Article

Implications From Factor Analysis for Central Auditory Processing Disorders

Ronald L. Schow
Idaho State University, Pocatello

Gail Chermak
Washington State University, Pullman

Central auditory processing disorders among school-age children have been challenging to identify and treat. Many issues remain that need to be resolved. Here, we compare and contrast findings on 331 school-age children who were given two of the more common central auditory processing disorder tests (Staggered Spondaic Word [SSW] Test and the SCAN Screening Test for Auditory Processing Disorders). These results replicate and reinforce many of the psychometric findings reported earlier. The use of factor analysis with these test results was explored. Significantly, two factors emerged, including an auditory binaural separation from competition factor and a monaural low redundancy degradation factor. These findings help us define the nature of processes probed by the SCAN screening test and the SSW test. Furthermore, these findings clarify the use of SSW and SCAN because they showed both SSW Left Competing and Right Competing loading within the same factor, whereas the three subtests on SCAN sorted into two rather than three factors.

Key Words: central auditory processing disorders, factor analysis, SCAN, SSW

Central auditory processing disorders (CAPDs) are among the most challenging disorders facing the school audiologist and other professionals concerned with identification and rehabilitation of auditory disorders. CAPDs are defined by an American Speech-Language-Hearing Association (ASHA) consensus document as deficits observed 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, or auditory performance with degraded acoustic signals (ASHA, 1996; Chermak & Musiek, 1997). McFarland and Cacace (1995; see also Cacace and McFarland, 1998) suggest defining CAPD as a unimodal, auditory perceptual deficit, but they note that the modality-specific nature of such a construct has not been proven. This paper assumes instead that CAPD often coexists with more global dysfunction that may affect performance across modalities (e.g., attention deficit and linguistic deficit), as proposed by the experts from ASHA (1996).

Purported methods for identifying these youngsters are plentiful, but the audiologist is faced with a confusing and extensive array of tools for this purpose (Musiek and Chermak, 1994). Most of these tools have not been subjected to extensive psychometric validation. The Staggered Spondaic Word (SSW) Test (Katz, 1968) and the SCAN Screening Test for Auditory Processing Disorders (Keith, 1986) are in the top seven most frequently used tests, according to a recent report (Chermak, Traynham, Seikel, & Musiek, 1998), and they have received more statistical scrutiny than many others. For example, Keith (1986) presents validity and reliability data on the SCAN with a standardization sample of 1034 children. Other studies have examined the reliability and validity of the SSW (Hurley, 1990; Katz & Arndt, 1979). Nevertheless, several authors (Amos & Humes, 1998; Cacace & McFarland, 1995, 1998) have raised concerns about SCAN reliability and, indeed, the reliability and validity of all CAPD tests. Keith, Rudy, Donahue, and Katbamna (1989) examined the relationship between SSW and SCAN scores for a group of 154 school-age youngsters (6 through 15 years) who had been referred due to academic underachievement, poor classroom performance, and/or attentional limitations. This study gave percentile scores across the involved ages for both the SSW and SCAN. Significant correlations were found between the two tests and associated subtests.

Even when comparisons are possible with large data sets as noted above, many questions remain concerning identification of children with CAPD, including questions about the reliability and validity of commonly used tests. A major problem is that there is no generally accepted gold standard for such identification, and thus, it is impossible to select a sample of children who have confirmed CAPD using behavioral measures. In the absence of such a standard, some have selected a single test like the SSW and used it as a criterion measure (Bedient, 1992; Stecker, 1992). Others have used the composite score from the SCAN or parental reports of attention problems as a point of reference (Chermak, Styer, & Seikel, 1995). Using a physiological standard, Jerger, Johnson, and Loiselle (1988) compared the performance of children suspected of CAPD to children with confirmed central nervous system lesions on the Pediatric Speech Intelligibility Test. McFarland and Cacace (1995) (see also Cacace and McFarland, 1998) have expressed strong concerns about current tests that are being used to diagnose CAPD. They proposed tests in different modalities as a method for improving the specificity of diagnosing CAPD, but very little data on multimodality testing exist.

