

Central Auditory Processes and Test Measures: ASHA 1996 Revisited

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The theoretical issues surrounding central auditory processing disorders (CAPD) are reviewed here, especially with reference to the central auditory behavioral processes and the auditory test measures as prescribed in the ASHA (1996, *American Journal of Audiology*, 5(2), 41–54) statement on CAPD. A simplified nomenclature is recommended that directly relates process and test measure to facilitate the diagnostic process in CAPD. This new terminology closely follows the ASHA (1996, *American Journal of Audiology*, 5(2), 41–54) document, but provides some refinement based on recent research in CAPD. To support this recommendation, a confirmatory factor analysis (CFA) was applied to the findings of Domitz and Schow (2000, *American Journal of Audiology*), who

proposed use of a battery of CAPD tests, the Multiple Auditory Processing Assessment (MAPA) for testing school children. The CFA was found to reinforce the four-factor model, which clearly emerged in the exploratory factor analysis of Domitz and Schow. The model was found to be reasonably consistent even when subtests from the SCAN were included in the analysis. Refinement and revision of ASHA (1996, *American Journal of Audiology*, 5(2), 41–54) is recommended to facilitate diagnosis, subclassification, and intervention for CAPD.

Key Words: central auditory processing disorders, CAPD, SCAN, MAPA, factor analysis, diagnosis

Central auditory processing disorder (CAPD) remains a challenging condition to diagnose, largely because of the purported comorbidity with associated conditions (e.g., attention deficit hyperactivity disorder, learning disabilities, speech-language impairment) and the diversity of signs and symptoms associated with it. Moreover, there is no clear acceptance of a “gold standard” test battery for assessment.

We want to reopen discussion concerning the ASHA task force’s proposed terminology for measures of CAPD (ASHA, 1996) in light of our recent findings (Schow & Chermak, 1999; Domitz & Schow, 2000) and based on a confirmatory analysis within this article. The ASHA Task Force on CAPD issued a technical report (ASHA, 1996) that has provided a useful framework for clarifying issues surrounding CAPD. One key component of this report

listed six behavioral phenomena that characterize auditory processing and defined CAPD as an observed deficiency in one or more of them. Although this definition was specific and useful, the relationship between processing phenomena and test measures was left somewhat unresolved in that only five behavioral auditory procedures were listed to measure the six areas in question. Further, the five auditory measures did not correspond in a simple way to the behavioral processes listed (see Table 1).

Specifically, “sound localization and lateralization” (Item 1), from the list of behavioral characteristics, matches with the second task “localization and lateralization” identified from the auditory measures, and “temporal aspects” (Item 4) from the behavioral characteristics list matches, presumably, with “temporal processes” (Item 1) from the list of auditory measures. Beyond these easily

TABLE 1. Behavioral processes and auditory test measures (ASHA Task Force on CAPD, 1996).

Behavioral processes
1. Sound localization and lateralization
2. Auditory discrimination
3. Auditory pattern recognition
4. Temporal aspects of audition, including resolution, masking, integration, and ordering
5. Auditory performance decrements with competing acoustic signals
6. Auditory performance decrements with degraded acoustic signals
Behavioral auditory test measures
1. Temporal processes: ordering, resolution, integration, and discrimination
2. Localization and lateralization
3. Low redundancy monaural speech (e.g., time compressed, filtered, interrupted, competing)
4. Dichotic stimuli including nonsense syllables, digits, words, and sentences
5. Binaural interaction procedures (e.g., masking level differences [MLDs])

defined matches there is no definite correspondence between behavioral phenomena and measures. It may not be possible to match precisely behaviors and test measures given that these processes are interdependent. Any one test of CAPD typically requires the listener to invoke multiple central auditory processes to successfully complete the task. For example, the Pitch Pattern (PP) task requires auditory discrimination, temporal ordering, and pattern recognition. Similarly, the Masking Level Difference (MLD) task requires binaural interaction and temporal processing. Nonetheless, we submit that this lack of correspondence between process and test makes the clinician's diagnostic task all the more difficult.

