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EXAMINING THE BEHAVIORAL CHARACTERISTICS OF CHILDREN AT-RISK OF SENSORY MODULATION DEFICITS AND AUDITORY PROCESSING DEFICITS

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Examining the Behavioral Characteristics of Children At-Risk of Sensory Modulation Deficits and Auditory Processing Deficits

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Abstract

Early childhood is a critical time for expediential neurological growth that provides the foundation for learning, playing, self-care, and social engagement. Deficits in processing auditory input beyond peripheral hearing can impede this early neurological foundation in children. Deficits in sensory modulation (SMD) and auditory processing (APD) are two disorders that appear to have similar auditory behavioral characteristics but have not been compared in the literature. The purpose of this study was to determine the number of children at-risk of these two disorders, determine if there was a relationship between the characteristics of children at-risk of these two disorders, and determine the predictors of each condition. A quantitative study using a non-experimental design was used to answer the research questions. Retrospective data from the Short Sensory Profile and the Tests for Auditory Processing Disorders were obtained from 309 children ages 5 years through 11 years, 11 months that were referred for an occupational therapy evaluation at a private clinic in western United States. Results indicated that 52.4% of the cases were at-risk of SMD and 5.9% of the cases were at-risk of APD. Those at-risk of both SMD and APD were 3.4%. There was a significant relationship between subjects having Attention Deficits Hyperactivity Disorder and being at-risk of SMD. There was also a significant relationship between having Autism Spectrum Disorder and being at-risk of APD. The odds of being at-risk of SMD were 2.75 times higher if the subjects had ADHD and the odds of being at-risk of APD were 5.12 time higher if the subjects had ASD. Results indicated that for this sample, the majority of children have auditory deficits within SMD and not APD. A very small number of cases had co-morbidity of APD and SMD. Professionals need to refer children with ADHD for evaluation for SMD and children with ASD for APD. Additional research is needed to examine these finding in the general population.

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Examining the Behavioral Characteristics of Children At-Risk of Sensory Modulation Deficits and for Auditory Processing Deficits

Sensory modulation disorder (SMD) is a neurological condition that encompasses an inefficiency in regulating and responding appropriately to sensory experiences resulting in impaired participation in daily life (Miller, Anzalone, Lane, Cermak, & Osten, 2007). Sensory modulation disorder is a subtype of the over-arching disorder identified as sensory processing disorder. Sensory modulation deficits specific to the auditory system occur when sound over-registers, under-registers, or causes a child to seek constant input, also referred to as sensory craving (Miller et al., 2007). Modulation deficits within the auditory system differs from other auditory deficits such as auditory processing disorder, which is the inability to identify the fine details of auditory sensation, such as hearing the difference between bad and lad (Kuczynski & Kolakowsky-Hayner, 2011). While these described auditory deficits have distinct definitions, in children they can present with similar behavioral expressions, such as inattention in a noisy environment (Chermak, Tucker, & Seikel, 2002; Dunn, 1999; Ferre, 2015). It is unknown if these two auditory deficits are related and if so, how are they related.

In clinical practice settings, it is typical for occupational therapists (OTs) to address sensory modulation deficits and for audiologists to focus on auditory processing deficits. While best practice calls for interprofessional collaboration in rehabilitation, it is more common for children with auditory deficits to be seen by only a single discipline (American Speech and Hearing Association [ASHA], 2005; Sharma, Purdy, & Kelly, 2012; Tazeau & Hamaguchi, 2013). Typically, audiologists evaluate children with auditory processing concerns with assessments, such as the Children: Tests for Auditory Processing Disorders, third edition (SCAN-3: C). This assessment measures various components of how auditory input is processed beyond the peripheral auditory system (Keith, 2009). Children who have difficulty in their everyday activities, such as school, play and self-care due to sensory deficits are often referred to OTs. Occupational therapists use screening tools, such as the Short Sensory Profile (SSP), which measures behavioral responses to auditory sensations and other sensations that occurs in their natural environment (Dunn, 1999). Common practice of only one discipline addressing auditory deficits could put children at risk for not receiving appropriate intervention for all auditory deficits impacting their development. In addition, there is a lack of research that has examined the number of children who are at-risk for either or both sensory modulation deficits and auditory processing deficits that interfere with childhood development (de Wit et al., 2017; Tazeau & Hamaguchi, 2013). Therefore, the purpose of this study is to determine the number of children at-risk of a sensory modulation deficit and being at-risk of an auditory processing deficit in children referred for OT and if there are characteristics associated with being at-risk of one or both of these conditions. To meet this purpose, the following objectives were addressed.

1. To determine the number of children at-risk of sensory modulation deficits, at-risk of auditory processing deficit, or at-risk for both.
2. To determine if there is a relationship between patient characteristics and being at risk of one or both of these conditions. If warranted, determine predictors of each condition.

Results from this study may be used to support a clearer understanding of the relationship among these two pediatric conditions and strengthen the ability to screen and refer these children appropriately. Results also have the potential to support therapists to design and implement treatments that are specific to the characteristics of identified deficits.

Literature Review

Sensory modulation deficits in the pediatric population can have a negative impact on childhood development (Ahn, Miller, Milberger, & McIntosh, 2004; Parham & Mailloux, 2015; Shapiro, 2016). Children may become overwhelmed and miss important auditory information in a noisy school environment causing poor academic performance (Aazh, Moore, & Prasher, 2011). Social events may be avoided due to the overwhelming sensory experience, impacting the ability to form and keep friendships (Ben-Sasson, Carter, & Briggs-Gowan, 2009; Cosbey, Johnston & Dunn, 2010). The National Center for Health Statistics reported that approximately 30% of all children identified with developmental concerns receive services prior to kindergarten (Rice et al., 2014; Salinas, Gutierrez, Garcell, & Hernandez-Montiel, 2013). Identifying developmental delays in and of itself can be challenging, relying on parent education, teachers, pediatrician's, and other health professional's knowledge of appropriate developmental screening tools, and follow through by families to obtain needed services when recommended (Center for Disease Control and Prevention, 2019). Based upon the literature, it is unknown the current percentage of children at risk for sensory modulation and/or auditory processing and how they are being identified during the early childhood period of development.

