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The Reliability and Validity of the SCAN and SCAN-C for Use with Children with Auditory Processing Disorders: A Systematic Review

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by

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A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology, The City University of New York

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Abstract

THE RELIABILITY AND VALIDITY OF THE SCAN-3: C FOR USE WITH CHILDREN WITH AUDITORY PROCESSING DISORDERS: A SYSTEMATIC REVIEW

By

Chana Stern

Advisor: Dr. Barbara Weinstein

Central Auditory Processing Disorder is a complex issue that affects many school-age children who require these processing skills to succeed in school. Prevalence has been found as high as 7% in this population making it a growing issue that must be addressed. Evaluating this population is exceedingly difficult due to the challenging nature of the pediatric population which requires a testing measure that will accomplish this task accurately and efficiently. The purpose of this paper is to systematically analyze the existing literature on the SCAN-C in order to investigate its' reliability and validity in diagnosing Central Auditory Processing Disorders. This paper included studies completed after 1985 with a minimum of 10 participants. Participants were required to fall within the ages of 5 and 13 and were previously tested for normal hearing or any other learning disabilities that would negatively affect the test results. Results revealed the increased performance after children were re-tested following a 6-7 week time period. In addition, results found that other tests such as the MAPA and the CELF-R contained aspects of APD that were not found in the SCAN. These results bring into question the validity of the SCAN and SCAN-C as a standalone diagnostic tool for APD in school age children.

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INTRODUCTION

What are Central Auditory Processing Disorders (CAPD)?

Central Auditory Processing Disorders (CAPD) are categorized by deficits found in the behaviors associated with the Central Auditory Processes. ASHA defined Central Auditory Processes as the mechanisms in the auditory system responsible for "sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance decrements with competing acoustic signals, and auditory performance decrements with degraded acoustic signals," (ASHA 1996). Cacace and McFarland (1995a; 2005; 2013) prefer the operational definition of APD as "a modality-specific perceptual dysfunction that is not due to peripheral hearing loss." The term central differentiates between issues at the brainstem and cortical levels versus concerns at the level of the periphery namely, cochlear and auditory nerve (Keith & Robert, 1999). Children who are diagnosed with CAPDs often present with normal peripheral hearing, nevertheless exhibit difficulties with processing acoustic stimuli, particularly in the company of background noise, have difficulty with following directions, as well as comprehending speech spoken at a rapid pace or has been corrupted in any form. These difficulties may in fact be due to a more global cause such as attention or memory deficits (Bamiou et al., 2001). In order for appropriate treatment to occur, diagnosis differentiation is imperative.

A Normal Central Auditory Processing System

The first step in understanding a Central Auditory Processing Disorder is to first appreciate the operation of a normal central auditory processing system. A normal system is determined by its ability to process auditory information in the central auditory nervous system

(CANS) (ASHA, 1996; Bellis, 2011). Based upon the concept of Information Processing Theory two approaches are necessary auditory information to be adequately processed: The "top-down" theory and the "bottom-up" approach. The "bottom-up" theory expounds on how auditory signals are encoded from the auditory signal all the way up to the brain (Bellis, 2011). Consequently, if there is interference at any point along the central auditory pathway, then encoding the entire auditory signal will prove to be problematic. The first step is ensuring that the auditory signal coming in to the ear and auditory nerve has not been compromised. Normal processing can only occur once the integrity of the auditory signal can be ensured. Once the non-compromised auditory signal has passed through the auditory nerve and reaches the Cochlear Nucleus (CN), true processing can begin as the CN is the first area where signal processing occurs, primarily focusing on contrast enhancement (Bellis, 2011). Following the CN, decussation begins to occur at the level of the Superior Olivary Complex (SOC) where information is accepted both ipsilaterally and contralaterally . Whereas any dysfunction taking place inferior to the SOC will result in ipsilateral deficiencies, from the SOC and above, dysfunction will result in abnormalities either bilateral or contralateral (Bellis, 2011) This is due to the intrinsic redundancy that occurs throughout the Central Auditory Nervous System (CANS). Intrinsic redundancy follows organization and composition of the auditory pathways whereby various and pathways conveniently and successively communicate information across the CANS. The extensive communications of the structures in the CANS are what cause a lack of deficits on a standard audiological evaluation, despite the presence of a lesion (as cited in Weihing, J. 2007). Because there are multiple representations of the information through the central auditory pathway, it allows for lesions to often have minimal effect as the information is most likely represented elsewhere where there might not be a lesion present. The SOC is essential for three primary functions: the processing of binaural information, localization, and hearing in background noise (Bellis, 2011). The Lateral Lemniscus (LL) is comprised of the axons of the neurons of the CN and SOC that venture to the Inferior Colliculus (IC). There are few studies that explore the functional properties of the LL but those that do indicate a vital part in binaural processing from contralateral pathways (Ehret & Romand 1997). At the level of the Inferior colliculus, frequency and intensity sensitivity along with binaural integration of information takes place. Following the IC the neurons travel through the Medial Geniculate Body all the way to the Primary Auditory Cortex where the information is then processed in the brain at the auditory cortex (Bellis, 2011).