Two recent studies (Domitz & Schow, 2000; Schow & Chermak, 1999) have allowed us to perform factor analysis on some of the more common behavioral measures. In Schow and Chermak (1999), exploratory factor analysis was performed on 331 children ages 6 to 17 years who had received the three subtests of SCAN (Keith, 1986) and two "subtests" (right competing and left competing) of the Staggered Spondaic Word (SSW) test (Katz, 1968). Two factors emerged from all five subtests, which were identified as "binaural competition" involving SCAN-Competing Word (CW), SSW-Right Competing (RC), and SSW-Left Competing (LC) and "monaural low redundancy" (separation/closure), which included SCAN-Auditory Figure Ground (AFG) and SCAN-Filtered Word (FW). In Domitz and Schow (2000) the SCAN subtests were administered to 81 third grade students, yielding three scores along with the Multiple Auditory Processing Assessment (MAPA) battery of tests (a monaural Selective Auditory Attention Test [mSAAT], Pitch Patterns [PP], Dichotic Digits [DD], and Competing Sentences [CS]). The MAPA yielded eight scores. When the eight subtests of MAPA were subjected to exploratory factor

analysis, four factors emerged: auditory pattern/temporal ordering (APTO), monaural separation/closure (MSC), binaural separation (BS), and binaural integration (BI). These four factors were expected, based on the suggestion of Chermak, Styer, and Seikel (1995) and Musiek and Chermak (1994) that these four tests allow us to evaluate different levels/processes within the auditory system. When the three SCAN subtests were subjected to exploratory factor analysis along with mSAAT and CS, two factors emerged. This finding was consistent also with the results from Schow and Chermak (1999). However, when all 11 subtests were factor analyzed, the expected four-factor structure did not emerge so cleanly.

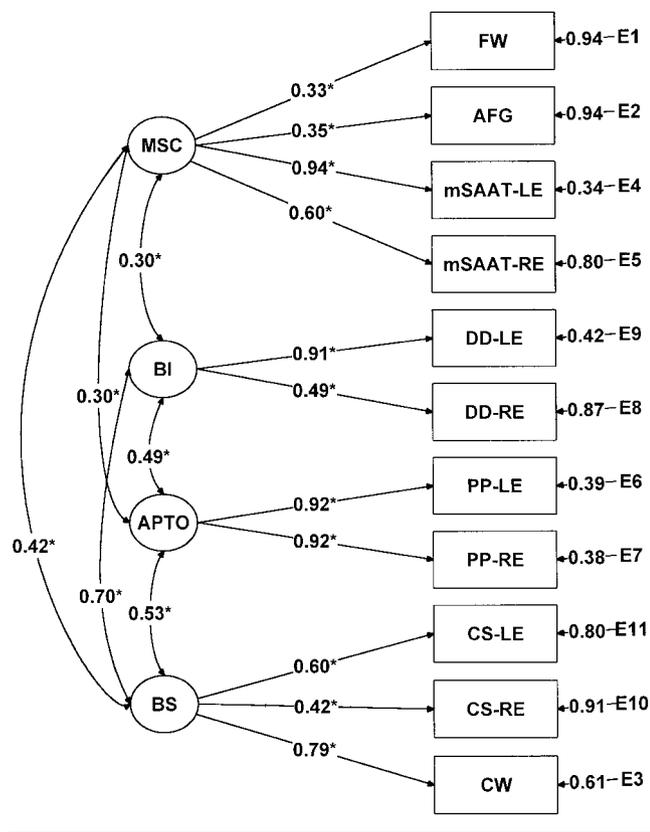
An alternative to the exploratory factor analyses described above is confirmatory factor analysis (CFA). A CFA has a few advantages over exploratory techniques. First, CFA is able to examine how well an existing theoretical model can replicate observed data. In contrast, exploratory techniques are best suited to the development of models. Given that the previous exploratory factor analyses had generated a reasonable model, testing that specific model seems an appropriate next step. Second, CFA will generate indices describing how well a specified model reproduces observed data. Many of these indices are not available with exploratory factor analysis. Although the best-fitting model will emerge from an exploratory analysis, the technique will not indicate how well that model actually fits. Third, exploratory factor analysis extraction and rotation methods are used to identify the model from an infinite number of possible models. An infinite number of possible solutions increases the probability that the final solution will depend on chance characteristics of the data. Because a CFA specifies a final solution a priori, CFA results are less likely to capitalize on chance characteristics of the data. As such, CFA results are likely to be more generalizable than exploratory results. Finally, all scores load on all factors in exploratory factor analysis. This strategy theoretically means that each of the 11 tests examined in our previous exploratory analyses is influenced by all four of the factors that emerged. Specifying a CFA model requires identifying the factors that will influence each observed score. Generally, any observed variable will be influenced by one, or a few, factors. The resulting CFA models are thus more parsimonious and interpretable.