The most recent research that examined the prevalence of sensory modulation disorder was nearly fifteen years ago (Ahn et al., 2004). Based upon results of a survey completed by more than 700 parents of kindergarten children, approximately 5% had deficits in sensory modulation (Ahn et al., 2004). The prevalence of auditory processing disorder in children has primarily been studied by the United States and United Kingdom (American Academy of Audiology [AAA], 2018; Hind et al., 2011). The most recent research published on the prevalence of auditory processing disorder was in 2011 (Hind et al., 2011). Approximately 5.1%

of children referred to an audiologist due to difficulty listening in noisy environments had auditory processing deficits (AAA, 2018; Hind et al., 2011). The ratio of males to females with sensory processing disorder was found to be 2:1 (Chermak & Musiek, 1997; Fraiser, Goswami, & Conti-Ramsden, 2010; Palfery & Duff, 2007). There is limited research exploring gender difference in children with sensory modulation disorder. A study by Schoen, Miller, and Flanagan (2018) identified a higher number of boys to girls (78% to 22%) with sensory processing disorder in a pre-post retrospective study looking at the efficacy of treatment. Articles located that included gender difference in children identified with sensory modulation deficits were under the umbrella term sensory processing disorder. An older article of 20 years identified auditory processing disorder was more prevalent in boys at the rate of 2:1 (Chermak & Musiek, 1997). This study aims to better described prevalence, characteristics, and possible relationship between sensory modulation deficits and auditory processing deficits that is lacking in the literature.

The Importance of Screening At-Risk Children

Early childhood has been identified as the critical period for screening and identifying developmental deficits based upon the neuroplasticity that occurs at a rapid pace during this time (González Salinas, Garcia Guierrez, Garcell, & Hernandez-Montiel, 2014; Mundkur, 2005). Neuroplasticity is influenced by a positive environment that presents opportunities for exploration, experience, and mastery specific to the needs of the child (Mundkur, 2005). An environment that is considered a poor fit for children's individual differences can cause stress and hinder the needed neuroplasticity that supports development (Barrasso-Catanzaro & Eslinger, 2016; Miller, Reisman, McIntosh, & Simon, 2001). Individualized intervention that supports development, first requires appropriate screening and referrals to the necessary professional services. Accurately screening children at risk for delay is dependent upon a thorough list of indicators and knowledge of overlapping behavioral characteristics among various developmental disorders (de Wit et al., 2017).

Professionals are challenged when the symptoms presented by a child do not fit into one single condition, thus there can be variability in referral and diagnosing the condition. A case study by Russell, Norwich, and Gwernan-Jones (2012) followed a six-year-old child that had symptoms of learning difficulties, who was assessed by an interdisciplinary team and three different school psychologists. The child received three different diagnoses, revealing the inherent overlapping characteristics of conditions that challenge learning (Russell et al., 2012). Unless there are clearly defined characteristics of a disorder, professionals are not able to decipher between a single condition or co-morbidity.

Studies addressing characteristics of auditory processing disorder and sensory modulation disorder with other pediatric disorders have occurred, but none have compared these two processing disorders. Characteristics of auditory processing disorder and attention deficits were studied by Gyldenkaerne, Dillon, Sharma, and Purdy (2014) concluding that APD and attention deficits co-exist in some children but were also independent conditions. A study examined the comorbidity of language and reading deficits in a group of children (*N* = 68) with auditory processing disorder (Sharma et al., 2012). Results indicated about half of the children had all three deficits, others had reading and auditory processing deficits, and others had language and auditory processing deficits. Stand-alone conditions were limited. When looking at co-morbidity in sensory modulation disorder, a study by Yochman, Alon-Beery, Scribman and Parush (2013) examined the ability to differentiate between sensory modulation disorder and attention deficit hyperactive disorder. Results indicated significant group differences in sensory responses but not attention. Miller, Nielsen, and Schoen (2012) compared behavior and physiological aspects of children with attention deficit hyperactive disorder (ADHD) and SMD. Based on the results, the researchers indicated children with ADHD had more behavioral deficits with inattention and children with SMD had more deficits in sensory and emotional behaviors. Also, children with SMD had a greater degree of physiological/electrodermal response to sensory experiences than children with ADHD (Miller et al., 2012). Another study used a Sensory Challenge Protocol, with results indicating sensory modulation deficits in children with ADHD based upon increased levels of cortisol and electrodermal measurements (Lane, Reynolds & Thacker, 2010). These are a few examples of studies that have examined sensory modulation deficits and auditory processing disorder with other diagnoses, yet the author was not able to locate one study that differentiated between sensory modulation and auditory processing (Ghanizadeh, 2011; Pfeiffer, Daly Nicholls, & Gullo, 2014; Rogers, Hepburn, & Wehner, 2003; Tomchek & Dunn, 2007). The lack of this research may hinder early identification and appropriate treatment of children at risk for these disorders.

Sensory Modulation Deficits

When it comes to screening children at risk for sensory modulation deficits, this disorder is not included in the Diagnostic and Statistical Manual of Mental Disorders-5th edition (DSM-5), which defines and classifies mental health conditions (Wikipedia, 2018). The current edition of Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood (DC: 0-5) does include sensory processing disorder under Axis 1: Clinical Disorders and defines this as behaviors that reflect abnormal regulation of sensory input (Zero to Three, 2016). The educational system identifies sensory modulation disorder as a condition which impairs academic achievement as “Other Health Impairment” (Lucker, 2015; Ohio Department of Education, 2014). Sensory modulation deficits occur when there is an inability to adapt and elicit an appropriate behavioral response comparative to the sensory experience (Miller et al., 2001). Responses may be influenced by task demand, intensity of sensory sensation, and duration of input (James, Miller, Schaaf, Nielsen, & Schoen, 2011). It is the combination of all these factors that may impact a child's reaction to sensory experiences. Children with efficient sensory modulation abilities are able to filter out undesirable or unimportant sensory information and focus on what is important (Miller et al., 2007).

There are three subtypes of sensory modulation, including sensory over-responsivity (SOR), sensory under-responsivity (SUR), and sensory craving (SC) (James et al., 2007). When a child has difficulty managing the sensory demand, it may be due to the sensation perceived with too much intensity, referred to as SOR (Miller et al., 2007). When considering SOR in the auditory system, children may react to non-noxious sounds as threatening, painful, loud, and/or extreme agitation (Ben-Sasson et al., 2009; Tyler et al., 2014). Auditory SOR has been identified as co-occurring in various diagnoses, such as Autism Spectrum Disorder (63%) (Van Hulle, Schmidt, & Goldsmith, 2012), Williams syndrome (95-100%) (Aazh et al., 2011), ADHD and Fragile X (Reynolds & Lane, 2007). The prevalence of children at risk for sensory modulation deficits with auditory SOR is unknown and it is unknown if this condition overlaps with auditory processing deficit.

Another behavioral response identified in some children with sensory modulation deficits is sensory under-responsivity (SUR) (Miller et al., 2007). This can be observed in children that do not respond or have a poor awareness to one or more sensation. Auditory SUR can present itself as children appearing not to hear their name called out, or the sound of a car coming toward them when running out to get a ball. The prevalence of children at risk for sensory modulation deficits with auditory SUR has not been determined, nor if this condition overlaps with auditory processing.