The top-down theory, as the title explicitly projects, works in the opposite direction with the higher order processes manipulating the auditory input from the very beginning (Bellis, 2011). Top-down cognitive functions, such as attention and memory, are necessary in order for the auditory input to reach the brain intact. For example, without functioning working memory and attention, the auditory input will be corrupted and thereby inoperative for the brain to interpret by the time it reaches the auditory cortex. Moreover, both the peripheral hearing loss and the ability to process auditory signal influences all of the information that is available to the individual. Therefore, information that is available to the person via top down processing may be negatively impacted by an issue related to either a peripheral hearing loss or a lack of adequate auditory processing skills (Bamiou et al., 2001).

Very often people who present with a lesion at any point along the central auditory pathway will function as well as their non-lesioned peers when listening to non-distorted speech stimuli due to the intrinsic redundancy of the CANS as well as the extrinsic redundancy of speech stimuli (Korabic et al., 1978). Redundancy allows for missed information to be recalled at a later opportunity. As explained previously, intrinsic redundancy, also named internal redundancy, occurs throughout the central auditory pathway which allows missed information due to a lesion at one point to be recollected at a later location along the pathway. Additionally, speech has considerable extrinsic redundancy which includes repetition, grammar, semantics, context, and visual cues. This information, both redundant and superfluous, accumulates to approximately 50% redundancy in any given language which assists in total comprehension despite the noise, interference, errors and missing elements that often accompany the speech signal. The listener is then provided with enough information to correct the inaccuracies and effectively deduce the message (Goldstein & Shulman, 1999; Korabic et al., 1978). The one caveat with redundancy is that its success is typically for undistorted stimuli. Once the speech has been degraded, the listener is no longer able to rely on extrinsic redundancy and performance may be compromised by the lesion. This is precisely why degraded speech is a more useful barometer when measuring for an APD (Korabic et al., 1978).

What Causes CAPD in Children?

It has been suggested by Chermak & Musiek (1997) that neurodevelopmental disorder often underlies CAPD in approximately 65 to 70% of diagnosed CAPD however, that theory has not been confirmed by other clinics (Cacace et al., 2013). The more commonly held belief is that an APD is caused by a lesion at some point along the central auditory pathway, including the peripheral system (i.e. person's hearing ability), which results in the brain's inability to adequately process the auditory input (Bellis, 2011). Other possible causes include tumors of the CANS, premature birth/low birth weight, extrinsic brain damage, metabolic disorders, cardiovascular disorders and epilepsy (Bellis, 2011).

Prevalence of Auditory Processing Disorders

The prevalence of APD in children has been difficult to determine as research on this topic is minimal; however, Chermak 2001 estimated APD in school children to be between 2% to 3%. In contrast, Jerger et. al, (2000) reported a higher prevalence at roughly 7%. Diagnosis and remediation has only begun to develop over the last 30 years which may lead to a higher diagnostic rate and a higher prevalence in the future (Bamiou et al., 2011). Pediatric testing brings with it many challenges which necessitates a testing protocol that anticipates these concerns and allows for accurate testing.

Resulting Learning Disabilities due to a Central Auditory Processing Disorder

Proper diagnosis of a disrupted Central Auditory Processing System is necessary primarily due to its effect on a child's ability to perform well linguistically and academically. There have been studies linking CAPD to learning disabilities; however, the results do not significantly prove causation (ASHA, 1996; Cacace et al., 1998). Very often children who may be exhibiting difficulty with verbal processing will be misdiagnosed with Attention Deficit Hyperactive Disorder (ADHD), learning disabilities or dyslexia. Additionally many of the hierarchal cognitive functions such as attention and memories that are affected by ADHD are necessary for proper auditory processing skills and the ADHD will corrupt the results of the APD evaluations, thereby creating a causation when in fact there is only a correlation. Understandably, many children with the aforementioned disorders do present with some level of language dysfunction so a multi-disciplinary approach is necessary to accurately diagnose the primary issue versus the secondary concerns following with a treatment plan that puts greater focus on the true underlying issue, whether it be CAPD or ADHD, dyslexia, or a learning disability (Chermak et al., 1999).

