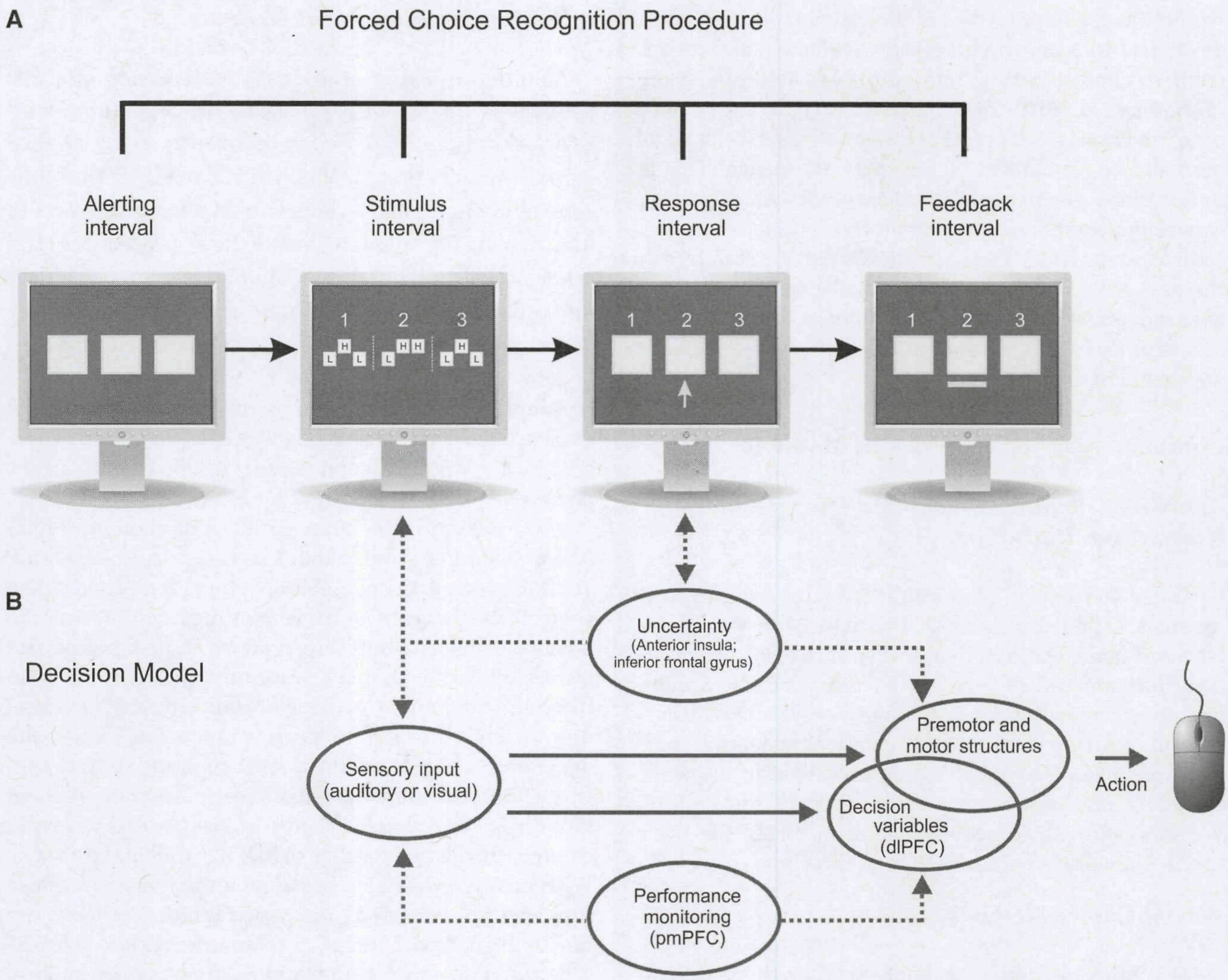

Figure 3. *A*: Temporal sequence of a computer-controlled forced recognition procedure. The computer monitor to the far left begins with an alerting interval, which is separated in time and followed by a stimulus interval, then a response interval, and finally a feedback interval. Whether to use feedback is typically based on the experimenter's discretion and/or the experimental question under consideration. In this example, a three-element binary frequency pattern is shown within a three-interval forced-choice (3IFC) paradigm. The task is to pick the frequency pattern that is different from the other two. In the first interval of the stimulus presentation, the frequency pattern is low-high-low; in the second interval, the frequency pattern is low-high-high, and in the third interval, the frequency pattern is low-high-low. The correct choice is interval 2, illustrated by the white arrow in the response interval. In the feedback interval, a white bar under the choice illustrates the correct answer. If the correct answer was different than the one selected, then the correct answer (interval) would be identified. *B*: Box diagram of processes and neural mechanisms involved in decision making within a behavioral forced-choice procedure (adapted from Heekeren et al, 2008).

Over the years, our group has successfully applied various adaptive procedures in a variety of experimental paradigms, in different age groups (adults and children), and in different clinical populations (those with and without brain damage, in those with reading disabilities, and in different otopathologic conditions, etc.). Our extensive experience allows us to advocate for their use in the clinical setting by providing examples in a wide variety of applications, including assessment of auditory and visual recognition memory and serial position effects (McFarland and Cacace, 1992), memory decay (Cacace and McFarland, 1992), memory span of binary sequential auditory and visual patterns and in visual-spatial stimuli in adults following temporal lobectomy for intractable epilepsy (Cacace et al, 1992), in tests of multimodal dual-task interference (McFarland and Cacace, 1997), in temporal-order discrimination in normal adults (McFarland et al, 1998), in remediation resistant reading impaired children with dyslexia (Cacace et al, 2000), in an adult with brain damage due to Moyamoya disease (Setzen et al, 1999), and in assessing the pitch and loudness of gaze-evoked and cutaneous-evoked tinnitus (Cacace et al, 1994, 1999).