Sensory craving is when a sensation is continually sought out without a meaningful saturation of input (Miller et al., 2007). Auditory SC is observed when a child constantly makes audible sounds either vocally (humming, talking, singing, or other non-verbal sounds) or through the environment (tapping a pencil, tapping finger on a desk, or tapping foot on the floor). Similar to both SOR and SUR, the prevalence of children at risk for SC has not been explored or determined if it overlaps with auditory processing deficits.

Screening for Sensory Modulation Deficits

Various tools are used to screen sensory modulation deficits in practice. The Sensory Processing Measure (SPM) includes subtests for both sensory modulation and postural disorders (Parham et al., 2007). Touch Inventory for elementary school-aged children (TIE) measures SOR in the area of touch (Royeen & Fortune, 1990). Sensory Experiences Questionnaire 3rd ed. (SEQ) measures SUR and SOR in children with ASD (Ausderau & Baranek, 2013), and the Sensory Processing Three Dimensions Inventory (SP3D) measures SOR, SUR, and SC (Miller, Schoen & Mulligan, 2016). The Short Sensory Profile (SSP) is frequently used as a screening tool by OTs when measuring sensory modulation deficits (McIntosh et al., 1999). During its development, its intent was to provide professionals an appropriate screening tool to identify sensory modulation deficits and to be used for research (Dunn, 2008). The SSP is a 38-item inventory that uses a 5-point Likert scale (Always-1 point, Frequently-2 points, Occasionally-3 points, Seldom-4 points, and Never-5 points) rating the frequencies of a child's behavioral response to sensory input. Higher scores indicate more typical responses to sensory experiences (McIntosh et al., 1999). This screening tool has been used with a variety of disabilities in research. These include autism

(Tomchek & Dunn, 2007), pediatric bipolar (Engel-Yeager et al., 2016), Phelan-McDermid syndrome (Mieses et al., 2016), behavioral problems (Gourley, Wind, Henninger, & Chinitz, 2013), fetal alcohol syndrome (Hansen & Jirikowic, 2013), prematurity (Crozier et al., 2016), among others. It has been found to discriminate between children with and those without sensory modulation difficulties (Dunn, 1999). The SSP items are mainly focused on behaviors that indicate SOR, with a few exceptions of SUR. Auditory items on the SSP related to sensitivity were used for this study (Dunn, 1999).

Auditory Processing Deficits

Auditory processing disorder is not included in the DSM-5, similar to sensory modulation disorder, nor the DC: 0-5 classification manual (Child Mind Institute, 2018; Zero to Three, 2016). The AAA (2010) and ASHA (2005) define auditory processing and its practice guidelines within their scope of practice. Auditory processing is the ability to recognize the fine details of spoken language, which is processed in the central auditory system. Deficits in auditory processing are not directly related to peripheral hearing loss, cognitive deficits, poor attention, or language disorder (ASHA, 2005). Specific auditory skills are related to auditory discrimination, binaural processing, and temporal processing. These three global areas involve the ability of an individual to lateralize and locate sound, order and integrate sound, and perform dichotic listening during competitive noisy situations. Auditory discrimination is the ability to analyze the fine details of sound, such as the phonemes of language. Binaural processing is the ability for both ears to work together to locate, attend, and listen to auditory sounds. Temporal pattern recognition is the ability to identify and separate the beginning and end of sounds presented is a sequence such as in a conversation (Ferre, 2015). Due to these many components of auditory processing, distinguishing auditory processing disorder from other dysfunctions require meticulous and accurate diagnostic skills (Bellis, n.d.).

To further understand auditory processing, five areas of listening are typically screened by audiologists for children demonstrating at-risk behaviors. These include auditory figure-ground, filtered words, competing words, and competing sentence (Keith, 2009; Ross-Swain, 2013). Auditory figure ground is the ability to process speech when in an environment with background sound. Filtering words is the ability to process distorted speech. Competing word is the ability to process speech when words are presented in each ear at the same time. Lastly, competing sentences is the ability to process and repeat back a sentence when unrelated sentences are presented in the left/right ears at the same time (Keith, 2009). Screening results determines if a global evaluation is deemed by the appropriate profession(s) (Chermak et al., 2002; de Wit et al., 2017).

Screening for Auditory Processing Deficits

The SCAN-3: C is the third edition of the children's version of Tests for Auditory Processing Skills, which is standardized to screen and contribute to the diagnosing of auditory processing deficits. It is used with children ages 5 years 0 months to 12 years 11 months, measuring auditory figure-ground, filter words, competing words-directed ear, competing sentences, and ear advantage (Keith, 2009). Using an EBSCO search, this screening tool has been used in around 90 research studies and have focused on etiology, diagnosis, therapy, prognosis, and clinical prediction. There is no gold standard auditory processing screening or diagnostic tool but the SCAN-3: C and its prior versions have been widely used in research and is considered an evidence-based diagnostic test battery (Keith & Farah, 2013).

Purpose of Study

Children may demonstrate early symptoms of SMD or APD as demonstrated by having difficulty processing sound at a very early age without having peripheral hearing loss. During infancy and toddler ages, behaviors such as a lack of response to sound, crying when in a crowded room, or lack of visual focus when competing sounds occur may indicate deficits in auditory processing or sensory modulation (Geffner, 2013; Williamson & Anzalone, 2001). Older children may have difficulty following verbal directions, mispronouncing words, or become aggressive when loud or unexpected sounds occur (Geffner, 2013; Tazeau & Hamaguchi, 2013). Many of these behaviors are described by parents and teachers when determining if further evaluations are needed. These behaviors are noted on screening tools used by both audiologists and occupational therapists. Confusion can occur when determining what professionals should be involved in screening and assessing these children secondary to overlapping symptoms or co-morbidity (Tazeau & Hamaguchi, 2013). Peripheral hearing loss is screened typically in school settings, primary care visits, or free community screening services (AAA, 2011). When there is no peripheral hearing loss, but children continue to have auditory deficits, further screening should occur to determine if a modulation or processing problem is occurring within the auditory system. Currently, there are no studies that have examined the same and/or different characteristics for SMD and APD, which can cause listening difficulties when there is no peripheral hearing loss. It is the purpose of this study to define these characteristics and evaluate the prevalence of children at risk for these two deficits. It is also the purpose of this study to determine if there is a relationship between these characteristics and being at risk for one or both of these disorders. If appropriate, determine the predictor factors for each of these conditions.

Clinical Relevance

When it comes to children with sensory modulation and/or auditory processing deficits, a single discipline is currently the primary practice approach used by health care professionals. It has been found that using an inter-professional approach to services has multiple benefits that outweigh the single discipline approach (Green & Johnson, 2015). These include empowering health professionals to make treatment recommendations, lessen the chance for missed deficits and miscommunication to client, provide a comprehensive view of client, promote affective and cost-efficient services, increase morale, and promote patient-center care (Education Management Solutions, 2017). As health and educational cost rises, an inter-professional approach to evaluation and treatment for children with auditory deficits can provide the efficiency needed to lessen the financial burden on families and health entities.