Testing for Auditory Processing Disorders: The Case History

Auditory Processing Evaluations for adults began in the 1950s when testing was exclusively completed on adults with brain lesions. Tests were necessary in order to asses both the temporal lobe and the brainstem. Tests created to evaluate temporal lobe function include low-pass filtered speech lists which found poor scores contralateral to the damaged hemisphere even though peripheral hearing was within normal limits (Musiek & Baran, 1987). Findings from those studies led to tests involving compressed/disrupted speech signals as well as speech in noise tests. Further test measures of the temporal lobe involve dichotic speech testing which began in the early 1960s where Kimura (1961 as cited in Musiek & Baran 1987) proved that when presented with stimuli using a dichotic model, depressed results were noted in the contralateral ear. On the heels of Kimura's success, The Staggered Spondaic Word test (SSW) was created modifying the dichotic paradigm to include speech signal (Katz 1962 as cited in Musiek & Baran 1987). Other dichotic tests, used to assess binaural summation and binaural integration, developed in the 60s and 70s included the dichotic CV test and Synthetic Sentence Index Test (SSI). Temporal ordering and sequencing tasks was brought on in the 70s where non-verbal stimuli was utilized to determine the presence of a lesion on the temporal lobe as well.

In order to evaluate the integrity of the brainstem, the creation of Binaural Interaction Tests, such as the Masking Level Difference Tests (MLD), were created in the 1980s (Musiek & Baran 1987). During that same time the use of electrophysiological began to gain traction as well with the incorporation of ABRs and MLRs in CANS assessment (Musiek & Baran 1987). Studies depicting the use of each of these tests for a specific measure allowed for the creation of a test battery that would allow for greater precision in a minimal time frame. This would eventually lead to the creation of the SCAN, a Screening Test for Auditory Processing Disorders, which is a compilation of tests of both the brainstem and temporal processing, thus providing a broad picture of the teste's ability to process auditory signals.

Testing for Auditory Processing Disorders: Current Paradigms

Testing for a CAPD requires a thorough case history, "systematic observation of auditory behavior," [and] audiometric test procedures" (ASHA 1996). The SCAN and SCAN-C (a test battery specifically designed for children) was developed by Keith (1986) and includes a Gap Detection test (an evaluation of temporal processing ability), Auditory Figure Ground (+8 dB), Competing Words (free recall), Filtered Words (tests auditory closure ability), Competing Words (directed ear) (both competing words test are able to test binaural integration ability), and Competing Sentences (used to asses binaural separation). There are also supplementary tests which consists of Auditory Figure Ground (+0 dB and +12 dB) as well as Time Compressed Sentences (along with filtered words, evaluates auditory closure ability). These tests expose the presence of temporal processing deficits, difficulty listening in background noise, dichotic listening ability, speech processing ability of degraded speech and the maturation of the auditory system (ASHA 1996)

Issues Surrounding a Central Auditory Processing Disorder Diagnosis

The subject of CAPD in school-aged children was termed as a "very large terra incognita," by Jerger (as cited in Cacace et al., 1998) due to the many ambiguities associated with both the testing protocols and the disorder itself. There are many underlying deficits that may contribute to a "failed" test result which will follow with a CAPD diagnosis where there is none. Thus when CAPD testing involves processing information with other sensory modalities rather than acoustic information alone, it proves difficult to isolate a CAPD from another underlying diagnosis (Cacace et al., 1998). For example, the presentation of Attention-Deficit Hyperactivity Disorder has shown to cause difficulty on tasks used to assess central auditory processing skills (Riccio et al., 1994). Furthermore, there are many reasons why a child may fail an APD evaluation such as inattentiveness, tiredness, hunger, or disinterest. Often the testing and resulting diagnosis is not an accurate assessment of the child's auditory processing ability; rather, the effects of other underlying causes (Musiek et al., 1990).

There is no gold standard in APD assessment primarily due to the fact that multiple areas need to be evaluated in order to determine a deficiency and a lack of ability in only one of the tested areas constitutes the presence of a CAPD (ASHA 1996). Consequently, differentiating between those who do poorly on some aspects of the test battery versus those who perform poorly on most or all of the evaluation proves difficult. The SCAN-3:C offers information regarding auditory processes but does not provide for a spectrum diagnosis. In contrast, Singer, Hurley, & Preece (1998) recommend incorporating the CDA (clinical decision analysis) in site of lesion testing. Furthermore, they suggest shortening the test battery by utilizing only one or 2 tests to identify CAPD in children. Many question the efficacy of their approach considering ASHA (1996) maintains that one test cannot provide a proper diagnosis since CAPD involves various areas of dysfunction which may in fact result in leaving many undiagnosed. Due to the scope of processing-related difficulties that are involved when diagnosing a CAPD and the necessity to incorporate multiple tests to evaluate every area of dysfunction, it is only logical that there is no one test that can determine a complete diagnosis of such a multifaceted matter (Cacace et al., 2013).

According to Musiek et al., (1994), the diagnostic evaluations were originally designed to detect the site of a neurological lesion in adults; however, they are currently being incorporated for pediatric diagnoses of auditory processing disorders. Therefore, new testing was required with lists appropriate for the particular age bracket tested. Moreover, it is rare to have distinct neurological lesions that will diagnose a definite CAPD diagnosis (Jerger, Johnson, & Loiselle, 1988) and in most children CAPD is suspected on the basis of behavioral and observational data but in the absence of discrete lesions.