In a recent paper, O'Beirne et al (2012) apply adaptive forced-choice methodology to a traditional low pass filtered speech test commonly used in APD test batteries.

However, rather than presenting filtered speech stimuli at a single arbitrarily cutoff value and using percent correct based on an arbitrary number of stimulus presentations to evaluate performance, O'Beirne and colleagues use an adaptive procedure that alters the corner frequency of the filter during testing. With this approach, the outcome variable is the low frequency cutoff value in Hz determined at a criterion level of performance. The assumption underlying this methodology is that individuals with APD will require more bandwidth than those without the disorder, and presumably this approach will help to separate normal from disordered groups. In a preliminary study using adults (n = 33; mean age 28.5, ±9.4 yr) and children (n = 30; 10.1, ± 1 yr) with no known history of listening or motor-skill difficulties, the authors found that adults performed better than children on this task. They argue that maturation of the CNS is involved in performance (note: subjects with presumed CAPD were not tested). While their adaptive approach is novel, altering the spectral and/or temporal aspects of stimuli in APD assessment (filtering, time compression, use of competing messages or noise, simultaneous presentation of different stimuli to separate ears, and so forth) is not unique. The approach of degrading stimuli to limit redundancy and increase task difficulty has been used for over 40 yr as a way to challenge the processing resources of the auditory system (e.g., Berlin and Lowe, 1972; Hodgson, 1972) and falls under the rubric of "sensitization." The point of emphasis here is that the adaptive technique utilized by O'Beirne and colleagues is a positive step in the right direction; it is novel, avoids floor and ceiling effects, and allows for group comparisons to be made at a similar level of difficulty. However, the method does not go far enough, and other important issues remain to be studied. For example, when applied to APD, the issue of modality specificity has not been addressed or even alluded to by the authors. The analogy in the visual domain could be the spatial frequency requirements needed for recognizing letters or words, an important issue related to reading (Kwon and Legge, 2012). In this context, altering the low pass spatial frequencies of letters or words can be used to assess the degree of blur, which contributes to the recognition of orthographic symbols. In both instances, bandwidth is the dependent variable, which could be put under adaptive computer control.