Musiek and Gollegly (1988) suggested that functional deficits in auditory processing may result from neurological disorders, maturational delays, or neurodevelopmental disorders. This categorization of causation seems to be increasingly accepted, but it further complicates the diagnostic picture (ASHA, 1996; Chermak et al., 1995). Beyond the issue of cause is the question of whether there is a discrete number of abilities involved in CAPD. Recently, there have been several multi-item schemes that purport to give a composite picture of the areas of concern in CAPD. According to Keith (1986), the SCAN subtests sample three different and important central auditory processing abilities that underlie the types of performance deficits that indicate CAPD. These areas include: Filtered Words (FW), Auditory Figure Ground (AFG), and Competing Words (CW). Musiek and Chermak (1994) proposed four procedures/tests to measure the relevant areas of CAPD in school-aged children, including the Dichotic Digits, Frequency (Pitch) Patterns, Pediatric Speech Intelligibility, and Competing Sentences Tests. These tests are used to sample processing behavior in the areas of binaural integration, temporal auditory pattern recognition, monaural degraded low-redundancy speech recognition, and binaural separation. Katz and Smith (1991) have proposed four major categories of auditory processing dysfunction: decoding, tolerance-fading memory, integration, and organization. They proposed using the SSW and two other tests for identifying these different forms of CAPD. For example, the decoding group reportedly performed poorly on the SSW Right Competing (RC) subtest (plus some abnormal Non-Competing, Order, and Ear Effects scores) and had a low score on phonemic synthesis tasks; the tolerance-fading memory group performed poorly on the SSW Left Competing (LC) subtest (plus some Order and Ear Effects) and had severely reduced scores for a speech test in noise.

The ASHA (1996) statement emerged from expert consensus and proposed that there are six auditory behaviors that may be deficient in some combination in CAPD: sound localization/lateralization, auditory discrimination, auditory pattern recognition, temporal processing, and auditory performance deficits for competing and degraded signals. It may not be possible at this time to evaluate each of these deficits in isolation, but it seems that a diagnosis of CAPD should be based on a discrete number of processing difficulties and that an efficient test battery would assess these processes. Whether there will be one, two, or more processing difficulties required for diagnosis and which tests will be most efficient and reliable in revealing these processing difficulties remain to be seen. Nevertheless, one statistical procedure that may be helpful in ascertaining the validity of models, such as that proposed by Katz and Smith (1991), and test batteries, as proposed by Musiek and Chermak (1994), appears to be factor analysis. If the three SCAN subtests are truly measuring discrete processes, then a factor study should show each subtest loading on a different factor. If the Katz and Smith (1991) four-factor system is valid, then factor study should help clarify this as well by, for example, an examination of the SSW RC and LC findings that should fall into different factors. In contrast, the more commonly used analysis of variance or *t* test and correlational analyses are designed to assess significant differences or relationships across groups of scores and thus serve a very different purpose.

Most CAPD studies until now have, in fact, used some form of descriptive, significant difference, correlational, or sensitivity/specificity approach to analyze CAPD results. Witkin, Butler, and Whalen (1977), however, made an early comprehensive effort to tease out the relevant factors in "auditory perceptual dysfunction" when they devised a group-administered audiotaped test, the Composite Auditory Perceptual Test. In their work, they used this test and more than 20 common subtests from measures of language such as the Illinois Test of Psycholinguistic Abilities, the Peabody Picture Vocabulary Test, and the Northwestern Syntax Screening Test. These tests were given to nearly 600 second-grade children to accommodate the factor studies. Witkin et al. (1977) were able to identify several different factors for "auditory processing" that they subsequently collapsed into what they described as three distinctly separate factors (short-term memory, auditory synthesis, and auditory figure-ground discrimination), along with two that were more general (speech-sound discrimination and receptive language processing). Although this effort appeared to be a promising approach to CAPD using factor analysis, we have been unable to find recent references to the Composite Auditory Perceptual Test or updated versions of it. Indeed, few studies have been conducted applying a factor analysis to central auditory processes.