The Development of the SCAN-C

The original SCAN: was created as a screening measure for children ages 3 to 11 years, standardized based on children in the US population. Combining costing tests used with adults, the purpose of the SCAN is to determine possible Central auditory nervous system disorders, identify auditory processing problems identify children who may benefit from therapies (Keith, 1995). In 2000, Keith revised his test battery into the SCAN-C due to concerns raised by researchers such as Emerson et al., (1997) and Amos and Humes (1998), (as cited in Keith, 2000). Their concerns included discrepancies between test results found in a quiet school setting versus the audiometric test booth, its' test-retest reliability and its' rational for computing the overall composite score (Keith 2000). Some of the modifications made included re-wording the test instructions for simplicity and ease of understanding by young children. Additionally, the audiocassette was replaced with a CD which has proven to contain a longer shelf life than the audiocassette. The Competing Words subtest was revised for better efficiency and accuracy of diagnosis. The Competing Sentences was added the test battery as well to increase its effectiveness in dichotic testing. Finally, normative data was collected by applying information provided on census figures which allow for more representation of different regions of the country and ethnic groups (Keith, 2000).

Major critics of the SCAN-C include Domitz & Schow (2000) who claim that the test battery included in the SCAN-C fails to incorporate all aspects of CAPD which may lead to failure to diagnose and provide treatment for all children who require it. Further investigation by Schow et al., (2000) confirms the original critique using a confirmatory factor analysis to analyze the results.

Objectives and Research Questions

The purpose of this review is to systematically analyze the existing literature from the year 1985 to the present investigating the reliability and validity of the SCAN and SCAN-C in diagnosing Central Auditory Processing Disorders in children.

(1) Is the SCAN and SCAN-C an appropriate measure for assessing Auditory Processing Disorders in school-age children?

(2) Which tests are the most and which are the least sensitive and specific?

Methods

Types of Studies

The studies included in this review were published after 1985. Only studies with 10+ participants were included to avoid results effected by small population size.

Participants

Participants for the studies were required to fall within the ages of 5 and 13 (often categorized as school aged children). These children were preferably tested and found to have hearing within normal limits and no learning disabilities or diagnosis of ADHD that would skew the results when testing for Auditory Processing Disorders.

Search Strategy for Identification of Studies

In order to complete this systematic review, a search was completed to discover pertinent studies relating to the research topic. A search of databases available via the Mina Rees Library included Google Scholar, CINHAL, Pub-Med, and Medline with Full Text. After the initial search, each article's bibliography was analyzed for additional articles that might have not appeared through the applied search engines. The key words implemented included: SCAN, SCAN-C, SCAN-C3, children, hearing loss, Auditory Processing Disorders, Auditory Processing Evaluations, APD, Temporal, brain stem, time compressed, SSW GIN, and filtered speech.

Those studies that did not meet the inclusion criteria were excluded from the review. The abstracts and full articles, when necessary, were examined manually to ensure that the studies fell within the inclusion criteria set for this review.

Results

Twenty-four articles were identified for abstract review employing various combinations of the selected keywords in the electronic databases earlier recognized following elimination of duplications. Abstract review of all twenty-four articles resulted in the exclusion of six articles which did not meet inclusion criteria. Full article review was performed on the remaining articles as the review of their abstracts did not revealed whether they met the inclusion criteria. Following the analysis of the full articles and investigating the age, hearing level and presence of comorbid factors in the participants, it was decided that only five articles met the inclusion criteria and would be included for the full systematic review. At the completion of the search process there were six articles that were found to meet all of the necessary inclusion criteria.

The search and retrieval process is illustrated in Figure 1.

Potentially pertinent articles, barring duplicates, identified utilizing search databased and key words and reviewing the accompanying abstracts.
N=24

Studies excluded after abstract review
N= 18
Reasons for exclusion:
Year of publication
Subject population
Language
Did not utilize full SCAN

Studies reviewed for the full article review

N= 10

Studies excluded after full article review
N= 8
Reasons for exclusion:
Not measuring SCAN benefit

Studies included in the systematic review
N= 6

Figure 1. Flow chart for the search and retrieval process for articles included in systematic review.

Research Question #1: Is the SCAN an appropriate measure for assessing auditory processing disorders in school-age children?

Table 1 summarizes the characteristic of each of these studies meeting the selection criteria in terms of participant characteristics, inclusion criteria, purpose and results of the study.