As we have pointed out previously, mere indication that stimuli have been sensitized does not specify what processes are being affected by these stimulus-related alterations (Cacace and McFarland, 2006). Consideration must be given to the possibility that sensitized stimuli can also render these tasks sensitive to nonperceptual factors or processes, such as sustained or divided attention. This issue has also arisen in the visual literature, both with respect to an interpretation of the results and in acquiring skills or strategies related to perceptual learning (Bernard et al, 2012). Indeed, these inadvertent and unwanted side effects can add additional complexity to interpretation of test performance. Clearly, further research is needed in order to address these highly relevant questions.

Importance of Response Selection

When we consider various testing paradigms used in the assessment of APDs, as a whole, the type of response selection utilized has never received the detailed scrutiny that it deserves. *Response selection* refers to that part of the experimental task involved in the decision making process, which includes some form of coordinated motor activity that can be viewed on a continuum from simple to complex. In a forced-choice recognition task, the simplicity of a button press on a mouselike device, the button press on a voting box, or the use of touch screen technology can be applied to indicate the correct choice on a task. This is contrasted with the use of verbal reproduction of stimuli as an indicator of performance. Of course, we cannot eliminate the motor response entirely from the test situation; however, it can be minimized. Below, we provide several relevant examples to illustrate why the type of response selection utilized is an important factor in test design and discuss how, if not controlled properly, it can affect the interpretation of test results.

Take, for example, dichotic stimulus presentation in the free-recall format. In this paradigm, "verbal reproduction" is the most common form of response selection utilized, and this format is used almost exclusively in testing for APDs. Yet it is never mentioned as a potential confound and is almost never discussed when these types of data are being interpreted. We argue that if errors are manifest during free-recall, then it becomes difficult, if not impossible, to ascertain if the underlying problem resides on the input end (difficulty with encoding), on the output end (difficulty with motor sequencing abilities), or at the intermediary interface between input and output (difficulty with perceptual-motor integration or verbal-motor planning, etc.). Indeed, similar concerns have been expressed by Shriberg et al (2012) in the context of understanding underlying anomalies associated with childhood apraxia of speech.

In the majority of reports in the literature where dichotic listening experiments have used verbal reproduction as the form of response selection, a so-called right-ear advantage or left-ear disadvantage in test performance is often observed, recognizing of course that this "advantage or disadvantage" is *not* an absolute effect and that, often times, it is quite subtle or even reversed (see Speaks and Niccum, 1977; Efron, 1990). Using dichotic digits in the free-recall format where verbal reproduction was used as the mode of response selection, Moncrieff and Wilson (2009) showed distinct age-related changes of the right-ear advantage. The right-ear advantage was largest in 10- to 14-yr-olds but was reduced markedly in the 15- to 28-yr-old age groups. While the interpretation of this effect has been an issue of contention for many years, Lawfield and colleagues (2011) showed that when performances of dichotic-digit perception were compared using recognition rather than reproduction, the right-ear advantage was essentially eliminated in the recognition format, but it remained as a prominent feature when verbal reproduction was utilized. Such an effect, based simply on differences in response selection, alters markedly the interpretation of the results and challenges existing models and theories of dichotic listening (see Lawfield et al, 2011).