The focus of occupational therapy is to promote health, well-being, and participation of daily activities that individuals find purposeful and meaningful (American Occupational Therapy Association [AOTA], 2014). The framework of the profession is carried out with the use of clinical reasoning, which includes an understanding of the scientific condition of the individual (Schell & Cervero, 1993). The clinical relevance of this study is to guide the early screening stage of services in order to make referrals to the most appropriate discipline for a more comprehensive evaluation. A clearer understanding of these two conditions can guide disciplines to develop and implement appropriate treatment according to the specific deficits. Each team member needs to understand their role on the team and ways to better collaborate. This research will provide the foundation for future research looking at the efficacy of treatment using an inter-professional team approach when working with children with deficits in the auditory system in order to promote health and well-being.

Method

Study Design

This was a quantitative study using a non-experimental design. Trochim and Donnelly (2007) describes this as a strong and appropriate method of research to uncover new meaning and describe what already exist. Retrospective data was obtained from charts of children evaluated for sensory modulation and auditory processing concerns at a private pediatric clinic in Greenwood, Colorado. The study obtained data from medical charts from January 1, 2010 to July 6, 2018. Before data was extracted from the medical records, the study was approved by the Institutional Review Board (IRB) at Shawnee State University. The Human Research Protection Program at the University of Indianapolis entered into a reliance agreement with Shawnee State University.

Participants

Potential participants were identified through hands-on examination of medical charts of children age 5 years, 0 months through 11 years, 11 months at the time of testing. The primary researcher (B. W.) determined participant eligibility through a review of their medical record. Inclusion criteria include:

- Age 5 years, 0 months through 11 years, 11 months.
- Evaluated at the facility for both sensory modulation and auditory processing concerns as identified by having a sensory modulation assessment (SSP) and an auditory processing assessment (SCAN: C/SCAN-3: C) completed from January 1, 2010 to July 6, 2018.

Exclusion criteria included:

- Children with noted neurological impairment (i.e. stroke, cerebral palsy, traumatic brain injury, and/or peripheral hearing loss).

- Incomplete charts missing composite test scores on the SSP and/or SCAN:C/SCAN-3: C.
- Any tests (SSP and SCAN: C/SCAN-3: C) in which the evaluator modified the standardized procedures as noted in the evaluation report.

Data Collection

All data for participants who met the inclusion criteria were collected and entered into a Microsoft Excel spread sheet by the primary researcher. This nonrandomized, purposeful sampling method was used to ensure only charts relevant to answer the research questions were used for this study. The following demographic information was collected from the charts: age, gender, ethnicity, parent education, diagnoses, ear tubes, as well as sub-scores and composite scores of the SSP and sub-scores and composite scores of the SCAN: C/SCAN-3: C. Each participant was assigned a unique study identification number that was used when entering data. Once all data was collected, all participant identifiers were permanently removed. Data was checked for errors, cleaned, and exported into a statistical software program for analysis.

Operational definition of variables. This study defined being at-risk for sensory modulation deficits as having a composite score from all seven subtests within the definite difference range (38-141) on the SSP. It also included at least one of the two auditory subtests of the SSP that indicated definite difference.

Being at-risk for auditory processing deficits was operationally defined as having a scaled score below 7 on two or more of the four diagnostic subtests (auditory figure-ground, filtered words, competing words-directed ear, competing sentences) on the SCAN: C/ SCAN-3: C. It also included a composite standard score that fell within the disorder range (69 or below).

Being at-risk for both SMD and APD were operationally defined as having scores fall within the definite difference range in one or both of the auditory subtests of the SSP and a composite score that fell within the definite difference range. It also included having a scaled score below 7 on two or more of the four diagnostic subtests and a composite standard score that fell within the disorder range on the SCAN: C/SCAN-3: C.

Instruments

Short Sensory Profile. The SSP is a 38-item inventory that uses a 5-point Likert-like scale that ranges from 1 = always to 5 = never and rates the frequency of a child's behavioral response to sensory input (McIntosh et al., 1999). The 38-items are categorized into sensory related groups that include: tactile sensitivity, taste/smell sensitivity, movement sensitivity, under-responsive/seeks sensation, auditory filtering, low energy/weak, and visual/auditory sensitivity. Subtest totals and total composite scores fall within one of three classifications, typical performance, probable difference, or definite difference. Higher scores indicate more typical sensory processing. Composite scores ranges: 155-190 for typical performance, 142-154 for probable difference, and 38-141 for definite difference was used for this study based upon the manual (McIntosh et al, 1999). Subtests for auditory filtering scores range are typical performance range from 23-30, probable difference range from 20-22, and definite difference range from 6-19 and visual/auditory sensitivity scores ranges are: typical performance range from 19-25, probable difference range from 16-18, and definite difference range from 5-15 (McIntosh, 1999). The composite score of all subtests and scores of auditory filtering and visual/auditory sensitivity was used as part of the analysis for this study.

The SSP has been found to have good reliability and validity. Cronbach's alpha ranged from .70 - .90 (Auditory Filtering $a = .87$) for internal consistency. The subtest constructs supported the factor structure of the assessment, ranging from $a = .25$ to .76, $p < .01$. Ohl et al. (2012) examined the test-retest of the Sensory Profile, the version which the SSP was obtained from. The intraclass correlation coefficient (ICC) results ranged from .50 to .81 (Ohl et al., 2012). It was also determined that 95% of the time the SSP discriminated between children with and those without sensory processing deficits. The SSP is most appropriate to use with children ages 5 years, 0 months through 10 years, 11 months (McIntosh et al., 1999).

Children: Tests for Auditory Processing Disorders. The SCAN-3: C is the third edition of the children's version of Tests for Auditory Processing Skills, which is standardized to screen and diagnose auditory processing deficits. It is used with children ages 5 years 0 months to 12 years 11 months, including both screening subtests and diagnostic subtests (Keith, 2009). The diagnostic portion of the assessment will be used for this study. This includes filter words, auditory figure-ground +8 dB, competing words-directed ear, competing sentences, and a composite score. Scaled scores of 7 or above on each subtest are considered normal and auditory processing weakness is considered when scaled scores below 7 occur on two or more of the subtests (Keith, 2009). Composite scores of 85 or above is considered normal, 70 to 84 is considered borderline, and 69 or below is considered disorder.

The test-retest reliability of the SCAN-3: C ranges from ICC = .54 to .77 and internal consistency $a = .91$ (Keith, 2009). The evidence of test validity of the SCAN-3: C was based upon test content, response processes, internal structure, and special group studies. Results of intercorrelations indicate strong validity with the highest correlation between tests of similar skills ($r = .74$) and the lowest correlation between tests measure different skills ($r = .22$) (Keith, 2009). Concurrent and predictive validity were not completed on this assessment or any of the most common standardized assessments used to identify auditory processing disorder (Friberg & McNarmara, 2010). The third edition added ear advantage, which was not used in this study. Both the second edition and third editions were located within the charts of the study. The sub-scores and composite scores of both editions used the same standard score of measurement to determine auditory processing results. Only composite scores were used in this study.