Table 1: Characteristics of the studies included in the Systematic Review

Author (s)	**Characteristics of Participants:**	**Inclusion Criteria:**	**Purpose of the Study:**	**Results of the Study as Pertain to the SCAN:**

Amos & Humes (1998)	47 participants Ages 6-9 years	-Normal hearing -Caucasian -English as primary language	To examine whether the SCAN outcomes remained constant after a 6-7 week period.	Every aspect of the SCAN performed better after a second test besides for Auditory Figure Ground
Dawes & Bishop (2007)	99 participants Ages 6-10 years	-Hearing thresholds within normal sensitivity (defined as thresholds at or below 25 dB at all frequencies within the range 250 Hz to 8000 Hz on screening audiometry bilaterally) Appropriate response to SCAN-C practice items.	To examine how the SCAN-C diagnoses auditory processing disorders in UK children is over-diagnosing auditory processing disorders in UK children despite language differences? This will reveal how language level and rater interpretation impacts the results.	UK participants performed significantly worse than their US peers in the Auditory Figure Ground and Filtered Word category as well as their overall composite score.
Domitz & Schow (2000)	81 participants Ages 8 years 8 months to 9 years 9 months	-Hearing within normal limits. -Normal Type A tympanograms -No diagnosis of mental retardation	Comparison of results between the MAPA (Multiple Auditory Processing Assessment) and the SCAN	The SCAN only measures 2 out of the 4 factors measured by the MAPA which may lead to missed diagnoses.

Emerson, M., Crandall, K., Seikel, J., & Chermak, G. (1997)	6 participants Ages 5 years 9 months -11 years 8 months	-Hearing within normal limits (as obtained through a hearing screening) -Normal middle ear function with Type A tympanograms. -No history of Otitis Media. -Passed otoscopic examination.	To assess whether the SCAN results will differ based on environments, necessitating the need for a sound proof booth for testing.	Children performed significantly poorly when tested in a school setting rather than the audiometric booth. This brings into the question the validity of using the SCAN (which is performed in a sound proof booth as a means of measuring Auditory Processing) which is a concern in a school setting.
Keith, R. W. (2000)	650 participants Ages 5 years, 0 months to 11 years and 11 months were studied. (stratified by age, race, gender, region and parent education level.)	-Ability to take the test in English in the standard fashion without modification -Have normal and symmetric peripheral hearing as tested by air-conduction pure-tone audiometry at 500, 1000, 2000, and 4000 Hz; and -Have intelligible speech with few articulation errors.	Analysis of new standardization data to describe SCAN-C, its design, and results of standardization procedures .	The Revision of the SCAN into the SCAN-C resulted in the new method of calculating the composite standard score which allows for equal weighting to each subtest of SCAN-C. Additionally, Subtest test-retest reliability was substantially improved over the original SCAN. Concurrent validity tests found that SCAN-C test results can be viewed with the same confidence as SCAN.

Keith, W., Rudy, J., Donahue, P. A., Katbamma, B. (1989)	155 participants Ages 6-15 years.	Inclusion criteria included: normal intelligence with I.Q.s measured above 90 and normal hearing sensitivity and normal tympanograms bilaterally	To compare the results of the SCAN with other central auditory and language tests. Specifically the SSW, Competing Sentence Test (CST), Peabody Picture Vocabulary Test (PPVT), and the Clinical Evaluations of Language Fundamentals-Revised (CELF-R)	-Competing word subtests of the SCAN correlate highly with the SSW and CST -Filtered Words and Auditory Figure Ground subtests showed low significant correlations with the SSW and CST. -Significant correlation between the SCAN and the PPVT -Standard Scores for the Auditory Processing Battery and the Production Battery of the CELF were NOT significantly correlated.

For the most part the studies differed considerably in terms of sample size, characteristics of participants, and methodology. However, across the board, the participants were mostly normal hearing children for whom English was the primary language.

Searching for suitable literature revealed a dearth of studies measuring the validity of the original SCAN, but for the SCAN-C, the search proved even more difficult. Of the six studies included, only two measured the SCAN-C (Dawes & Bishop 2007; Keith, R. W. 2000) in contrast to the remaining four studies that focused on the original SCAN (Amos & Humes 1998; Domitz & Schow 2000; Emerson, M., Crandall, K., Seikel, J., & Chermak, G. 1997; Keith, W., Rudy, J., Donahue, P. A., Katbamma, B. 1989). Keith (2000) completed a study evaluating the revised SCAN-C when compared to its predecessor the SCAN. His research aimed to demonstrate the utility of the improved version. The revision of the SCAN into the SCAN-C included enhancements such as the transition from audio cassette to CD and a reworded list for simplicity. These along with other additions resulted in the new method of calculating the composite standard score which allows for equal weighting to each subtest of SCAN-C. Moreover, Subtest test-retest reliability was substantially improved over the original SCAN (Keith 2000). The SCAN-C while an improvement from the SCAN, is still found to over diagnose children who are not American-bred as seen when results from children from the UK were evaluated (Dawes & Bishop 2007). Dawes and Bishop (2007) aimed to explore the ramifications of differences in language and rater interpretation when comparing results of the SCAN-C yielded from American children versus UK children. His results revealed that UK participants performed significantly worse than their US peers in the Auditory Figure Ground and Filtered Word category as well as their overall composite score. It was noted, that with a few minor modifications, these hurdles are easily overcome and the SCAN-C may be incorporated into the auditory processing evaluation test battery for children in the UK.