Another example concerns the response requirements of three-element binary frequency (pitch), intensity, or duration pattern tests used clinically. Even after we consider that eight stimulus combinations are possible given three-element binary patterns (2^3) and after eliminating all high and low sequential frequency pattern combinations (i.e., high-high-high/low-low-low), this test paradigm is more complicated than just a simple perceptual exercise. Figure 4 shows a block diagram conceptualizing hypothetical peripheral, central, and motor-processing requirements for this task. As shown, the individual is required to encode the stimuli, store the stimulus representation in working memory, assign a linguistic label to the individual stimulus elements, and then reproduce the entire sequence verbally. In the case of a binary frequency pattern consisting of two high and one low frequency tone (i.e., 1000 Hz, 1000 Hz, 500 Hz), the response requirement by the individual is to verbally reproduce the sequence using the linguistic labels "high, high, low." While other processing schemes could be envisioned, the figure illustrates our point. An alternative to attaching linguistic labels to stimuli is to ask participants to "hum" the sequence (e.g., Bellis and Ross, 2011). We contend that use of either verbal reproduction or humming as the mode of response selection are suboptimal approaches that are subject to interpretive error, and in our view, should be avoided. Similar to the arguments made above, when errors are made in the humming task, there is no clear way of localizing the site of processing dysfunction that would inform the tester regarding the authenticity of a perceptual dysfunction. Humming is not only a complex motor task, but it is also unduly subjective in terms of how correct or incorrect responses are scored by the tester. In the study of Bellis and Ross (2011), no criteria were proposed for evaluating the response components of the task, and consequently, there is no way to validate these results objectively in current implementations since they were obtained in real time. Obviously, these criticisms apply equally to duration and intensity pattern tasks as well. For example, consider the scenario whereby the participant encodes the sequence properly but lacks distinct musical skills, is a poor hummer, and cannot reproduce the sequence accurately; how then are the responses to be interpreted? Obviously, this is an open question. However, it is one that can be easily avoided if a recognition paradigm in a forced-choice format is utilized!

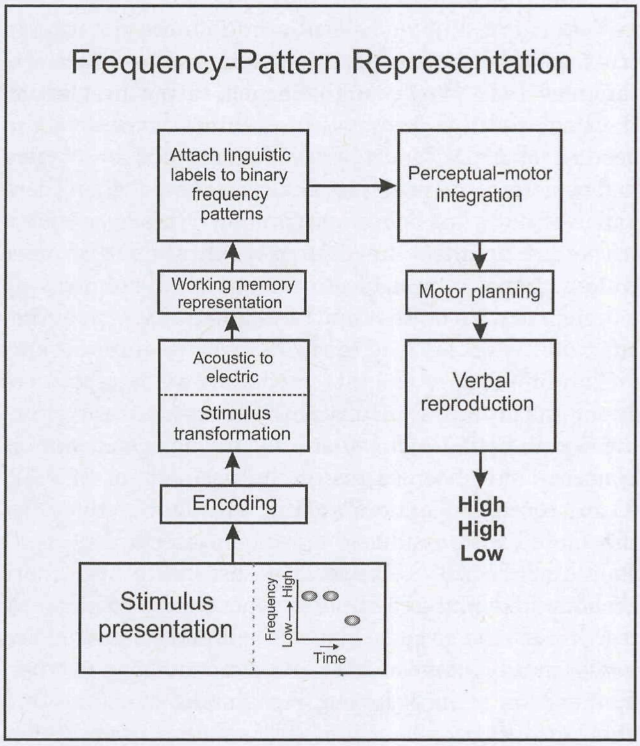

Figure 4. Box diagram of hypothetical processes related to frequency pattern performance using the clinical convention of three-element binary frequency patterns and reproduction-mediated response selection (Musiek, 1983).

While considering that use of reproduction-based response selection tasks leaves much to be desired in behavioral testing formats of APD, the forced-choice paradigm is the logical alternative that should be embraced and endorsed. Indeed, new and important information is being gained on perceptual decision making during a simple forced-choice task (e.g., Heekeren et al, 2008; Hare et al, 2011). Using a systems neuroscience approach, Heekeren and colleagues (2008) propose the architecture of a distributed neural system that fills the gap between stimulus representation and response selection (see Figure 3B). For example, under conditions of stimulus uncertainty, it has been proposed that when additional attentional resources are required for perceptual judgments, the anterior insula and inferior frontal gyrus (IFG) can be engaged. Another system, involving the posterior medial prefrontal cortex (pmPFC), detects when errors occur and actively adjusts decision strategies in order to maximize performance. Thus, the accumulation of sensory information through serial and parallel pathways is used by the dorsolateral prefrontal cortex (dlPFC) to compute a decision and activate a motor response. Thus, even with the simplest forced-choice recognition paradigm, complex brain systems appear to be involved in the decision process and in the response. Given that the intent of APD tests is to measure perceptual abilities, there is *no* good reason for increasing the complexity of the task further by adding a complex motor component to the testing situation.