Procedures

Each subject was assigned a unique study identification number that was used when entering data. Once all data was collected and analyzed, all participant identifiers were permanently removed. The primary researcher entered all demographic information and tests scores from medical charts of children that met the inclusion/exclusion criteria. The research assistant pulled medical charts and flagged the data for entry. Scores were double checked by the primary researcher at the time of entry to ensure accuracy when collecting assessment scores prior to entering them into Excel. Methods of ensuring accuracy of entry were by visually double-checking chart with entry, adding subtest scores to ensure they equaled the composite scores, and double-checking sum of scaled scores to the ensure they correlated with the composite score. Any discrepancy was reviewed by the primary investigator and corrected as needed.

Data Analysis

Data were analyzed using Microsoft Excel and R statistical package (R Core Team, 2013). An alpha level of less than .05 was considered statistically significant. To answer the first question of the number of children at risk for SMD, APD, and/or both disorders, Microsoft Excel was used to determine frequency/percentage. To answer the second research question of determining the relationship between the characteristics of children and being at risk of SMD, APD, and/or both disorders, descriptive statistics were first conducted for the entire sample using Microsoft Excel and R (R Core Team, 2013). Descriptive characteristics included the mean/standard deviation for age, and frequency/percentage for gender (male=0, female=1).

Diagnoses were identified by parents/guardian on the intake document and were coded as 0 for not having the diagnosis, and 1 as having the diagnosis, which included: Attention Deficit Disorder (no=0, yes=1), Attention Deficit Hyperactive Disorder (no=0, yes=1), Mood Disorder (no=0, yes=1), Autism Spectrum Disorder (no=0, yes=1), Dyslexia (no=0, yes=1), Emotional (no=0, yes=1), Learning Disorder (no=0, yes=1), other (no=0, yes=1). A 0 was coded if the subject had a different race other than white and 1 if the subject's race was white. A 0 was given for each parent of the child if he/she did not have college degree or a 1 if he/she had a college degree. Pressure Equalizer (PE) tubes were coded as 0 meaning no tubes or 1 meaning had tubes inserted. Initially, race was analyzed using Microsoft Excel based on data obtained (white, black, Hispanic, Asian, and other). The percentage was so high for those of the white race that this variable was converted to 0 as non-white and 1 for white. The same procedure was used for the parent's level of education. The initial data included high school, 2-year degree, bachelor, master's or doctorate degree. Due to the high percentage of college graduates of a bachelor's degree or higher, the variables were change to a 0 indicating no college education or 1 for having a college education.

Independent sample t tests were also conducted to answer the second question for subjects at risk of SMD, at risk of APD, and at risk of both across AGE. Independent sample t tests were used in order to test the statistical differences between the means of two groups (Portney & Watkins, 2009). The data met the requirements for this test since AGE is a continuous level of measurement, at risk for each condition is a categorical measurement (yes/no), there was no relationship between the subjects, normal distribution was met, and homogeneity of variances was assumed (Portney & Watkins, 2009). The level of significance was set at $p < .05$ to ensure results are at an acceptable level of probability, thus considered not occurring by chance (University of Connecticut, 2019).

Chi Square techniques were also used to determine if there is a true relationship between categorical variables (Statistic Solutions, 2019). The data must meet the requirements of being random, large expected cell counts of 5 or more, and subjects independent of each other (Kent State University, 2019). Field, Miles & Field (2016) suggests a correction to the Pearson formula using Yates Continuity Correction when examining 2x2 continuing tables in order to address inflated Type 1 errors. Using crosstabulation and $p < .05$, results determine if there is a statistical relationship between the categorical variables (Statistic Solutions, 2019). This study met the stated requirements and examined the relationship between the following categorical predictors; gender (GEN), attention deficit hyperactivity disorder (ADHD), mood (MOOD), autism spectrum disorder (ASD), learning disorder (LD), other (OTH), race (RC), mother's education (MOM), father's education (DAD), and tubes (TUB) and being at-risk for SMD, APD, and both. Field, Miles, and Field (2016) reported that expected cell frequencies should be greater than five to address low power thus lessening the chance for a Type II error.

To further explore the relationship established by Chi Square tests, standard logistic regression can be used to determine a model based upon binominal probability theory (Newsom, 2007). Standard logistic regression is not limited to dichotomous variable as with Chi Square and also not limited to one predictor (Newsom, 2007). Standard logistic regression analysis was performed on subjects that were identified as being at risk for the outcome SMD (Model 1) (0=NO, 1=YES) using ten predictors: age (AGE), gender (GEN), Attention Deficit Disorder (ADD), Attention Deficit Hyperactivity Disorder (ADHD), Mood (MOOD), Autism Spectrum Disorder (ASD), Dyslexia (DYSL), Emotional (EMO), Learning Disorder (LD), and Other

(OTH). Logistic regression analysis was also performed on subjects that were identified at risk of APD (Model 2) using eight predictors: age (AGE), gender (GEN), Attention Deficit Disorder (ADD), Attention Deficit Hyperactivity Disorder (ADHD), Mood (MOOD), Autism Spectrum Disorder (ASD), Dyslexia (DYSL), and Learning Disorder (LD). Coefficient estimate, odd ratios, 95% confident intervals (CIs), were examined at a .05 significance. Results from Chi Square and logistic regression were able to predict which variable increased the probability of SMD and APD. Due to low cell count for those identified with both conditions (Model 3), results were uninterpretable.

Standard logistic regression techniques were followed by backward stepwise regression models. This technique removes nonsignificant characteristics one at a time until only those characteristics that are significant remains (Portney & Watkins, 2009). The final predictor model based on the backwards regression was used to determine cut off points to create adequate sensitivity (true positive) and specificity (true negative) (Pedroli, 2019). A receiver operating characteristic graph (ROC), which has been shown to be a reliable technique for visualizing, organizing, and selecting classifications based on performance was conducted. Swets (1988) found that ROC analysis could be extended for use in visualizing and analyzing behavior of diagnostic systems and for determining accuracy of a test using the area under the curve. Receiver operating characteristic curve findings are interpreted based upon 1.0 being the strongest classification to predict having the behavior and <0.6 being the weakest classification (Pedrol, 2019). Percentage of accurate cases (PAC), sensitivity and specificity, backward elimination models, along with ROC were examined for each model to determine accurate classification and prediction.

Results

Demographic Characteristics

Table 1 describes the characteristics of the sample that were analyzed using descriptive statistics. Three hundred and ten cases were determined to meet the inclusion criteria for the study. Results indicated that the majority of the cases were a little older than 7 years old, white males, with parents having a college education.

