The Importance of Modality Specificity in Diagnosing Central Auditory Processing Disorder

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Purpose: This article argues for the use of modality specificity as a unifying framework by which to conceptualize and diagnose central auditory processing disorder (CAPD). The intent is to generate dialogue and critical discussion in this area of study.
Method: Research in the cognitive, behavioral, and neural sciences that relates to the concept of modality specificity was reviewed and synthesized.
Results: Modality specificity has a long history as an organizing construct within a diverse collection of mainstream scientific disciplines. The principle of modality specificity was contrasted with the unimodal inclusive framework, which holds that auditory tests alone are sufficient to make the CAPD diagnosis. Evidence from a large body of data demonstrated that the unimodal framework was unable to delineate modality-specific processes from more generalized dysfunction; it lacked discriminant validity and resulted in an incomplete assessment. Consequently, any hypothetical model resulting from incomplete assessments or potential therapies that are based on indeterminate diagnoses are themselves questionable, and caution should be used in their application.
Conclusions: Improving specificity of diagnosis is an imperative core issue to the area of CAPD. Without specificity, the concept has little explanatory power. Because of serious flaws in concept and design, the unimodal inclusive framework should be abandoned in favor of a more valid approach that uses modality specificity.

Key Words: central auditory processing disorder, modality specificity

New discoveries, technical innovations, and novel ideas are some of the driving forces behind the advancement of science. A key building block in this process is the interchange of information. Information exchange allows for debate, discussion, and, in many instances, resolution of often contentious and highly charged issues, so that new ground can be broken and science can progress. Common modes of interchange include podium and poster sessions at scientific meetings, publications in peer-reviewed journals, books, book chapters, magazine and newspaper articles, and, most recently, postings on the Internet. Publication in peer-reviewed journals is considered the hallmark of scientific information exchange, in large part because peer review by experts in the field is a sine qua non for demonstrating the quality of work and the novelty of ideas. Although the peer review process is not perfect, it has stood the test of time and remains an important element in establishing the credibility of any form of scientific inquiry. As part of scientific inquiry, information evolves through various stages of development: from the idea stage, to the experimental stage, to the consensus stage, and ultimately to the knowledge stage. Attainment of the knowledge stage of development means that the idea has been accepted and validated. Although reaching the knowledge stage is time- and labor-intensive, obtaining convergence by multiple independent investigators is worth the effort. Validation therefore remains an important final hurdle to be surmounted before new constructs can be introduced into science (Campbell & Fisk, 1959). Consequently, when the knowledge stage is reached, the boundaries of the archival literature expand and the historical record adds another

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element to its repository from which to build upon. It is at this point in the scientific process that information can be broadly disseminated so that society at large can benefit from this achievement. Clearly, this is a dynamic process that continuously evolves as new information is incorporated into the knowledge base.

Although books have been written, committees have been formed, and consensus conferences have been convened, central auditory processing disorder (CAPD) has *not* reached the knowledge stage of development. In our view, this area of inquiry has stalled somewhere between the experimentation and consensus stages of development. This state of affairs is a dual-edged sword: On the positive side, it offers a unique opportunity for researchers to study and refine this topic; however, for clinicians, educators, and students, it is problematic because in many instances the information content currently found in books offers a dubious representation of how CAPD should be conceptualized and diagnosed. The stalling of the field at this stage of development also affects how students are taught and how clinicians are trained. Related issues, such as management and treatment of CAPD, are often discussed, but validated models do not yet exist. Indeed, books and book chapters that have been written on this topic are still based largely upon "expert opinion." In the present health care environment, where evidence-based medicine is becoming the standard of care, policy decisions based on expert testimony alone do not carry the same weight that they once did. This holds true for evaluation and treatment and for third-party reimbursement.

In sum, there are many issues of contention and general lack of agreement on various topics in the area of CAPD, due in large part to reliance on expert opinion rather than on controlled experiments. Testing paradigms used by many in this field are similar to those proposed more than 50 years ago. Therefore, it can be argued that ideas and beliefs that are still used to characterize the area of CAPD have outlived their usefulness. This apparent unwillingness to accept change has contributed to the area of CAPD becoming stagnant and has thwarted its development such that the field has not progressed in any meaningful way. Our interest is to change this position and redirect research efforts in a positive direction. The concept and application of modality specificity is one way to achieve this goal and to allow for the area of CAPD to move forward.

Modality Specificity as a Criterion for Diagnosing CAPD: The Underlying Logic

In order for specific topics to be studied with precision and rigor, it is important to have a definition that is unambiguous and straightforward, one that allows hypotheses to be tested and diagnoses to be made. We take the position that a key conceptual element for differentiating CAPD from other conditions is derived from the premise that CAPD represents an auditory perceptual dysfunction; accordingly, we argue that perceptual dysfunctions are modality specific (McFarland & Cacace, 1995b). Based on this idea, we assert that the primary deficit in CAPD should be linked directly to the processing of acoustic information; deficits should *not* be apparent (or at least should be manifest to a lesser degree) when similar types of information are presented to other sensory modalities. Therefore, CAPD should be distinguishable from cognitive, language-based, and/or supramodal attentional problems in which modality-specific perceptual dysfunctions are not expected. Following this logic, we define CAPD as a *modality-specific perceptual dysfunction* that is not due to peripheral hearing loss.[1] However for this approach to be effective, multimodal testing is necessary. This requires an orientation for assessment of CAPD that is different from what is commonly employed. Although there are other approaches to CAPD diagnosis, we believe that this is the simplest and most direct to implement clinically. We also emphasize that this position does *not* exclude the possibility of modality-specific linguistic or nonlinguistic processes, attention, memory, and so on (McFarland & Cacace, 1995b).