Another difference found within the studies was apparent in the methods. Only two of the studies compared the SCAN to other auditory processing evaluations such as the MAPA (Domitz & Schow 2000; Keith et al., 1989) as well as the Competing Sentence Test (CST), Peabody Picture Vocabulary Test (PPVT), and the Clinical Evaluations of Language Fundamentals-Revised (CELF-R) (Keith et al., 1989), whereas the remaining four studies focused solely on the SCAN or SCAN-C on its own without comparisons to other APD testing protocols (Amos & Humes 1998; Domitz & Schow 2000; Emerson et al.,1997; Keith 2000).

Domitz, Schow, and Keith et al., (2000; 1989), compared the SCAN to other APD tests recognized its limitations in being the singular method for measuring auditory processing. Domitz & Schow (2000) found that the SCAN came up short by two separate factors when compared to the MAPA as they found that the MAPA was developed to measure monaural separation/closure (MSC), auditory pattern/temporal ordering, binaural integration, and binaural separation (BS). The SCAN alone was only able to measure two out of the four factors: MSC and BS. Keith et al., (1989) agreed that the SCAN lacked certain qualifications for evaluating APDs that were present in other assessments. For example, when compared to the CELF-R, a lack of correlation was found, indicating that that each of these assessments evaluate different facets of auditory processing. To complete the CELF, the child must utilize abilities related to syntax, semantics, memory, and word retrieval. In contrast, the SCAN focuses primarily on the primary reception stage by requiring an imitative verbal answer (Keith et al., 1989).

Another limitation of the SCAN was determined by Amos & Humes (1998) who sought to determine whether the SCAN provided adequate reliability when re-tested after a considerable amount of time. They found that when the test was re-administered after a 6-7 week time period, scores improved significantly for filtered words (FW), competing words (CW) as well as the overall composite score. The only subtest that showed no significant improvement was the Auditory Figure Ground (AFG) subtest. These findings encourage the use of multiple evaluations over a significant time frame in order to discover the child's true, best performance which is ideal when diagnosing an APD along with treatment options (Amos & Humes 1998).

Other limitations of the SCAN were considered by Emerson et al., (1997) who sought to discover whether the location of the SCAN test administration provided an unrealistic test environment that was much unlike the true classroom setting which is where the students who are diagnosed with an APD will have the most trouble. The sound proof booth, where the SCAN is generally administered, is the ideal listening environment for any child whereas the classroom is fraught with noisy distractions which interfere with the child's ability to understand and interpret speech effectively. Results from this study revealed a significant decrease in scores when tested in a classroom-like setting which may impact diagnosis. This study, however, was a pilot study with only 6 participants which requires further testing to corroborate these results.

Research Question #2: Which tests are the most and which are the least sensitive and specific?

Table 2: Summary of Sensitivity and Specificity of the SCAN

Citation	**Gold Standard**	**Sensitivity of the SCAN (%)**	**Specificity of the SCAN (%)**	**False Positives (%)**	**False Negatives (%)**
Domitz & Schow (2000)	-2 SD below the mean	45	95	5	55

After an exhaustive search, only one study even discussed the sensitivity and specificity of the SCAN or SCAN-C. Understanding the sensitivity, is a positive diagnosis a true positive, and the specificity, is the negative diagnosis a true negative, plays an important role in how we rely on the results of the test. Sensitivity is determined by measuring the ratio of the number of participants with CAPD detected by the SCAN as compared to the total number of participants with the CAPD within the sample analyzed (known as the "hit rate") ASHA 2005). In contrast, the specificity is categorized as the ratio of participants who do not have the disorder who provide negative responses when compared to the total amount of those without the disorder in the sample analyzed. Typically, the specificity of the test decreases as the sensitivity increases; however, it is possible (and it is the ultimate goal) to have a test that is as close to 100% sensitive and 100% specific as possible (ASHA 2005). The term, Efficiency, is used to determine the combination of both the sensitivity and specificity of the evaluation. In order to properly calculate the efficiency, one must first define a gold standard which results from properly documented populations of individuals with the disorder as well as documented populations that do not contain the same disorder.

Due to the variable nature of the profiles of CAPD, an absolute gold standard for deriving both sensitivity and specificity data for CAPD evaluations, does not exist (ASHA 2005). To overcome this, suggestions have been made for determining test efficiency as it is necessary in order to ascertain whether the test is worth conducting. The first suggestion is the use of a lesion-based approach. This approach involves including individuals with identified, known, pathologies along the central auditory pathway in order to establish sensitivity and specificity data for dysfunction in the central auditory system (ASHA 2005). Therefore, we utilize data from patients who have anatomically confirmed central auditory dysfunction as a means for identification of the presence of central auditory dysfunction in individuals who are suspected to contain a CAPD (ASHA 2005).