Confirmatory Factor Analysis

Given the modest instability of the exploratory factor analysis mentioned earlier, data from Domitz and Schow (2000) were reanalyzed using a CFA. To capitalize on the advantages of this technique, we enlisted the participation of a psychologist/statistician experienced in factor analysis and in test development. The analyses reported below are the result of our collaboration. Some additional information is provided with CFA results because these techniques have not often been reported in our literature.

The previous exploratory analyses suggested that four factors influence the 11 auditory processing tests examined by Domitz and Schow (2000). Those four factors are

FIGURE 1. Parameter estimates for the four-factor solution ($.05$ level of significance). LE = left ear, RE = right ear; FW = SCAN filtered word subtest; AFG = SCAN auditory figure ground subtest; mSAAT = monaural Selective Auditory Attention Test; DD = dichotic digits; PP = pitch patterns; CS = competing sentences; CW = SCAN Competing Words subtest; MSC = monaural separation/closure; BI = binaural integration; APTO = auditory pattern/temporal ordering; BS = binaural separation.



MSC, BI, BS, and APTO. Each factor was clearly linked with both right ear (RE) and left ear (LE) results from one test when the eight MAPA subtests alone were examined. When the SCAN subtests were added, most auditory processing subtests continued to be influenced by a single factor. The PP tests loaded mostly on the APTO factor, the mSAAT tests loaded mostly on MSC, and the DD tests loaded mainly on BI. However, there were four exceptions: The CS scores, SCAN-AFG and SCAN-CW, seemed to load on multiple factors. In short, the factor structure showed more uniformity when the SCAN tests were not included with the other eight subtests.

For the CFA we specified a model in which each test loaded on one of the four factors, and factors were allowed to covary. Freeing the factors to covary creates a problem if SCAN-CW tests, for example, were allowed to load on both the BS and BI factors, and the earlier factor findings did at times show CW linkage with each of these. Essentially, any relation between the BS and BI could be accounted for by a ϕ coefficient (the correlation between model factors) or by the fact that both factors are being determined by the same observed variables. To

overcome this problem, SCAN-CW scores were allowed to load only on the BS factor. Figure 1 illustrates the relations among the four auditory processing factors (identified by circles) and 11 auditory processing subtests (identified as squares). The figure also indicates the influence of unique factors (identified as E's) on the 11 subtests.

The CFA used maximum likelihood procedures to generate standardized parameter estimates for the model, and those estimates are listed on each line in Figure 1. The values on the curved bidirectional arrows among the four factors are the ϕ correlation coefficients, and the asterisks indicate which of those coefficients are statistically significant at $\alpha = .05$. Those correlations range from 0.30 (the correlation between MSC and BI as well as the correlation between MSC and APTO) to 0.70 (the correlation between BI and BS), and all six correlations among the four factors are statistically significant. The coefficients on the unidirectional arrows from the factors to the subtests are the factor loadings, and squaring a factor loading provides an index of the proportion of a subtest's variance explained by the corresponding factor. For example, the loading of BI on DD-LE is 0.91. This value indicates that approximately 83% of the variance in DD-LE scores is accounted for by the BI factor. As was the case with the ϕ Phi coefficients, all 11 loadings are statistically significant. Thus, each subtest was significantly influenced by the hypothesized underlying factor. Finally, the values on the unidirectional arrows from the unique factors (E's) are the disturbance loadings, and squaring those loadings indicates the amount of unexplained subtest variance. For example, the disturbance factor loading for DD-LE is 0.42, indicating that approximately 18% of the variance in DD-LE scores is influenced by a factor (or factors) other than BI. Because disturbance variance may be simultaneously produced by multiple causes (e.g., random measurement error or other latent factors) tests of statistical significance are inappropriate. In sum, the model in Figure 1 suggests all correlations among the factors as well as all loadings of factors on subtests were statistically significant.

More important than the parameter estimates given in Figure 1 is the comparison between the subtest correlation matrix predicted by the Figure 1 model and the actual correlation matrix. The data analyzed by the structural equation model are the 55 correlations among the 11 subtests, and the 11 subtest variances. That is, the data are the entries in an 11 subtest correlation matrix (Table 2). The values on the diagonal are the standardized variances, whereas the entries under the diagonal are the subtest correlations. Because all correlations above the matrix diagonal are redundant with those below, only those 55 below the diagonal were analyzed. The structural equation model analysis generates predicted scores for each subject on each of the four factors. The predicted factor scores and path coefficients are then used to generate predicted subtest scores for each subject. The correlations among the 11 predicted subtest scores are then compared with the actual correlations among the 11 subtests in order to generate omnibus indices for the model. A good model will result in only small differences between