SCAN was subjected to factor analysis as part of the original standardization study (Keith, 1986), but factor analysis was not the main focus of the standardization work, and only selected results on certain age groups were reported. No overall rotated factor results were presented. The findings presented did not show loadings by the three subtests on three different factors. In fact, they were in general agreement with the 11-year age group in which only two factors were found, with FW and AFG loading on the same factor and CW loading separately. When a third factor appeared, it came from ear differences within the younger subjects. Amos and Humes (1998) used factor analysis to examine the performance of 47 first- and third-grade normal hearing children on the SCAN. The three subtests were found to be associated with one factor and loaded on that factor with similar weights.

Method

This study primarily involved a factor analysis to determine the number of factors responsible for performance scores on the SCAN and SSW. In addition, but less importantly, the study involved replication of an earlier correlational and descriptive statistical analysis on SSW and SCAN by Keith et al. (1989).

It should be noted that this was a retrospective study, involving a reanalysis of data that were collected and reported elsewhere (Schow, Newman, & Vause, 1992). The data analyzed involved a group of 331 schoolchildren who were referred for central auditory testing due to underachievement, poor classroom performance, and/or attentional limitations. These children were representative of the Idaho school district from which they were drawn. They all used English as their first language and were predominantly Caucasian, with a small sampling of minority groups. There were 230 males and 101 females ranging in age from 6 to 17 years. There was a mix of socioeconomic levels, but they were primarily middle class. All of these children were administered the SSW and SCAN tests to help evaluate their central auditory status and to guide the school audiologist in recommending remediation strategies. All were found to have hearing thresholds within normal limits (20 dB HL or better) from 500 to 4000 Hz as well as normal speech thresholds and word recognition scores in quiet.

These children were thought to be an appropriate sample for the purposes of this study. They comprised a heterogeneous sample of subjects at different cognitive, linguistic, academic, and auditory performance levels, and yet, this heterogeneity was appropriate in view of our inclusion criteria. All these children were referred for CAPD testing based on behavioral observations but were not a group with confirmed CAPD. A group of youngsters with a potentially broad spectrum of deficits and a range of abilities within important areas of auditory processing was desired so that a factor analysis could be performed. Restricting the range of scores with a confirmed CAPD group would have been counterproductive and attenuated the effects that we were examining. Whether the wide range of scores is obtained from youngsters who have CAPD alone or CAPD difficulties that were secondary to other related conditions, such as learning disabilities, or to a global difficulty is of secondary importance, and these children were not differentiated in this study. Indeed, there was really no compelling reason that a large sample of normal youngsters could not be used for the same purpose had they all received the SCAN and the SSW tests. Keith (1986), after all, standardized his initial findings on SCAN with a cross-section of 1,034 school-age youngsters because he was simply establishing the normative range and the outliers in various measures of auditory abilities. Finally, the need in factor studies to include a large sample size (*N*) and the need to sample in a similar method to that of Keith et al. (1989) explains the use of children across a wide age range. Any concern about the influence of developmental language was addressed by a factor analysis on the entire sample and simultaneously on a younger and older age span.

The SSW and the three subtests of the SCAN were administered to each subject individually in audiometric sound suites at two different locations. All testing was completed by one ASHA-certified audiologist (the school audiologist). The SSW was always given first, and the three subtests of the SCAN were given next in the order suggested by the Psychological Corporation tape (FW, AFG, and CW) (Keith, 1986). Because the scoring was complex and was not completed until both tests were administered, no noteworthy order effect and/or bias effect was thought to have occurred, aside from a minor practice effect. Nevertheless, some elements of the design were subject to the clinical methods in use and not subject to elaborate experimental design. The test protocols followed those prescribed in the manual and were given on audiometers that were calibrated extensively on an annual basis and maintained thereafter by daily monitoring and listening checks. A variety of descriptive statistics were calculated using percentile scores derived from the SCAN manual, and in the case of SSW, the percentile method used was recommended by Keith (1983). Comparable percentile calculations were also used by Keith et al. (1989) on SCAN and SSW, and accordingly, these data were compared with those similar findings.