Table 1. Demographic data

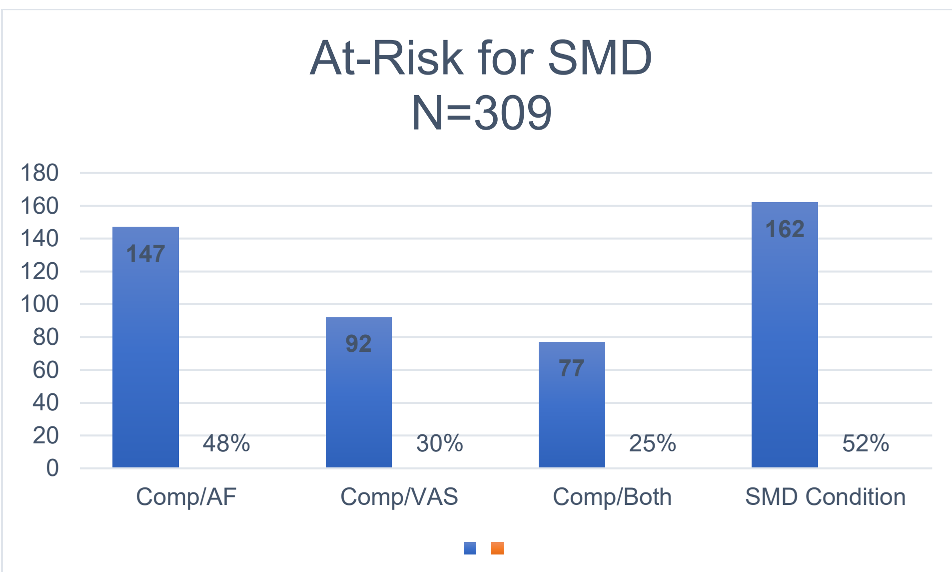
Descriptive variables	Frequency (Percentage)	
Gender (N=310)		
Females	78 (25.2%)	
Males	232 (74.8%)	
Race (N=288)		
White	237 (82.3.%)	
African American	1 (<1%)	
Asian	8 (2.7%)	
Latin American	9 (3.1%)	
Hispanic	12 (4.2%)	
Other	22 (7.6%)	
Parent Education (N=221)	Mother	Father
High School	11 (5.0%)	18 (8.2%)
Bachelor's degree	125 (56.1%)	105 (47.7%)
Graduate degree	86 (38.9%)	98 (44.5%)
Conditions (N=310)		
SMD and APD concerns only	206 (66.5%)	
ADD	8 (2.6%)	
ADHD	40 (12.9%)	
Mood	32 (10.3%	
Autism Spectrum Disorder	31 (10.0%)	
Dyslexia	5 (1.6%)	
Emotional	7 (2.3%)	
Learning Disability	15 (4.8%)	
Other	26 (8.4%)	
Medical Procedure		
PE Tubes	46/16.6%	

At-Risk of Sensory Modulation Disorder

Three hundred and nine cases had complete SSP scores to analyze. One case was not included due to missing test scores. Using R (R Core Team, 2016), 162 cases (52.4%) were at-risk for SMD based upon the operational definition for this study (definite difference on the SSP composite score and definite difference on at least one of the auditory subtests).

Specific to the auditory subtests on the SSP, 147 cases (47.6%) scored definite differences in auditory filtering and a composite score of definite difference. Ninety-two cases (29.8%) scored definite difference in visual/auditory sensitivity and a composite score of definite difference. Seventy-seven cases (24.9%) had both auditory filtering and visual/auditory sensitivity in the definite difference range and a composite score of definite difference. Figure 2 describes types of auditory deficits within SMD.

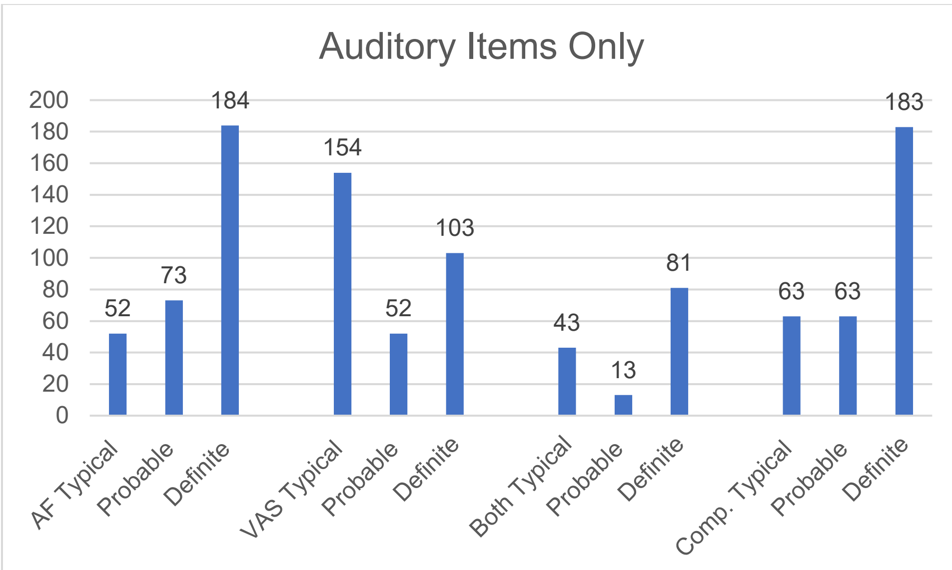
Figure 2. Results of cases at risk of sensory modulation disorder



Comp (composite score on the Short Sensory Profile), AF (auditory filtering), VAS (visual auditory sensitivity, Both (Auditory filtering and visual auditory sensitivity), SMD Condition (composite score of definite difference and a score of definite difference on at least one auditory subtest)

The auditory items on the SSP without combining the subtests with the composite scores, indicated deficits (probable and definite differences) occurred most often in the area of SMD auditory filtering (N = 309, 83.2%). This data is noted on the first set of bars (AF Typical, Probable, and Definite) in Figure 3 with additional auditory results included.