TABLE 2. Observed correlations among the 11 subtests

	FW	AFG	CW	mSAAT-LE	mSAAT-RE	PP-LE	PP-RE	DD-LE	DD-RE	CS-LE	CS-RE
FW	1.00 (1.00)										
AFG	.35 (.12)	1.00 (1.00)									
CW	.24 (.11)	.28 (.12)	1.00 (1.00)								
mSAAT-LE	.31 (.32)	.31 (.33)	.37 (.31)	1.00 (1.00)							
mSAAT-RE	.11 (.20)	.26 (.21)	.27 (.20)	.57 (.56)	1.00 (1.00)						
PP-LE	.31 (.09)	.13 (.10)	.35 (.39)	.31 (.26)	-.03 (.17)	1.00 (1.00)					
PP-RE	.18 (.09)	.16 (.10)	.36 (.39)	.25 (.26)	.06 (.17)	.85 (.85)	1.00 (1.00)				
DD-LE	.15 (.09)	.06 (.10)	.50 (.50)	.25 (.26)	.11 (.16)	.42 (.41)	.41 (.41)	1.00 (1.00)			
DD-RE	-.02 (.05)	.05 (.05)	.31 (.27)	.26 (.14)	.27 (.09)	.21 (.22)	.16 (.22)	.44 (.44)	1.00 (1.00)		
CS-LE	.06 (.09)	-.10 (.09)	.46 (.48)	.11 (.24)	-.18 (.15)	.31 (.29)	.28 (.30)	.47 (.38)	.14 (.21)	1.00 (1.00)	
CS-RE	-.07 (.06)	.11 (.06)	.33 (.33)	.17 (.17)	.18 (.11)	.36 (.20)	.32 (.20)	.11 (.26)	.14 (.14)	.32 (.25)	1.00 (1.00)

Corresponding predicted correlations are shown in parentheses.

LE, left ear; RE, right ear; FW = SCAN filtered word subtest, AFG = SCAN auditory figure ground subtest, CW = competing words, mSAAT = monaural Selective Auditory Attention Test, PP = pitch patterns, DD = dichotic digits, CS = competing sentences.

actual and predicted correlations among the subtests. A χ^2 statistic may be used to determine the likelihood that the predicted matrix is actually different from the observed matrix. Given an expectation of no difference between the two matrices, we anticipate a nonsignificant χ^2 . Unfortunately, the two matrices in our study were significantly different ($\chi^2 [39] = 81.36, p < .001$). This difference seems to suggest a poor model. However, χ^2 significance tends to be overly conservative, especially when applied to models with several observed variables (Tabachnik & Fidell, 1996). In our case, the model attempted to reproduce a matrix with 55 nonredundant correlations. Even at this level of significance (.001), chance sampling factors make it likely that some of the predicted correlations will be significantly different than the observed.

Because of the conservative nature of the χ^2 significance test, some have suggested using the ratio of χ^2 to degrees of freedom to determine a model's fit (i.e., how well a model is able to reproduce the observed correlation matrix). Generally, a χ^2/df ratio of ≤ 2.00 indicates a good model (Tabachnik & Fidell, 1996). In our CFA, the ratio was 2.09. Thus, our model comes very close to one of the criteria used to identify "good" models.

Several comparative fit indices have been proposed as omnibus evaluations of a model. Most of these are expressed on a 0 to 1 scale, with higher values (i.e., $>.90$) indicating good fits. All of the comparative fit indices were <0.90 for the model we tested. The non-normed fit index was 0.79, whereas the incremental fit index was 0.86 and the comparative fit index was 0.85. The Lisrel goodness-of-fit index (GFI) and adjusted GFI (AGFI) are comparable to R^2 and adjusted R^2 in regression (Joreskog & Sorbom, 1984). The model we tested yielded GFI = 0.86 and AGFI = 0.77.

Although the omnibus fit indices do not reach traditional levels associated with good models, the results are encouraging. To our knowledge, confirmatory analyses have not been used to test the factor structure underlying

central auditory processing subtest performance. Our finding that the four-factor model identified in previous research generates fit indices that are approaching traditional "good fitting" levels suggests we are on the right track. That is, we think the results somewhat bolster the argument that the 11 auditory processing subtests are actually assessing four different (but related) auditory processing factors. Hopefully, future research using similar confirmatory strategies will enable us to make conclusions about these ideas with more confidence. Future CFA studies could test other models such as a three-factor model, blending binaural factors (BS and BI) as suggested by some of our findings. Specifically, loadings of CS (which is considered a test of BS) and CW (which is often considered a test of BI) may ultimately comprise one binaural factor. However, the preponderance of data that we used supported four factors, so we have chosen to pursue that direction. As current tests are refined and when other combinations of tests are administered, this work of developing a standard battery and an accepted nomenclature can progress as well, but for now we have a start.