Descriptive Results and Discussion

The means and *SD*s of findings by age group were often found to be in close agreement, albeit with some exceptions, with those of a similar group of youngsters studied by Keith et al. (1989; Table 1). For all subjects pooled together, the mean percentile differences ranged from 2 to 9 and averaged less than 6. Within age groups, the mean differences in 48 comparisons were within 5 in 18 cases and within 10 in 32 cases. The correlations between the tests and subtests showed some agreement with the earlier study, although they were generally poorer (Table 2). Perhaps the larger *N*, which is nearly twice that of the earlier sample, is giving us more accurate estimates of the true correlations. Nevertheless, these findings tend to support the general replicability of the SSW and SCAN data, as reported previously for children at risk for CAPD, and confirm that the current sample of youngsters is as representative of a CAPD group as the earlier study sample (Keith et al., 1989) .

Other reports have appeared comparing SCAN and SSW (Bedient, 1992; Stecker, 1992). However, these latter reports involved only a few children ($N = 24$ and

TABLE 1. Means ($\bar{x}$) and *SD*s by age for SSW and SCAN subtest percentiles (this study, total $N = 331$, 6–13 year $N = 311$; Keith et al. (1989), total $N = 154$, 6–13 year $N = 147$).

Age (years)		Source (*N*)	RC[a]	LC	FW	AFG	CW	Comp
All								
	$\bar{x}$	This study (331)	38.6	34.8	64.7	47.1	45.7	49.9
		Keith et al. (1989) (154)	27.5	32.3	56.6	43.0	41.5	43.5
	SD	This study	30.0	30.6	33.7	22.6	26.1	25.2
		Keith et al. (1989)	27.5	29.7	26.1	25.9	30.6	30.2
6								
	$\bar{x}$	This study (32)	39.3	28.3	60.9	55.6	48.6	53.2
		Keith et al. (1989) (13)	31.3	31.7	57.8	47.3	42.5	48.0
	SD	This study	28.7	29.3	22.2	18.9	22.7	22.9
		Keith et al. (1989)	30.3	29.9	32.2	31.1	26.1	31.2
7								
	$\bar{x}$	This study (67)	41.5	44.5	65.5	47.9	42.5	44.0
		Keith et al. (1989) (27)	35.7	39.3	54.7	42.9	39.5	42.7
	SD	This study	31.5	31.7	58.4	22.1	21.2	20.5
		Keith et al. (1989)	34.8	34.3	29.9	27.4	32.6	35.5
8								
	$\bar{x}$	This study (76)	29.8	31.0	60.9	44.7	44.5	49.2
		Keith et al. (1989) (32)	27.6	37.8	55.3	38.9	47.5	47.1
	SD	This study	30.8	32.2	27.3	22.4	27.4	26.4
		Keith et al. (1989)	28.9	32.9	28.6	21.5	30.8	31.2
9								
	$\bar{x}$	This study (58)	39.9	34.3	63.8	50.3	52.0	55.4
		Keith et al. (1989) (25)	22.7	33.6	60.2	42.7	35.9	40.2
	SD	This study	30.7	23.5	24.0	23.9	28.1	27.8
		Keith et al. (1989)	27.3	24.9	26.0	24.1	33.7	29.9
10								
	$\bar{x}$	This study (36)	45.3	36.7	61.1	46.1	39.7	45.2
		Keith et al. (1989) (17)	20.4	30.3	52.9	34.4	38.4	37.4
	SD	This study	29.1	31.9	22.8	23.6	26.4	23.8
		Keith et al. (1989)	26.2	29.8	30.6	21.5	30.7	28.8
11								
	$\bar{x}$	This study (18)	39.6	24.1	70.1	34.4	41.8	46.0
		Keith et al. (1989) (15)	20.2	22.3	50.3	42.2	30.6	31.9
	SD	This study	29.4	28.1	18.9	21.0	25.9	25.2
		Keith et al. (1989)	19.3	30.8	28.9	31.9	26.2	24.9
12								
	$\bar{x}$	This study (13)	35.3	22.5	78.5	51.5	53.1	60.5
		Keith et al. (1989) (12)	24.6	13.8	65.8	47.8	44.2	41.2
	SD	This study	19.9	26.6	13.0	20.9	27.9	25.0
		Keith et al. (1989)	22.1	18.1	26.1	27.7	31.9	30.6
13								
	$\bar{x}$	This study (11)	34.6	34.5	68.7	38.6	43.5	46.1
		Keith et al. (1989) (6)	38.6	31.5	61.7	63.0	64.7	66.6
	SD	This study	24.8	37.5	24.1	24.6	30.3	31.2
		Keith et al. (1989)	15.1	28.3	26.2	20.4	22.8	19.4