Furthermore, one might ask whether lateralization effects observed for dichotic listening or verbal reproduction performances used to codify frequency, intensity, pattern, or duration patterns are specific to verbal materials. Unfortunately, data addressing this issue is limited, due in large part to the fact that recognition and reproduction types of response selection strategies are *not* typically compared in the same experiment. However, there is a trend in the literature indicating that verbal stimulus materials might not be the crucial factor in this regard. Our observations in this area suggest that a more general "interference effect" is operating under these conditions. Using nonverbal auditory and visual memory tasks and binary sequential tonal and color patterns, we found that that the serial position of sequential items was affected by the type of response selection utilized (McFarland and Cacace, 1995b). Serial position effects of sequential material in sensory-memory experiments reflect higher performance on both the initial (primacy effect) and terminal items (recency effect) (McFarland and Cacace, 1992). In other experiments performed by McFarland and Cacace (1995b), the serial-position curve was found to be preserved when "recognition" was used as the form of response selection. However, when participants were asked to "reproduce" multiple-element binary frequency sequences, the recency effect of terminal items was eliminated. This result indicates that the use of reproduction-mediated response selection in tasks purported to assess sensory processes adds potential sources of variance to the data that are associated with "motor skills" rather than with "perceptual processes."

Optimizing Task Difficulty by Varying Sensory/Perceptual Dimensions

Many of the tests commonly used for the assessment of APD are given at a single, minimal level of difficulty, as already discussed vis-à-vis O'Beirne and colleagues (2012). This can result in ceiling effects where control subjects all have virtually the same perfect scores. Ceiling effects result in data with undesirable statistical properties and low reliability and sensitivity (Uttl, 2005). Another issue concerns whether assessments strategies should be concerned only with the *presence* or *absence* of a disorder, as in the use of receiver operating characteristics (ROCs) when assessing sensitivity and specificity of test results in the assessment of APD or in considering the effects of brain lesions. Some investigators make the assumption that "a clinical patient either has or does not have a disorder" (e.g., Musiek et al, 2011). However, many if not all human abilities are distributed across a range of values. Testing for peripheral hearing disorders is a good case in point. In the general population, peripheral hearing loss can range from mild to profound, with many levels in between. Obviously, testing absolute thresholds at only one sound level (e.g., 20 dB HL) might be useful to screen individuals for the presence of normal or abnormal hearing sensitivity, but it would obviously fail to characterize the range of sensitivities distributed across individuals.

Nevertheless, when measures of SDT like ROCs are applied to real-life situations as noted above, a "gold standard" is required to distinguish normal from pathologic conditions. In this context, Swets (1988) has maintained that "good test data can be very difficult to obtain" owing to problems with the "truth" against which a diagnosis is made. Thus, applying SDT when it is not known with certainty whether a case is positive or negative with respect to a particular diagnostic classification in question can be problematic. In this situation, four ideals have been proposed when evaluating the genuineness in classifying normal from pathologic conditions (Swets, 1988). They include: (1) adequacy of truth, (2) independence of truth determination and system operation, (3) independence of truth sample and system operation, and (4) representation of the sample. With respect to the first ideal, the tester should know with certainty whether tests accurately classify individuals with respect to the trait in question; here a "gold standard" is required. The second ideal suggests that truth should be determined without regard to the system's operation. In other words, if accuracy of measurement is scored against a determination of truth set forth by an erroneous classification scheme, then accuracy will be inflated and viewed more generously then it actually is. The obvious example here is the comparison between the inclusive unimodal framework with the stronger concept of modality specificity used in the assessment of APD (Cacace and McFarland, 2012). Ideal three refers to the fact that procedures used to establish the truth should not affect the selection of cases under consideration, and ideal four reflects the fact that the sample of test items should reflect, in an equitable manner, the population of cases to which the diagnostic system is applied. As we have noted above, auditory processing abilities lie along a continuum, rather than being delineated into two exclusive categories; disordered or not disordered.