Conclusions

Given the reasonably consistent findings from these various factor studies, we propose an expanded nomenclature based on our results. Table 3 contains behavioral processes, categories of behavioral auditory measures, and examples of common tests that we have found within these categories, based on our revised schema.

From our data we have seen differentiation of four measurable behavioral processes through factor analysis using the common CAPD tests listed in Table 3. These processes are labeled as APTO, MSC, BS, and BI and involve pattern or temporal ordering, an MSC task and two binaural factors involving separation and integration. This approach involves two distinct binaural factors and their associated test measures. The present data clearly support the theoretical underpinning that prompted us to

TABLE 3. Behavioral processes and auditory test measures.

Measurable behavioral processes
1. Auditory pattern/temporal ordering
2. Monaural separation/closure (as required in low redundancy listening due to competition or degradation)
3. Binaural separation (directed listening and reporting of one or both ears in a precise order)
4. Binaural integration (nondirected listening and reporting of both ears)
Other measurable complex behavioral processes
5. Localization, lateralization, and/or binaural interaction
6. Auditory discrimination (as in same/different judgments in monaural speech recognition)
7. Other temporal aspects (e.g., gap detection/fusion, release from masking through phase shifting, duration judgments)
8. Others
Behavioral auditory test measures
1. Auditory pattern/temporal ordering (APTO) tasks (e.g., pitch patterns)
2. Monaural separation/closure (MSC) tasks (e.g., SCAN-auditory figure ground, SCAN-filtered word, or monaural Selective Auditory Attention test)
3. Binaural separation (BS) tasks (e.g., competing sentence) (SCAN-competing word or staggered spondaic word tests?)*
4. Binaural integration (BI) tasks (e.g., dichotic digits) (SCAN-competing word or staggered spondaic word tests?)*

*May be BS or BI

use both binaural tests. When more than the four tests of MAPA are used, the findings are not so clear cut, especially with respect to SCAN-CW, but even in view of this lack of clarity, nothing in our current study led us to conclude that a collapsed binaural factor would be more helpful. We were encouraged that through factor analysis we were able to support a rather straightforward correspondence between a subset of recommended auditory measures and auditory behavior.

We suspect that the other behaviors identified by the ASHA committee (numbered 5 through 7 in Table 3), underlie the first four in some less straightforward manner. That is, these processes are probably recruited to support the first four processes identified through factor analysis. Arguably, with the exception of temporal aspects, clinical audiologists do not generally assess and isolate these remaining behaviors in CAPD testing, and their linkage to the first four behaviors remains unclear. Hence, direct measures of these remaining behaviors do not appear in Table 3, except for temporal aspects. Localization and lateralization involve binaural interaction and will require more study to learn if they will factor separately and how they should be measured. Our impression is that auditory discrimination is a component of all the auditory phenomena. Nonetheless, it can be measured independently (e.g., the Wepman [1958] Auditory Discrimination Test). Similarly, temporal processes are clearly fundamental in auditory processing, responsible for marking distinctions, which are segmental (e.g., voice-onset time), as

well as helping decipher suprasegmental prosodic detail (e.g., rate, emotion, intonation, stress) (Phillips, 1999). Temporal processes underlie a number of auditory processes, including auditory discrimination, binaural interaction, pattern recognition, localization/lateralization, monaural low-redundancy speech recognition (e.g., compressed speech), and binaural integration. Given the influence of temporal processes across the spectrum of central auditory processes, one might expect a separate temporal factor besides pattern recognition to emerge, or alternatively, the temporal factor might merge within other factors. Additional research using factor analysis with a broader range of tests may clarify the role of temporal processing in central audition. Finally, under “others,” we might consider, for example, electrophysiological tests (e.g., Mismatch Negativity [MMN] P300), which involve another approach to assessing complex auditory phenomena (e.g., auditory discrimination via MMN), and which may, at some time, become a standard procedure in the central auditory test battery (McPherson & Ballachandra, 2000).

In conclusion, we want to open a dialogue within the profession and propose a modest revision of categories presented in the ASHA (1996) document. Our current proposed revision involves a clear linkage between the behavioral processes that characterize CAPD and some test measures of these behaviors. Such a revised categorization may permit refinement of procedures in assessment, perhaps allowing for subtyping of CAPD, and more targeted and efficacious intervention.

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