Figure 3. Auditory subtests of the SSP

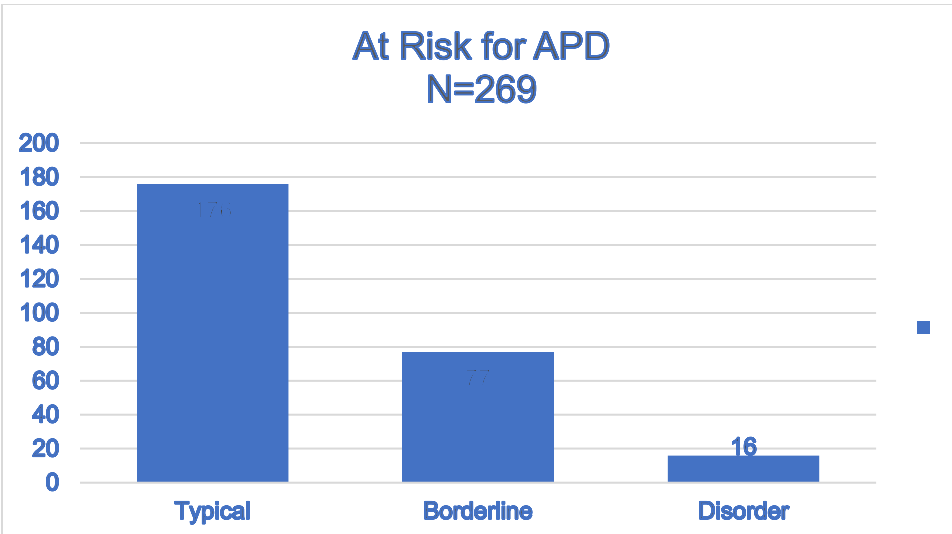


AF=Auditory Filter, VAS-Visual Auditory Sensitivity, Both=Auditory Filtering and Visual Auditory Sensitivity, Comp=Composite Score of the SSP

At Risk of Auditory Processing Disorder

Two hundred and sixty-nine cases had composite scores on the SCAN:C/SCAN-3:C to analyze. Forty-one cases out of the original 310 cases were not included due to missing test scores. Some charts had subtests from one version (SCAN-C) and subtest scores from the newer version of the assessment (SCAN-3: C), thus no composite scores were reported for these 41 cases. Using R (R Core Team, 2016), 16 cases (5.9%) were identified as being at risk of APD based upon the operational definition for this study (composite standard score that fell within the disorder range of 69 or below and a scaled score below 7 on two or more of the four diagnostic subtests). Seventy-seven cases (28.6%) scored within the borderline scale, and one-hundred seventy-six cases (65.4%) had composite scores within the normal range. See Figure 2 for details.

Figure 4. At risk of Auditory Processing Disorder

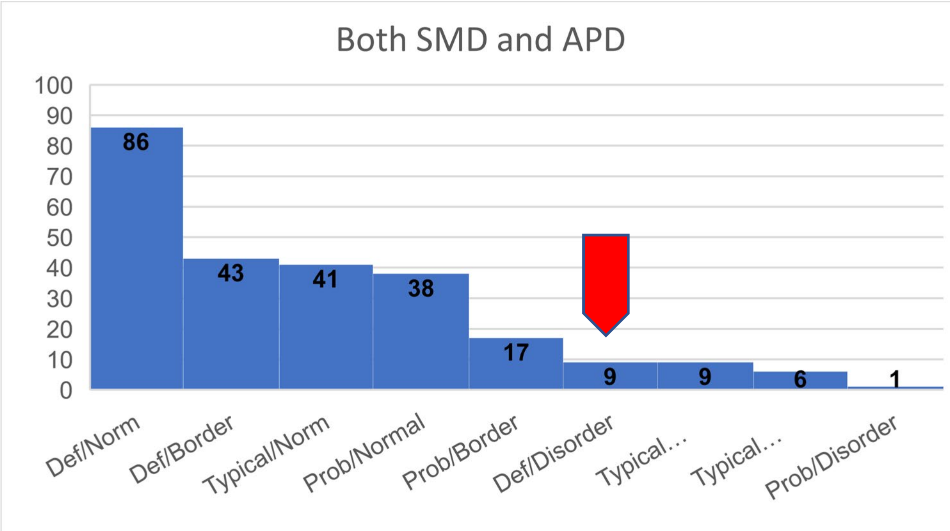


APD=Auditory Processing Disorder

At Risk of Both SMD and APD Conditions

Nine cases (N = 268, 3.4%) were at risk of both SMD and APD based upon the operational definition for this study. Thirty-one cases (15.2%) had composite scores on the SSP and the SCAN-C/SCAN-3: C that were in the typical/normal range for both conditions. Eighty-six cases (N =268, 32.1%), were at risk for SMD but had normal results for auditory processing. The remaining cases varied in results. Figure 5 describes these outcomes.

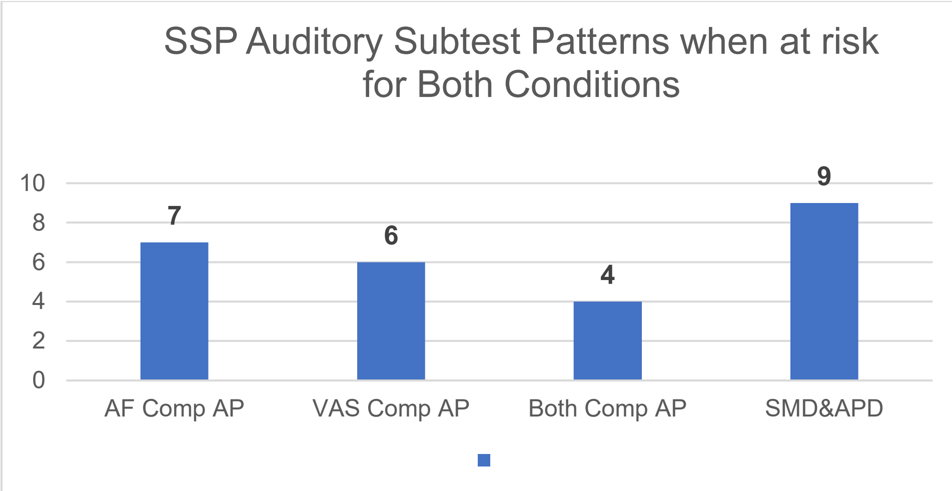
Figure 5. At Risk of both SMD and APD



SMD=Sensory Modulation Disorder, APD= Auditory Processing Disorder, Def=definite difference, Norm=normal, Border=borderline, Prob=probable. The first term is the results of the SSP and the second term is the results on the SCAN-3: C (SSP/SCAN-3: C).

When looking more closely at the SSP auditory processing subtests for those cases that were at risk for both SMD and APD (composite SSP as definite difference and disorder result on the SCAN-C/SCAN-3: C), there were 7 cases that had a sub–score of definite difference for auditory filtering. There were 6 cases that had a sub-score of definite difference for visual-auditory sensitivity and 4 cases that had sub-scores in the definite difference range for both auditory filtering and visual auditory sensitivities. Figure 6 describes these outcomes.

Figure 6. Auditory subtest results when at risk of both SMD and APD



AF: Short Sensory Profile Auditory Filtering subtest, Comp: Short Sensory Profile Composite score, AP: SCAN-C/SCAN:3C composite score

Relationship Between Patient Characteristics When Identified as Being at Risk of SMD, APD or Both Conditions

Independent sample t tests were conducted for subjects at risk of SMD, at risk of APD, and at risk of both across AGE. Age was not statistically significant between subjects who were at risk of SMD (M= 7.52, SE = 1.84) compared to subjects who were not at risk of SMD (M=7.37, SE=1.83); t (304.4) = - 0.72, *p* =.47. Likewise, for subjects at risk of APD with those who were not at risk for APD t (17.73) = -1.68, p = 0.11, and at risk for both; t (8.94) = -0.69, p = 0.51. Effect sizes ranged from small to medium (r =. 04 SMD, r = .22 APD, and r = .37 both). The results are presented in Table 2 for all values.