Another issue arises if one wishes to compare test scores in a profile, as with testing for modality specificity or perhaps in characterizing subtypes of APDs. In this case, it is desirable that the tests be psychometrically matched. Unless tests are matched in terms of features such as level of difficulty and reliability, any differences observed between tests might simply be due to these characteristics rather than aspects of the test that the examiner is interested in evaluating (Mungas et al, 2003). These concerns are better controlled with adaptive forced-choice testing than with traditional formats.

Ideally, task difficulty is varied by some perceptual characteristic of the stimulus. Consider, for example the use of multiple digits in the dichotic-digits task. With only a single pair of digits, performance is generally perfect or near perfect in most individuals. In order to make the task more difficult, multiple digit pairs are used (e.g., Musiek, 1983). In this case, the number of items to be stored in working memory (memorized) is increased in order to avoid perfect performance in all subjects. However, this approach makes the test much more sensitive to individual differences in memory. If the desire is to study memory, then a simpler task could have been constructed using binaural presentation of material. Alternatively, if a test of dichotic listening is presumed to be a measure of central masking, then some other characteristic of the stimulus that affects its discriminability should be varied (see Hugdahl et al, 2008). Thus, in "sensitizing" a test, care should be taken to ensure that what is being accomplished conforms to the intent of the experimental design.

Summary

Auditory processing disorders are best conceptualized as latent traits that are assessed by tests that are subject to error. Since tests vary in the extent to which they are influenced by many factors other than what they are intended to measure, and because there is not a one-to-one correspondence between test scores and what the tests actually measure, paying more attention to these "other variables" will improve test construction and implementation measurably. Fortunately, modern computerized technology makes the presentation of complex auditory and visual stimuli much easier than in the past. Improvement in theory and obtaining a valid diagnosis could have several important advantages. Most notably, construct validation, if successful, could provide a crucial step for inclusion of the APD by major classification systems of disorders and diseases (DSM-IV-TR [American Psychiatric Association, 2000]; ICD-10 [World Health Organization, 1992]) and could lead to third-party reimbursement of services, which either does not exist (see Aetna Insurance, 2011) or, as noted by some, can be a very difficult process to both navigate and justify (e.g., Tillery, 2009, p. 638; Academy, 2010).

CONCLUSION

Using computer-controlled forced-choice psychophysical methods provides a platform for structuring APD testing paradigms in a simple and unambiguous manner. Minimizing memory and attentional demands, avoiding floor and ceiling effects, ensuring the appropriate level-of-difficulty across tests, improving test efficiency, controlling decision processes (response criterion or response bias), limiting the use of motor processes in response selection, and applying the concept of modality specificity, are methodological considerations of test design that can help to eliminate ambiguities of interpretation, avoid unwanted confounds, delineate perceptual from cognitive processes, and avert indeterminate diagnoses. In combination, addressing these issues can transition the field to a new and improved era of audiological assessment. Finally, to emphasize and reiterate a crucial theme presented throughout, if the modality specificity of the deficit cannot be demonstrated with any degree of certainty in assessment of APD, then there seems to be no basis for concluding that the patient has an auditory-perceptual disorder. A situation most people in this field would wish to avoid.

NOTES

1. Theoretical constructs are also referred to as "latent traits"; a "latent variable" is a variable that cannot be directly observed. This is in contrast to "manifest variables," or ones that can be directly measured. As a theoretical construct, (auditory) perception can serve as a potential explanation of behavior, although it is not itself a behavior.
2. The inclusion criteria used to diagnosis of CAPD was based on the performances on two or more tests of central auditory function falling below cutoff values imposed.
3. In this context, sensitivity represents the proportion of individuals correctly diagnosed out of the total diagnosed whereas specificity represents the proportion of individuals not diagnosed out of the total who do not have the disorder.

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