A second suggestion for a gold standard when assessing efficiency is the use of a behavioral gold standard. In order to identify the behavioral gold standard researchers have recognized individuals with and without the behavioral attributes of a CAPD, defined by ASHA (2005), and then identified the degree to which their test measure was sensitive and specific in its identification of (C)APD (Schow et al., 2007). However, this approach is not ideal as without direct physiological measures the physiology remains a mystery (Schow et al., 2007). The inherent weakness is found within this system, for one can never make an absolute claim about the presence or location of a CANS lesion in a patient diagnosed with a CAPD. The conclusions can be how well the tests predicts the behavior that led to the development of the test (Schow et al., 2007). Despite its limitations, there is utility in this approach (Domitz & Schow 2000; Schow et al., 2000).

Domitz & Schow (2000) compared the SCAN to the MAPA which was used as the behavioral gold standard to assess whether the SCAN had a good sensitivity and specificity when evaluating for a CAPD. The MAPA contains five different subtests and requires skills present in three of the five domains ASHA (2005) states it is necessary for adequate auditory processing skills (Schow et al., 2007). They tested 81 school age children using this assessment and those that fell 2 standard deviations (SD) below the mean were determined as to have a deficit in auditory processing skills. This initial measurement constituted the behavioral gold standard against which Domitz & Schow (2000) compared the SCAN to. They found a sensitivity of 45% and a specificity of 95% with the percentage of false positives coming in at 5% and the percentage of false negatives at 55%. In simpler terms, we can rely almost emphatically on the results of the SCAN when they ascertain that the child does NOT have an APD. However, when the results indicate a positive diagnosis, it's imperative that further objective testing be completed to fully corroborate the results.

Discussion

This systematic review was designed to examine the evidence regarding the use of the SCAN and SCAN-C for diagnosing school-age children with Central Auditory Processing disorders. The purpose was to systematically review studies which have been published since 1985 that exhibit the reliability and validity of the SCAN and subsequent SCAN-C as an appropriate measure for CAPD.

Is the SCAN an Appropriate Measure for Assessing Auditory Processing Disorders in School-age Children?

When diagnosing school age children with an Auditory Processing Disorder, it's imperative to factor in all aspects of the disorder and its' effect on the child's ability to process information. An appropriate means to go about doing so would be a test battery that includes information on the child's ability to attend, temporal processing ability, binaural integration and summation, the ability to process degraded speech and auditory closure. All current research reviewed points to the usefulness of the SCAN and SCAN-C in the diagnosis of CAPD as long as it's incorporated to a much larger test battery and not utilized as a standalone measure. The reason being so as not to cause a scenario where children who may be suffering from an auditory processing disorder are not identified and subsequently do not receive proper intervention. Therefore, by incorporating the additional tests along with the SCAN, the evaluator is able to identify and treat more children who may be experiencing difficulty with auditory processing skills.

When compared to other measures of CAPD the SCAN falls short in evaluating certain skills necessary for proper auditory processing ability that are present in the MAPA and the CELF-R (Domitz & Schow 2000; Keith et al., 1989). Furthermore, even though there were significant correlations between the Filtered Words and Auditory Figure Ground subtests with the SSW and CST, the correlation was very low which further exhibits the need for a test battery that is multifaceted (Keith et al., 1989).

The revisions made to the SCAN, culminating into the SCAN-C, allowed for improvements made to the original test based on the concerns proposed by other researchers (Keith 2000). Despite those improvements, the SCAN-C created many false positive APD diagnoses when used for assessing children in the UK. However, those concerns were easily mollified with the use of modifiers to account for the language differences.

Other researchers, such as Emerson et al., (1997), were more concerned with the test setting rather than the test itself. Their argument being that when measuring school-age children for an APD which will create learning difficulties in the classroom, the test setting should mimic the classroom setting proving difficult for them. By testing in an idealized setting, there was a concern that many children who may have difficulty in the classroom will not be properly diagnosed as the test setting is not reflective of the child’s learning environment (Emerson et al., 1997). In addition to test setting, the timing of the evaluation is a vital component as well. When children were re-tested after a 6-7 week time frame their scores increased significantly on the SCAN (Amos & Humes 1998). Therefore to infer the child’s best performance it is necessary to perform multiple tests over a few weeks’ time.

Which Tests are the Most and which are the Least Sensitive and Specific?

There is a lack of evidence pointing in either direction whether the SCAN, SCAN-C or any subtext of the SCAN is adequately sensitive or specific when diagnosing an APD against an anatomical gold standard or a behavioral gold standard. However, according to Domitz and Schow (2000) it's been established that the SCAN is highly specific but only marginally sensitive when utilizing a behavioral gold standard and comparing the SCAN alongside the MAPA (Domitz and Schow 2000; Schow et al., 2007). . These results indicate that we can almost always rely on a negative diagnosis (indicating a lack of an APD); however, a positive APD diagnosis (indicating the presence of an APD) conducted by the SCAN requires further testing.