The rationale for adopting modality specificity as a criterion for diagnosing CAPD is based on the assumption that any given test can be affected by multiple factors (Cacace & McFarland, 1998; McFarland & Cacace, 1995b). For example, even a simple detection experiment can be viewed as reflecting multiple factors. Signal detection theory (Green & Swets, 1974) holds that the subject's behavior is a joint function of sensitivity to the physical stimulus and a subjective criterion. The utility of this distinction has been demonstrated by showing that the detection of a stimulus in noise is influenced by factors such as monetary contingencies. This illustrates that there is not a one-to-one correspondence between a subject's behavioral response and sensitivity to a specific stimulus. More complex "sensitized" tests, often used in CAPD assessment, introduce the potential for additional factors to influence performance. Indeed, factors such as attention, motivation, and the complexity of the motor response may not involve central auditory mechanisms. One way to evaluate the impact of such supramodal processes is to systematically vary the nature of the stimulus while holding all other factors constant. For example, discrimination performance on auditory frequency pattern tasks can be contrasted with discrimination performance on visual color-pattern tasks (e.g., Cacace, McFarland, Emrich, & Haller, 1992; McFarland & Cacace, 1997). If reduced performance is due to auditory-specific processes, then the deficit seen on acoustic versions of the task should be greater than that seen when other stimulus modalities are used. In this way, dissociation between performances on parallel versions of a task using different stimulus modalities can be established.

[1]This position is concordant with the definition of CAPD originally proposed by McFarland and Cacace (1995b) and one that was embraced by participants involved with the Bruton Consensus Conference, ca. 2000 (Jerger & Musiek, 2000, p. 468). The Bruton Consensus Conference also suggested that use of the term CAPD be replaced with the term *auditory processing disorder* (APD; Jerger & Musiek, 2000). The change in terminology was suggested to maintain an operational definition, so as to avoid imputation of anatomic locus, and to emphasize interactions between peripheral and central sites. Nevertheless, an operational definition of APDs may not be appropriate. Furthermore, knowledge of the neuroanatomical basis of any disorder of the central nervous system would ultimately be beneficial (see McFarland & Cacace, in press). In this article, we will use the term CAPD. Other authors may use or prefer the alternative term APD. We view these terms as being equivalent, and the arguments presented here apply to both.

When this is done, interpretations of deficient performance in terms of supramodal, cognitive, and/or linguistic processes can be ruled out.

The efficacy of audiologic testing can be evaluated by means of clinical decision analysis. Turner (1988) discussed an example of this approach by considering the differential diagnosis of cochlear and retro-cochlear lesions. This analysis combined audiologic data with near-definitive radiological tests. In this way, a 2×2 contingency table can be assembled, whereby hits, misses, false alarms, and correct rejections are tabulated. A receiver operating characteristic (ROC) curve can then be constructed by varying the criterion for acceptance of a positive result, so that data can be summarized in terms of *d* prime (d'). Based on signal detection theory, the information value of a diagnostic system increases as the ROC curve deviates from chance performance, that is, as d' increases in magnitude.

However, a key requirement for applying signal detection theory to evaluate the efficacy of a diagnostic system is knowing with certainty whether every item in the test sample is a positive or negative with respect to the topic or disorder of interest (Swets, 1988). Therefore, "adequacy of truth" is a problem for clinical decision analysis when a gold standard is lacking. Consequently, the analysis can be no better than the accuracy with which positive and negative cases are identified. Under these conditions, signal detection theory cannot be expected to provide a valid measure of a test's accuracy (McFall & Treat, 1999).

The field of CAPD lacks a gold standard against which to evaluate proposed tests. As a result, tests of auditory processing are frequently evaluated by imprecise criteria, such as their ability to detect "suspected" or "presumed" cases of CAPD (Keith, 1986). Singer, Hurley, and Preece (1998) applied clinical decision analysis to evaluate the utility of auditory processing tests. Their analysis combined a CAPD test battery with the presence or absence of presumed CAPD. Positive cases were children who "had a history of reading problems and difficulty following verbal directions and paying attention in class" (Singer et al., 1998, p. 75). The resulting analysis indicated that the test battery was able to identify children with a history of learning problems. However, the issue of whether these learning problems were due to auditory processing problems was not addressed by this kind of analysis. The authors noted that the CAPD group "did not constitute a gold standard" (Singer et al., 1998, p. 82). In instances where differences in performance on auditory tests were observed between a group of children with suspected APD and normal controls, the need for documenting specificity of the deficit and explicating differences between groups remains as a shortcoming of the unimodal approach to testing (Vanniasegaram, Cohen, & Rosen, 2004). Furthermore, the use of questionnaire-based screening tools for suspected cases of APD has *not* been encouraging (Meister, von Wedel, & Walger, 2004), and these authors question the validity of this approach. They call for "clearer definition of subjects with APD and the development of standardized, multimodal tests" (Meister et al, 2004, p. 436).