[a] RC = Right Competing, LC = Left Competing, FW = Filtered Word, AFG = Auditory Figure Ground, CW = Competing Word, Comp = Composite.

TABLE 2. Pearson *r* correlation coefficients for SCAN and SSW subtests as found in this study ($N = 331$) and Keith et al. (1989) ($N = 154$). Other correlations in this study only: FW and CW = .22; AFG and CW = .33; FW and AFG = .19; Comp and CW = .92; Comp and FW = .36; Comp and AFG = .54; Comp and RC = .40; Comp and LC = .46; RC and LC = .37.

	SSW			
	RC[a]		LC	
SCAN	This study	Keith et al.	This study	Keith et al.
Comp	.40	.57	.46	.53
CW	.39	.57	.50	.56
FW	.22	.23	.18	.23
AFG	.15	.34	.09	.21

[a] RC = Right Competing, LC = Left Competing, FW = Filtered Word, AFG = Auditory Figure Ground, CW = Competing Word, Comp = Composite.

N = 8, respectively) and do not allow the same comparisons as do the data of Keith et al. (1989).

Factor Analysis and Discussion

A factor analysis was run on the total group because this approach facilitated the use of a large, adequate sample size (Gorsuch, 1983). The rotated factor loadings for the rotated solution for each variable are shown in Table 3. The five test scores (variables) were evaluated (SCAN [FW, CW, and AFG], and SSW [RC and LC]). The orthogonal solution (rotation) with principal components factoring was considered appropriate because this method provides the simplest solution and assumes complete independence. The latter assumption seems appropriate because the two factors had a low correlation (0.19). In any case, the oblique findings were nearly the same (within 0.09 of the other loadings). A two-factor solution emerged; the first had an eigenvalue (i.e., index of variance) of 2.09, and the second had an eigenvalue of 1.01. The first factor accounts for 41.7% of the variance, and the second accounts for 20.2% more, for a total of 61.9% accounted for by the two factors. Thus, the first two factors each accounted for substantial portions of the variance. After rotation, the first factor accounted for 35.5%

TABLE 3. Rotated orthogonal factor loadings for each of the five subtest scores along with their groupings within the two emerging factors.

	Factor 1	Factor 2
LC[a]	.83	.01
RC	.74	.07
CW	.73	.39
AFG	.08	.82
FW	.11	.69

[a] LC = Left Competing, RC = Right Competing, FW = Filtered Word, AFG = Auditory Figure Ground, CW = Competing Word.

of the variance (eigenvalue = 1.78), and the second factor accounted for 28.3% of the variance (eigenvalue = 1.42). Both factors are assumed to be authentic. In contrast to the findings of Amos and Humes (1998) on a much smaller *N*, our findings clearly show two interpretable factors. Furthermore, the two-factor solution here is also consistent with the findings of Keith (1986).