Recommended CAPD Evaluation Protocol

Built on the systematic review conducted and the research available the following protocol is a reliable and valid means to assess a child for an auditory processing disorder:

- Case History: A thorough case history is the first step in the evaluation of a CAPD and is vital in order to ascertain the child's age, communication difficulties, family/ genetic history and language history. The history should further include information on the child's educational and social development, cultural and linguistic history, and any therapies or current treatments that he is currently undergoing (ASHA 2005).
- Peripheral assessment of the auditory system: Before beginning an auditory processing evaluation one must ensure that the child has a fully functional peripheral system through which sound can accurately pass through. If the peripheral system isn't working properly, the results of the evaluation may not be correct. A basic peripheral assessment includes measuring hearing thresholds, speech testing,

tympanometry and acoustic measurements, ABR testing, and optoacoustic emissions (OAEs). If there are inconsistent results, further testing is necessary to rule out AN/AD before continuing with the auditory processing evaluation (ASHA 2005).

- The Selective Auditory Attention Test (SAAT): This test evaluates the child's ability to attend adequately in order to accomplish the tasks asked of him during an auditory processing evaluation. This assessment is vital to ensure that the results obtained are accurate and not skewed due to the child's inability to attend. Often the effects of the child's attention disorder will negatively interfere with the results which may lead to an erroneous diagnosis of CAPD (Chermak et al., 1999).
- Dichotic Testing: dichotic testing includes the competing words and competing sentences tests within the SCAN-C test battery which evaluates both binaural integration and binaural separation. Additional dichotic tests such as dichotic digits and the Staggered Spondaic Word Test (SSW) should be included for further information on binaural integration. Dichotic testing is useful as a means of providing information on the temporal lobe as well (Musiek & Baran 1987; ASHA 2005).
- Temporal Processing and Patterning Tests: These tests are useful in examining the child's ability to analyze acoustic stimuli over time, such as sequencing and patterns (completed in the Pitch Pattern test) as well as the Gap Detection test incorporated in the SCAN-C. The results of these tests are valuable in measuring the temporal lobe. (Musiek & Baran 1987; ASHA 2005).
- The SCAN-C: Further subtests in the SCAN-C test battery such as the Time Compressed Sentences test is useful when measuring auditory closure ability (ASHA 1996).

This thorough protocol is recommended as the SCAN-C test battery alone has low sensitivity. Therefore, we cannot guarantee that a positive diagnosis is a true positive. By following the full protocol with the additional tests, we can ensure that the resulting diagnosis is a true measurement of the child's auditory processing ability.

Rehabilitation & Management

Following the diagnosis of a CAPD, most often treatment protocol attempts to address three goals simultaneously: direct skills remediation, compensatory strategies, and environmental modifications (ASHA 2005). Direct skills remediation utilizes the bottom-up approach and is also referred to as auditory training (ASHA 2005) includes procedures attempting to address intensity, frequency, gap discrimination, pattern recognition, temporal ordering/ sequencing, and understanding auditory stimuli presented in background noise (ASHA 2005; Bellis 2011).

The second facet of treatment, compensatory strategies, employs the top-down theory by minimizing the effect of the residual CAPD that hasn't been addressed via auditory training. Compensatory strategies strengthen higher order central resources (such as attention, language and memory) which help alleviate the difficulties involved with poor auditory processing skills as they improve communication, listening, social outcomes (ASHA 2005).

Finally, the third means of addressing an auditory processing disorder is environmental modifications that eliminate any distractions or impedances presented by the environment that might exacerbate the CAPD. Environmental modifications may include preferential seating, the use of visual aids and/or assistive listening devices (FM system) (ASHA 2005). These modifications ensure that the child has adequate access to the acoustic stimuli they must process.

Conclusions

Clinical Implications:

1. Testing should occur twice over a reasonable time frame to allow for the child's best performance.
2. When testing children from the UK, modifications should be made to adjust for language differences and rater biases.
3. When testing for a CAPD, the SCAN or SCAN-C alone should not be the sole determinant for diagnosis. A complete diagnostic test battery should be incorporated to achieve maximum diagnostic potential. This would include the addition of the MAPA (incorporates testing for temporal ordering and binaural integration (Domitz & Schow 2000) and the CELF which provides information on the child's ability to utilize abilities related to syntax, semantics, memory, and word retrieval (Keith et al., 1989).

Research Needs:

1. Further research is required on the SCAN-C as it is the most recent version making it the more utilized test battery.
2. There is a need for more research on how to incorporate the SCAN-C into a broader test battery in order to ensure that no child is miss-diagnosed.
3. Additional research is required on the sensitivity and specificity of the SCAN in order to better rely on the diagnostic results.

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