Modality specificity can serve as a means of differentiating auditory processing problems from more generalized supramodal dysfunction. However, modality specificity alone cannot serve as a gold standard for an APD, since it does not ensure that deficient performance is actually associated with a meaningful disability. A modality-specific effect could potentially be a trivial effect. In order to be useful clinically, a test of auditory processing should be able to predict performance on current or future behaviors that are of practical relevance and are ecologically valid. A highly relevant example illustrating this concept is based on results of a large-scale, multiyear project among school-age children, undertaken to establish which sensory (auditory and visual), linguistic, and cognitive abilities were predictive of future academic success in reading, mathematics, and overall academic achievement. With respect to performance on commonly used tests in the assessment of CAPD, Watson et al. (2003) found that measures of auditory processing were not highly predictive of future academic skills. In comparison with other measures, CAPD tests accounted for very little variance in academic achievement.

Experimental Approaches: Dissociation and Double-Dissociation Designs

Multimodal testing can demonstrate the modality-specific nature of CAPD by dissociating performance on tasks in different sensory modalities. This approach assumes that distinct abilities can be inferred when performances on comparable auditory and visually presented tests are evaluated. Use of the dissociation design addresses the issue of discriminant validity; that is, does the test in question measure a construct distinct from other constructs? Indeed, the dissociation and double-dissociation designs have been used widely in the cognitive and neuropsychological literature specifically for this purpose. In addition to revealing distinct abilities, the double-dissociation design has the potential to demonstrate both the sensitivity of the task and the specificity of the deficit under consideration (Teuber, 1955).

The dissociation design has been used to demonstrate the modality-specific nature of CAPD. For example, Cacace et al. (1992) found a double disassociation for tests of auditory and visual pattern recognition in individuals with temporal lobe lesions. In one individual, recognition memory was normal for visual color-pattern sequences but abnormal for auditory frequency-pattern sequences. In a second individual, recognition memory for visual color-pattern sequences was abnormal while memory for auditory frequency-pattern sequences was normal. The results provide evidence that visual and auditory pattern sequences are sensitive indices of two distinct abilities. Moreover, Jerger, Weikers, Sharbrough, and Jerger (1969) demonstrated modality specificity of CAPD more than 25 years ago, in a hallmark case study of bilateral temporal lobe lesions secondary to sequential occlusions of the left and right middle cerebral arteries. They showed that temporal lobe lesions led to impaired speech intelligibility, intensity discrimination, temporal order discrimination for pitch, and spatial localization abilities. In this example, multimodal testing was used to evaluate whether impaired performance on the auditory spatial-localization task was modality specific or represented a more generalized deficit that also included impairment in the judgment of angles. Normal performance on an analogous visual-perceptual task allowed these investigators to conclude that the auditory localization deficit was a modality-specific effect. As a result, Jerger et al. (1969) distinguished themselves from other early workers in this area by the strategic application of multimodal testing to clarify the modality specificity of test performance. Thus, in the examples discussed above, the proof of principle was confirmed, the logic of applying psychometrically matched auditory and visual tests was demonstrated, and a precedent was established for the use of this approach on a larger scale.

McFarland and Cacace (1995b) discussed three categories of individuals who perform poorly on tests involving the processing of auditory information. The first category performs poorly only with test materials that use auditory stimuli. This group represents CAPD in its "purist" form. The second category consists of individuals with auditory perceptual problems that coexist with other specific processing problems. This group would be expected to have a mixed pattern of deficits. The third category includes individuals who perform poorly on tests of auditory processing, not because they have auditory perceptual problems, but because of global supramodal problems involving factors such as motivation, attention, or language skills. Individuals in this latter group would be expected to perform poorly on tests that use either auditory or visual stimuli. The important point of emphasis here is that these three examples cannot be discriminated unless multimodal testing is performed.

Through the use of comparable tasks in multiple sensory modalities, dissociation of function can be observed, and the modality-specific nature of the deficit can be ascertained. The idea underlying this approach is to keep visual and auditory tests similar in all respects other than for sensory modality. In this way, method effects can be evaluated, and specificity of processing deficits can be either established or rejected.

We next discuss illustrative examples of multimodal tasks that have been developed to enhance specificity of CAPD diagnosis. What differentiates these tasks from commonly used audiotape or CD procedures is that testing is under computer control and tasks are embedded within forced-choice psychophysical paradigms. Several design features are noteworthy; forced-choice methodology provides a criterion-controlled estimate of performance and minimizes response bias (Green & Swets, 1974). Testing emphasizes recognition rather than reproduction, which avoids measuring characteristics of motor systems (Tattersall & Broadbent, 1991) and thus serves to minimize issues of interpretation related to the role of motor abilities (McFarland & Cacace, 1995b). Adaptive forced-choice methodology is particularly noteworthy for the clinical arena because of efficiency of design, simplicity of instructions, and avoidance of floor and ceiling effects during testing. These factors also ensure that task difficulty is appropriate for a wide range of individuals. Taken together, these design features and their underlying rationale minimize the role of nonperceptual factors and therefore are well suited for clinical CAPD assessment.

A relatively simple but potentially powerful approach to multimodal testing uses binary sequential stimulus patterns to evaluate temporal order discrimination. In this way, frequency and intensity features in the auditory domain can be contrasted with size, orientation, and color features in the visual domain (e.g., McFarland, Cacace, & Setzen, 1998). These binary, sequential, multimodal temporal order tasks are both appealing and well suited for use in CAPD assessment because they are applicable for use with children, adults, and individuals with brain damage (Cacace, McFarland, Ouimet, Schrieber, & Marro, 2000; McFarland et al., 1998; Setzen et al., 1999). In addition, these tasks may help to clarify specific issues related to language, reading, and cognitive dysfunctions. In this context, when multimodal temporal order tasks were applied to the study of information processing in reading impaired children, it was found that perceptual deficits underlying their problem were neither modality specific nor temporal specific (Cacace et al., 2000).