Factor 1, which we identified as a binaural separation/competition factor, loaded on LC, RC, and CW. Factor 2 loaded on AFG and FW. Although AFG and FW might have been expected to reflect two factors due to background competition or degradation, they sorted instead into a composite monaural low-redundancy degradation factor that involves auditory closure on the part of the subject. This latter combined loading of AFG and FW also was found by Keith (1986) in his original standardization report and again supports the current factor findings as reinforced by a sample of over 1,000 youngsters. It appears they fall into one factor because of the monaural nature of the task in both cases, but as Keith suggests, they are both measures of central auditory processing in the presence of general distractions. It is interesting that Factor 1 includes dichotic processing (binaural separation) mentioned by Musiek and Chermak (1994), whereas Factor 2 includes a monaural version of the two subtypes of auditory performance decrements (competition/degradation) mentioned within the six factors proposed by ASHA (1996).

The loadings (basically multiple regression) reported in Table 3 for Factor 1 lie within the 0.73 to 0.83 range and suggest that LC was the most strongly associated with this factor, whereas RC and CW were slightly less so. All, however, seem strongly correlated. AFG and FW loadings were from 0.69 to 0.82 within Factor 2, with AFG being stronger; both show high correlations.[1] The sizes of these correlations reflect the extent of relationship between each CAPD subtest and each latent factor.

These factor findings must be considered preliminary, pending other testing and multimodal study. Furthermore, had there been other scores available on these youngsters, it is possible that other factors might have emerged. It appears that RC and LC do not sort out separately as might be implied from the theoretical model of Katz and Smith (1991). The three SCAN subtests give us two rather than the three separate factors that might have been expected. The right ear advantage could alter these results for younger children (3 to 5 years of age), but, of course, that advantage decreases as a function of maturation, and in this typical sample of older schoolchildren LC/RC merge within one factor.

The communality of each variable across the two factors combined was found to be as follows: LC = 0.70, CW = 0.68, AFG = 0.67, RC = 0.55, and FW = 0.49. Communality expresses how much one variable has in common with the two factors. Stated differently, we can see the amount of variance within each test found within the two factors, so tests with higher communality have less unique information that is not accounted for within the factors and vice versa. It is clear that each of the tests has a high degree of its variance explained within the two factors, but LC, CW, and AFG are the most notable in this regard. Nevertheless, the amount of unexplained variance suggests that another measure, perhaps one of temporal processing, might provide some unique information regarding central auditory processing and perhaps underlie a third and/or fourth factor that is not identified here.

Conclusions

Factor analysis is a statistical tool that can help bring some order to a controversial field of study. In addition to testing models of central auditory processing and CAPD to establish their construct validity, factor analysis of central auditory performance scores provides an important method by which we can group the underlying deficits that purportedly comprise CAPD. Such factor studies can, indeed, help in defining a gold standard because there is as yet no universal agreement on the appropriate model. Of course, even the current data are preliminary. These identified factors can only be definitive when we have a gold standard to identify CAPD. Statements like the recent ASHA (1996) document listing six areas of concern need to be tested further in much the way they have been here. Although the current study was possible using the mass of accumulated data on only the SSW and SCAN tests, we recommend that more use be made of this basic statistical tool with other tests. Future efforts, some now in progress, should and will involve administering a number of tests, including modality-specific tests and tests to distinguish between auditory specific and more generalized processing deficits, as recently suggested by Cacace and McFarland (1998). By more extensive testing on persons with suspected or confirmed CAPD using tests that measure the key areas of concern, we may find evidence of other factors beyond the two identified here and reconfirm these two. As such work is completed, we will be in a stronger position to diagnose and treat CAPD.

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[1] Confirmatory factor analysis was used to test whether the model changed across different age groups. The model fit children 8 years old and younger as well as those 9 years old and older. In other words, the specified two-factor model predicted correlation among test scores in the younger children as well as it was able to predict correlations among test scores within the older children.

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Contact author: Ron Schow, Box 8116, Idaho State University, Pocatello, ID 83209. Email: schorona@isu.edu