Additionally, we have shown that auditory and visual pattern sequences can be used to assess other areas relevant to CAPD. One particular area of interest is in the assessment of auditory memory. Memory is a logical area to study because it underlies all aspects of life and figures prominently in contemporary theories of cognition (e.g., Baddeley, 1976; Cowan, 1984, 1988), and because research has shown that auditory and visual sensory memory stores can be dissociated (Colombo, Rodman, & Gross, 1996). Binary pattern sequences in multiple modalities can be used (a) to assess sensory memory capacity by obtaining sequence length thresholds (span lengths); (b) to measure memory decay using auditory sequential, visual sequential, and/or visual spatial stimuli; (c) to measure serial position effects; and (d), with dual-task designs, to measure modality-specific processes (Cacace & McFarland, 1992; Cacace et al., 1992; McFarland & Cacace, 1992, 1995a, 1997).

Of course, testing need not be limited to nonverbal stimuli. The assessment of speech in noise commonly used in CAPD assessment (Keith, 1986) can also be integrated into a multimodal framework by including comparable tasks in the visual domain. Recent work by Chung, Levi, Legge, and Tjan (2002) and Pelli, Levi, and Chung (2004) provides examples of techniques used to evaluate perception of degraded text in patients with amblyopia. Like CAPD, perceptual characteristics, which define amblyopia, are not completely understood but appear to have a central visual system origin. Chung et al. (2002) and Pelli et al. (2004) examined effects of low-pass filtering and of adding noise on the identification of visual letter stimuli. These tasks can be viewed as analogues to low-pass filtered speech and speech-in-noise tests. Conceivably, tests employing degraded visual text and auditory speech material could be developed to provide a means of examining modality specificity. Moreover, the testing protocol could be simpler than that described by Chung et al. (2002) and Pelli et al. (2004), since the goal here would be to rule out the involvement of supramodal effects, rather than to characterize the nature of complex visual disturbances, such as amblyopia. To facilitate the development of tests in the visual domain, a powerful visual psychophysics toolbox is available (e.g., Brainard, 1997; Harley & Lofus, 2000). Voyer and Boudreau (2003) used a dichotic listening task with consonant vowel syllables and an analogous visual dichoptic test to demonstrate concurrent validity of these tasks across modalities. They found that dichotic and dichoptic tasks appear to measure different underlying processes. If validated, such multimodal tasks may also be well suited for use in a CAPD test battery. Ideally, such tests of auditory and visual perceptual abilities should be reliable; they should also predict performance in relevant real-life situations, and they should allow for the assessment of modality-specific effects.

The dissociation design has been criticized because it depends on the concept of modularity (Van Orden, Pennington, & Stone, 2001). The concept of modularity is based on the premise that there are independent subsystems that can be characterized by a specific domain under which they operate. A strong form of the modularity hypothesis holds that components are encapsulated, in the sense that they interact only when one component completes its processing and makes the end product available to the next set of components. Fodor (1983, 1985) argued for the concept of encapsulated modularity, suggesting that it is particularly well suited to perceptual systems. As discussed by Farah (1994), this assumption of locality is not necessary. In a more general sense, modularity may reflect a "considerable division of labor among different parts of a functional architecture" (Farah, 1994, p. 59). However, this does not rule out the possibility that dynamic interactions between subsystems occur.

The utility of the double-dissociation design continues to be debated; in fact, an entire issue of the journal *Cortex* was devoted to this topic (Dunn & Kirsner, 2003). Lyons (2003) suggested that complete independence introduces an element of idealization. He noted that overlap and independence can occur in degrees. The question can then be framed in terms of how distinct two systems are. In the case of specific modules related to reading, current evidence for modularity may well be tenuous (e.g., Van Orden et al., 2001). However, the modularity of auditory processing may be a more reasonable assumption. Research in neuroscience clearly points to the existence of a central system specialized for auditory processing.

Polster and Rose (1998) reviewed the utility of the modularity concept in APDs. They noted that several distinct disorders of auditory processing have been documented in the literature. These include cortical deafness, pure word deafness, auditory agnosia, and phonagnosia. In each of these disorders, dissociations have been demonstrated. For example, pure word deafness refers to the inability to comprehend spoken words despite intact reading ability. This dissociation between auditory and visual language comprehension indicates that distinct mechanisms are involved in auditory and visual processing of language.

As we have noted previously (McFarland & Cacace, 1995b), it is not certain to what extent similar dissociations can be shown in other populations suspected of having CAPD, such as children with learning disabilities or the elderly. With respect to the elderly, Humes (2005) has directly challenged the unimodal approach to testing and questions whether this framework is capable of delineating perceptual from cognitive processes. Indeed, his data on more than 213 participants provide a compelling argument for the use of multimodal testing in order to better delineate perceptual from cognitive processes. Validation of the utility of CAPD as an explanation for the problems seen in learning disabilities and the elderly will require research that demonstrates dissociations between performances on tasks using stimuli in multiple sensory modalities. This is an extremely important point, since the viability of the CAPD concept depends upon the demonstration that distinct auditory abilities exist in these populations. If deficits in these populations occur equally with auditory, visual, and tactile stimuli, then one cannot rule out supramodal factors as contributing to deficient test performance. Consequently, it follows that evidence would be insufficient to describe such dysfunction as being "auditory" in nature.

If subjects with lesions to the auditory nervous system are used to validate tests of CAPD, then it is important to ensure that damage is limited to areas exclusively involved in auditory processing. Most clinical cases involving lesions of the brain do not have localized damage (McFarland & Cacace, 1995b). As a result, human lesion studies have not been entirely effective in validating CAPD. In contrast, modality specificity provides an objective criterion that is well suited in cases when imprecise criteria (suspected or presumed cases of CAPD) are involved or when the effects of a brain lesion are at issue.

While demonstration of modality specificity ensures that a test measures auditory perceptual processes rather than supramodal processes, it does not ensure that a test is able to predict performance on relevant measures of function. In our view, in order to be a useful index of an APD, it should be possible to show that deficits on tests of auditory processing are modality specific, are reliable, and are able to predict performance of behaviors related to a relevant outcome such as school performance or activities of daily life. Thus, modality specificity is one of several important criteria necessary for establishing the utility of a test of auditory processing.

Modality Specificity From a Neurobiological Systems Perspective

From a developmental neuroscience viewpoint, the feature that all sensory systems have in common is the general segregation of each receptor at the most peripheral level of processing. Segregated input continues through tracks and nuclei in the brainstem to thalamocortical projection areas, where modality-specific features are mapped onto the primary sensory areas of the temporal, parietal, and occipital lobes. This architectural design holds true for tonotopic features of the auditory system (e.g., Merzenich & Brugge, 1973; Merzenich, Knight, & Roth, 1975), for retinotopic features of the visual system (e.g., Mason & Kandel, 1991), and for various somatotopic features of the somatosensory system (e.g., Kaas & Pons, 1988). It is also well established that this organizational pattern begins at a very early stage of human development, when neurons from different sensory receptors migrate to targeted modality-specific cortical areas, as the organism develops. Indeed, in brains of vertebrate and invertebrate organisms, modality specificity is an established feature, and the columnar organizational pattern found at the primary cortical level is a documented principle of design. The modality-specific nature of cortical columns has been clearly observed in single-unit neurophysiological studies of the postcentral gyrus in somatosensory areas (e.g., Mountcastle, 1984; Powell & Mountcastle, 1959) and is probably best known from the Nobel Prize–winning work of Hubel and Wiesel (1977) in the striate cortex, visual area V1. The auditory cortex is also characterized by a similar modality-specific organization. In addition to an orderly tonotopic organization, which is observed orthogonal to the isofrequency dimension, spatially segregated bands of excitatory and inhibitory areas related to binaural information processing (Merzenich, Colwell, & Andersen, 1982) exist in organized columns (Schreiner, Read, & Sutter, 2000) with distinct bandwidths, intensity thresholds, and cell assemblies representing phase and intensity maps (Imig & Adrian, 1977; Razak & Fuzessary, 2000).

The Evolution of the Unimodal Inclusive Framework

In a recent review (McFarland & Cacace, in press) and in a previous section of this article, we discussed what might be the first application of multimodal assessment of central auditory function, based on a case study of bilateral temporal lobe lesions (Jerger et al., 1969). The compelling argument made then is directly pertinent to present-day discussions; that is, the rationale for multimodal assessment is to delineate a modality-specific process from more generalized dysfunction. Although the logic was in place and the principle tested many years ago, it is not entirely clear why most researchers instead chose a path that limited the evaluation process of CAPD to a "unimodal" framework, which by default has taken on an "inclusive" point of view. Here, we refer to this construction as the unimodal inclusive framework. Proponents of the unimodal framework argue that performance on auditory tests alone provides sufficient evidence to diagnose an audition-specific dysfunction. This viewpoint is reflected in a technical report developed in 1996 by a committee from the American Speech-Language-Hearing Association (ASHA). This report defined CAPD as a deficit in one or more of the following central auditory processes: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance with competing acoustic signals, and auditory performance with degraded acoustic signals. The report stated that CAPD often coexists with more global dysfunction (i.e., attention or linguistic deficits) that may affect performance across modalities. The ASHA report also stated that the issue of whether a child has a language disorder or a CAPD is often impossible to resolve and, further, that this distinction is not important for planning intervention. However, we contend that an APD is modality specific, while a language disorder is not. Furthermore, the most effective interventions will be based on accurate knowledge of the problem (Friel-Patti, 1999). Thus, the issue of specificity should not be ignored. Therefore, we contend that the unimodal inclusive framework and the views held within the 1996 ASHA technical report are problematic for several reasons: (a) the modality-specific nature of auditory-based speech, language, and learning problems has seldom been established; (b) the technical report failed to address how the specificity of the deficit is to be determined; and (c) the report failed to take into account misclassification of individuals whose deficits were not perceptual in nature (Cacace & McFarland, 1998).

Concern About Use of Sensitized Tests: What Do They Measure and What Do They Predict?

In the assessment of CAPD, so-called sensitized tests of auditory function are commonly applied. The implication is that simpler measures are inadequate, because lesions of the central auditory nervous system are typically unaffected by simple monaural tasks due to the redundancy (crossed and uncrossed nature) of ascending auditory pathways. This conceptualization has provided the rationale for increasing the complexity and reducing the redundancy of test stimuli, as means to uncover the effects of lesions. The term sensitized refers to the modification of stimuli, such that certain dimensions of the stimulus have been altered in some way, so as to challenge the processing resources of the auditory system. Sensitization can include alterations to stimuli by filtering, time compression, reverberation, and/or use of ipsilateral or contralateral competing messages or noise (e.g., Berlin & Lowe, 1972; Hodgson, 1972). If monaural or binaural (diotic or dichotic) stimulus presentation is pursued, then how the stimuli are routed or switched between the ears also becomes a relevant issue. However, mere recognition that stimuli have been sensitized does not specify what processes are affected by these alterations or what brain areas are involved. Therefore, consideration must be given to the possibility that sensitized stimuli render these tasks vulnerable to nonperceptual factors (Cacace & McFarland, 1998, in press). As a consequence, these inadvertent and potentially unwanted side effects can add an additional degree of uncertainty to the interpretation of test performance and thereby obfuscate differential diagnosis.

Arguments Against the Use of Modality Specificity in CAPD Diagnosis

Whereas we have advocated multimodal testing as a means by which to clarify issues in the relationship between CAPD and other disorders (Cacace & McFarland, 1998, in press; McFarland & Cacace, 1995b), some authors have raised objections to this approach. For example, Keith (1999) asserted that the construct of CAPD proposed by Cacace and McFarland (1998) is exclusive, since it includes only nonlinguistic factors and "limits the approach to assessment and remediation that professionals would take" (p. 340). Likewise, Bellis and Ferre (1999) contended that our "unitary view of CAPD as a deficit in the processing of acoustic-phonetic features of speech is unrealistically narrow" (p. 319). Neither of these statements, however, adequately describes our position. In fact, Keith's assertion is inaccurate. In our initial review of this topic, we discussed in detail modality-specific language disorders such as pure word deafness (McFarland & Cacace, 1995b). Contrary to the contention of Bellis and Ferre (1999), we have previously discussed modality-specific disorders, such as auditory agnosia, that are not language specific (McFarland & Cacace, 1995b).

An update of the 1996 ASHA technical report on APDs rejects outright the use of modality specificity as a criterion for the identification of APDs and continues to support the unimodal inclusive framework (ASHA, 2005). The updated ASHA technical report maintains that modality specificity, as a diagnostic criterion, is "neurophysiologically untenable" (p. 2). It states that the literature in neuroscience indicates that there are "few, if any, entirely compartmentalized areas in the brain that are solely responsible for a single sensory modality" (p. 2). This document cites the work of Poremba et al. (2003) and Salvi et al. (2002) as evidence in support of this statement.

Our view of the neuroscience literature is fundamentally different. We do recognize that sensory input can be "modulated" by concurrent stimulation from other sensory modalities and/or by top-down influences such as attention. However, these modulatory aspects of brain function do *not* negate the concept of modality specificity. Indeed, interaction and integration of information among and between sensory modalities is a hallmark of higher cortical functions; on a scale of phylogenetic development, such processing is characteristic of more evolutionary advanced organisms. Association areas of the brain are important for this purpose and serve as an interface to motor areas, so that action can be taken by the organism when necessary. At present, it is reasonable to state that we do not have a clear understanding of how multisensory integration is accomplished. Research laboratories around the world are actively pursuing this issue, and available evidence suggests that steady progress is being made. Below, we elaborate on our position and show that the concept of modality specificity has a long and robust history in mainstream philosophy, psychology, medicine, and neural science.

First, we consider the specific studies cited by the updated technical report on APD (ASHA, 2005). Poremba et al. (2003) examined glucose use in rhesus monkeys in response to passive listening as a means of mapping the auditory system. These authors described modality-specific areas such as the supratemporal plane and contrasted them with areas that overlap with visual areas mapped in a prior study (Macko et al., 1982). These include the superior temporal sulcus (STS) and the intraparietal sulcus, which are probably involved in multisensory integration. Clearly, this reference described both auditory-specific and polysensory regions of the cortex. Salvi et al. (2002) examined positron-emission tomography (PET) activations in response to speech, noise, and speech in noise. They described their results as showing activations in auditory and motor areas for repetition of words in quiet, and as additionally involving linguistic, attentional, and cognitive areas involved in the perception of speech in noise. Note that neither Poremba et al. (2003) nor Salvi et al. (2002) made any specific arguments against the existence of specialized auditory areas.

Modality Specificity in the Neurosciences

The basis for classification of stimuli in terms of specific types of energy is well established in modern physics (Urone, 1986). Indeed, it is noteworthy that even philosophers have a long tradition of being interested in modality specificity, largely from the vantage point of whether the senses should be considered as anchors of knowledge or as sources of its contamination (De Gelder & Vroomen, 1994). The idea of separate senses can be traced to Aristotle (trans. 1951). Aristotle distinguished between sense-objects particular to a single sensory modality (e.g., only sight perceives color) and those common to all (e.g., both sight and touch perceive movement). Cajal (1988) described visual, acoustic, somatosensory, gustatory, and olfactory cerebral territories. Even Lashley (1931), who is known for his theory of mass action and equipotentiality, subscribed to the concept of specific sensory projection fields. In his classic text on the history of psychology, Boring (1950) reviewed the concept of modality specificity in a chapter on specific energies of nerves and concluded that the division of perception by senses is a fundamental principle of classification. Moreover, the concept of modality specificity continues to be used by theorists and investigators in the cognitive and neural sciences. Indeed, modality specificity serves as an organizing principle in the domains of neurophysiology, neurology, cognitive neuroscience, and cognitive psychology. The broad application of this concept may be due to the ease by which stimuli can be identified in terms of their modalities, as well as the fact that peripheral receptors initiating the sensory transduction process are so obviously distinct. In any case, modality specificity is one of the few concepts common to these diverse fields.

In neurophysiology, for example, the neocortex has traditionally been divided into sensory, association, and motor areas. Thompson, Johnson, and Hoopes (1963) described modality specificity in the electrophysiological response of single units as a criterion for identifying primary sensory cortex. Thompson et al. noted that differentiation between sensory and association cortex can be made easily and with complete reliability. Likewise, Mountcastle (1997) described modality specificity as a defining characteristic of sensory cortex. Recently, Wallace, Ramachandran, and Stein (2004) examined sensory responsivity of cortical neurons in rats. They found that "multisensory" neurons were rare within the major modality-specific domains. Instead, they found that multimodal neurons were concentrated in polysensory regions located at the boundaries of modality-specific areas. Therefore, their work suggests a cortical organization in which polysensory regions are located between modality-specific sensory areas.

Standard textbooks in neurology adhere to the parceling of cortex into sensory, association, and motor areas (e.g., Adams & Victor, 1989; Krieg, 1966). Mesulam (1998) also describes modality-specific impairments, such as pure word blindness and pure word deafness, that are due to disconnections of primary sensory areas. According to Mesulam (1998), "one of the most important principles in the organization of primate cerebral cortex is the absence of interconnections linking unimodal areas that serve different sensory modalities" (p. 1023).

Investigators in the area of cognitive neuroscience also use the concept of modality specificity as an organizing principle. For example, Booth et al. (2002) examined functional magnetic resonance imaging (*f*MRI) activations during judgments of semantic relatedness of words presented in the visual or auditory modality. In this work, both modality-specific and polysensory activations were observed. Auditory-specific activations were observed in the superior temporal gyrus, visual-specific activations were observed in the fusiform gyrus, and polysensory activations were observed in the left inferior frontal gyrus. Using PET, Bright, Moss, and Tyler (2004) obtained similar results with semantic categorization and lexical decision tasks. Schacter, Dobbins, and Schnyer (2004) reviewed evidence for stimulus, associative, and response specificity in priming. They noted that support for the existence of modality specificity in priming comes from human studies of individuals with mesial temporal lobe amnesia who show robust within-modality priming but deficient cross-modal priming.

Cognitive psychologists also make use of the concept of modality specificity. For example, Barsalou, Simmons, Barbey, and Wilson (2003) discussed theories of cognition in which knowledge is viewed as residing in an amodal semantic system that is separate from modality-specific perceptual systems. They contrasted this view with evidence suggesting that modality-specific systems are involved in the representation of conceptual knowledge. Tsapkini, Jarema, and Kehayia (2004) discussed a model of lexical processing that involves modality-specific representations at a surface level with modality-independent representations at a deeper level.

As these diverse examples illustrate, the idea of distinct sensory modalities has been pervasive across time and is currently pervasive across various disciplines in the sensory, cognitive, and neural sciences. However, some authors have questioned the utility of such a distinction (e.g., Shimojo & Shams, 2001). Pertinent to their argument are studies based on cross-modal interactions that occur, for example, with multimodal temporal order judgments, motion perception, and the so-called McGurk effect. Because the updated ASHA technical report (ASHA, 2005) focused on the McGurk effect, we discuss it next.

In the McGurk effect, visual lip movements associated with a speech token have been shown to alter the identification of a different auditory speech token, when the two stimuli are presented concurrently (McGurk & MacDonald, 1976). This and other paradigms have been used to artificially impose conflict between sensory modalities as a means of studying cross-modal interactions and as a way to gain insight into processing stages of multisensory integration (Shams, 2002). Likewise, visual speech in the form of congruent lip movements observed concurrently with a degraded auditory message (i.e., acoustic speech presented in the presence of background noise) can serve to enhance speech perception (e.g., Schwartz, Berthommier, & Savarizux, 2004; Sumby & Pollack, 1954). Some investigators view the McGurk effect as evidence that low-level auditory perceptual processes are modified by visual stimuli; an alternative interpretation is that the results of low-level modality-specific auditory and visual processes are associated at more abstract levels (Bernstein, Auer, & Moore, 2004).

Grant, van Wassenhove, and Poeppel (2004) have examined the effects of temporal synchrony on judgments based on cross-spectral and cross-modal cues. This work involves assessment of temporal asynchrony between narrow bands of audio speech and between audio and visual speech tokens. They cite work by Silipo, Greenberg, and Arai (1999) that found a narrow and symmetrical function relating recognition to the degree of temporal asynchrony between audio bands. Work by Grant and Greenberg (2001) showed that the function relating audio and visual asynchrony to recognition was much broader and asymmetric. In the study by Grant et al. (2004), these differences between auditory-auditory and auditory-visual synchrony effects were replicated using judgments of synchrony. Thus, observers are much more sensitive to temporal disparities between audio bands than they are to temporal disparities between audio and visual tokens. These differing time constraints suggest that different processes are involved in auditory and in auditory-visual stimulus processing.

Several neuroimaging studies have examined cortical activation during McGurk-type experiments, thus allowing for previous "black box" models to be examined more comprehensively. Using PET and *f*MRI, Sekiyama, Kanno, Miura, and Sugita (2003) found unimodal activations for acoustic speech stimuli in superior temporal cortex and for visually presented letter stimuli in middle temporal areas. In addition to these areas, bimodal stimuli activated an area of the STS. Using *f*MRI, Wright, Pelphrey, Allison, McKeown, and McCarthy (2003) observed that the response to bimodal stimuli in the STS was greater than that to either modality alone. They characterized STS as a polysensory area, in contrast to unimodal auditory and visual areas. Using PET, Macaluso, George, Dolan, Spence, and Driver (2004) systematically varied spatial and temporal overlap between visual and auditory presentations of words. A 240-ms asynchrony is outside the temporal window for McGurk-like effects, while a hemifield mismatch produces a "ventriloquism effect." Macaluso et al. found that temporal asynchrony affected the left STS while spatial asynchrony affected the right parietal lobe. Van Attevekit, Formisano, Goebel, and Blomert (2004) also presented temporally congruent and incongruent letters and speech sounds. They found the STS to be most sensitive to congruent pairs of stimuli. Some areas on the superior temporal cortex also responded preferentially to congruent pairs, but these were posterior and lateral to primary auditory cortex. Thus, McGurk-like effects appear to recruit polysensory regions such as STS. Interestingly, STS is located between superior temporal auditory areas and midtemporal visual areas, an organization consistent with the model of polysensory organization of Wallace et al. (2004) discussed earlier.

The model of Belin, Fecteau, and Bedard (2004) is useful in conceptualizing auditory-visual interactions.

These authors suggest that low-level (i.e., modality-specific) auditory and visual analyses are combined in separate polysensory streams that analyze speech, affect, and recognition of personal identity. Other available research, based on functional imaging studies, suggests that primary auditory cortex is not a critical element during visual speech perception (e.g., Bernstein, Auer, Moore, Ponton, & Don, 2002). Convergence of emotional facial expression with voices occurs in polysensory areas of the brain (Pourtois, de Gelder, Bol, & Crommelinck, 2005).

Whereas the McGurk effect appears to recruit brain areas characterized as being polysensory, there have been reports of activations in primary auditory areas during silent lipreading (e.g., Calvert et al., 1997; Pekkola et al., 2005). Differences in auditory cortex activation observed between Bernstein et al. (2002) and Pekkola et al. (2005) cannot be accounted for by increased magnetic field strength (3.0 T vs. 1.5 T), because Calvert et al. (1997) detected activation of auditory cortex at 1.5 T. Therefore, other alternative explanations, such as the use of subvocalization during visual speech perception, may be contributing. In this respect, it should be noted that sensory and association areas are differentiated by the criterion of modality specificity. Brain areas such as Heschl's gyrus and the medial geniculate nucleus are appropriately classified as parts of the central auditory system to the extent that they are specialized for processing auditory stimuli and because, by and large, they do not respond to stimuli in other modalities. The relevant question here concerns the distance into the central nervous system over which modality specificity is maintained. Although we cannot say for certain, it is probable that there is not a sharp demarcation, so that some border areas will be found to be mainly, but not entirely, sensitive to auditory stimuli (i.e., predominantly specialized for auditory processing and driven mainly by auditory stimuli), while others will not.

Even peripheral receptors are known to be sensitive to alternative forms of energy, as when mechanical force imparted to the retina causes the sensation of light (phosphenes). This exceptional case does not negate the fact that the retina is specialized for processing light and that its activity is largely determined by light (i.e., the adequate stimulus is light). It merely illustrates that the design of visual receptors is not perfect. Likewise, Heschl's gyrus is probably specialized for processing sound, and the firing of neurons in this region is highly dependent upon the acoustic environment.

However the issue of where and when information from the separate senses is combined in the nervous system does not speak to the issue of modality specificity or to the utility of this important concept. Multimodal processing may occur relatively early, or it may occur later in time. Likewise, multimodal processing may involve primary sensory cortex, or it may be largely restricted to higher order sites. This issue of early versus late fusion of input from different sensory modalities is currently the subject of much experimentation and debate. The eventual outcome of this issue will determine whether modality-specific processes are best seen as being restricted to early, low-level processes or whether they might also apply to later, higher level processes. It is our contention that this issue will determine the extent of the domain of CAPD, an issue that remains to be resolved.

Summary

Anatomical and physiological investigations point to the existence of neural systems specialized for the processing of auditory information. Concepts of modality-specific processes, such as auditory perception, are useful in accounting for behavioral effects and are consistent with the idea that there are modality-specific human abilities. We have emphasized throughout this document that unless supramodal factors are ruled out as alternative explanations, diagnosis of a perceptual disorder in general, or an auditory perceptual disorder in particular, cannot be made with any degree of certainty. The utility of the unimodal inclusive framework for diagnosing CAPD is questionable since test paradigms restricted to auditory stimuli alone result in an incomplete assessment and an indeterminate diagnosis. Stated differently, auditory testing is a necessary but *not* a sufficient means for making the CAPD diagnosis. For these reasons, we argue that because of serious flaws in concept and design, the unimodal inclusive framework should be abandoned in favor of a more valid approach. We contend that modality specificity is a pertinent core issue for validating the CAPD concept and should be a criterion for diagnosis. Indeed, if the auditory system were not modular in a general sense, then the concept of an APD would *not* be meaningful. If the symptoms of an APD have no specificity, then use of CAPD as a diagnostic label has little, if any, explanatory power. However, this does not appear to be the case. Modality specificity continues to be an important organizing concept in a diverse collection of disciplines. In order for the field to progress in a meaningful way, efforts should be made to evaluate the extent to which modality-specific effects can be documented in suspected or presumed cases of CAPD.

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