Table 2. Age

Variables	Test statistics	df	Sig	95 % CI lower	95% CI upper	Effect Size
SMD	-0.72	304.4	.47	-0.56	0.26	.04
APD	-1.68	17.73	.11	-1.54	0.17	.37
Both	-0.69	8.94	.51	-1.45	0.77	.22

"df=degrees of freedom, Sig=*p* value CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

Chi square techniques were used to examine the relationship between the categorical variables; gender (GEN), attention deficit hyperactivity disorder (ADHD), mood (MOOD), autism spectrum disorder (ASD), learning disorder (LD), other (OTH), race (RC), mother's education (MOM), father's education (DAD), and tubes (TUB) with being at-risk for SMD, APD, and both. Field et al. (2016) reported that expected cell frequencies should be greater than five to address low power, thus lessening the chance for a Type II error. Using test statistic value, the odds ratio was calculated to determine the strength of association of the 10 characteristic's and SMD. The results are presented in Table 3 with the variables that emerged with frequencies higher than five for SMD. All variables for APD and both SMD and APD emerged with cell frequencies lower than five, thus were not included. There was a significant relationship between subjects having ADHD and being at risk for SMD, (χ^2 (1) = 4.90, p < 05. The results indicated that the odds of being at risk for SMD were 2.34 times higher (1.10, 5.29) if the subjects had ADHD.

Table 3. Chi-square results for SMD with Yates Continuity Correction

Variable	Test Statistic	Sig	Exp (B)	95% CI Lower	95% CI Upper
Gender	1.33	.25	.715	.41	1.2
ADHD	4.90	.03*	2.34	1.1	5.3
Mood	0.42	.52	1.37	.61	3.1
ASD	2.59	.11	2.04	.88	5.0
LD	1.95	.16	2.60	.75	11.
Other	1.39	.24	1.79	.73	4.7
Race	0.00	.99	0.95	.50	1.8
Mother's Education	0.23	.63	0.61	.13	2.5
Father's Education	2.32	.13	0.39	.11	1.2
Tubes	0.58	.44	.743	.37	1.5

Sig=*p* value, Exp (B)= Odds Ratio, CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

Prediction of the odds of being at risk for SMD, APD, or both conditions

In order to determine if a subject's characteristics predicted the likelihood of being at risk of one or both of these conditions, standard logistic regression analysis with all characteristics entered into the equation at the same time was performed (Portney & Watkins, 2009). Additionally, backward stepwise regression was used by removing nonsignificant characteristics one at a time until only those that were significant remained (Portney & Watkins, 2009).

Prediction for SMD (Model 1).

First, standard logistic regression analysis was performed on being at risk of SMD (0=NO, 1=YES) as outcome and ten predictors: age (AGE), gender (GEN), Attention Deficit Disorder (ADD), Attention Deficit Hyperactivity Disorder (ADHD), Mood (MOOD), Autism Spectrum Disorder (ASD), Dyslexia (DYSL), Emotional (EMO), Learning Disorder (LD), and Other (OTH). SMD was identified as Model 1. After deletion of 1 case with missing values, data from n = 309 cases were available for analysis: 147 (47.6%) subject's classified as not being at risk of SMD and 162 (52.4%) subject's classified as being at risk of SMD. Analysis was performed using R (R Core Team, 2015). Race, mother and father's education, and tubes were eliminated due to a high percentage of missing data and limited variation.

A test of the full model with all ten predictors against a constant-only model was not statistically reliable, χ^2 (11, N = 309) = 13.0, p = .29, indicating that the set of predictors did not reliably distinguish between those who were at risk of SMD and those who were not at risk of SMD. The variance in risk of SMD was small using McFadden's Pseudo R Square = 0.034, df = 11. Prediction success (using 0.5 as the threshold) was unimpressive with 178 of 309 cases (57.6%) accurately classified and predicted correctly with sensitivity and specificity values of 0.38 and 0.79, respectively.

Table 4 shows regression coefficients, Wald statistics, odds ratios, and 95% confidence intervals for odds ratios for each of the ten predictors. According to the Wald criterion, only ADHD reliably predicted being at risk of SMD, z = 2.24, $p < .05$. A model run with ADHD omitted was not reliability different from a constant only model; however, this model was reliably different from the full model, χ^2 (1, N = 309) = 5.48, $p < .05$, which confirmed that ADHD is the only reliable predictor of being at risk for SMD among the set of predictor variables. The odds ratio of 2.64 showed significant change in the likelihood of being at risk for SMD based on being diagnosed with ADHD. Variance Inflation Factors (VIF) values ranged from 1.04 (Other) to 1.28 (ADHD), indicating that multicollinearity was not a problem. Examination of the significance levels of the additional predictors created by examining the interaction between each quantitative predictor (AGE) and the log of itself (Hosmer & Lemeshow, 1989) indicated that a linear relationship between the predictor variables and the being at risk of SMD status may be assumed.

Table 4. Logistic Regression for "At-Risk" for Sensory Modulation Disorder (Model 1)

Variables	B	SE	Wald	Exp (B)	Sig	95% CI Lower	95% CI Upper
Intercept	-0.11	.49	0.22		.82	-0.18	3.34
Age	0.01	.07	0.17	1.01	.87	-0.22	0.13
Gender	-0.26	.27	0.94	0.77	.35	-0.74	0.68
ADD	-0.01	.80	0.02	0.99	.99	-1.16	2.72
ADHD	0.97	.43	2.24	2.64	.03*	-0.26	2.17
Mood	-0.13	.43	-0.31	0.87	.76	-1.38	0.63
ASD	0.50	.42	1.17	1.64	.24	-0.25	2.08
Dyslexia	-1.66	.07	-1.55	0.19	.12	-3.75	1.02
Emotional	-0.10	.84	-0.12	0.90	.91	-0.18	5.16
LD	0.79	.67	1.18	2.21	.24	-1.12	2.02

B=Regression Coefficient, SE=Standard Error, Exp (B)= Odds Ratio, Sig=*p* value CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

The standard logistic regression analysis was followed up with a backward elimination logistic regression analysis for SMD in order to identify a reduced model that best explains the data (Hocking, 1976). Using this analysis reduces the risk of multicollinearity. Beginning with the full set of predictor variables, after 4 Fisher Scoring iterations, a statistically reliable reduced model emerged, $\chi 2$ (4, N = 309) = 9.6, $p < .05$ with three predictors: ADHD, Dyslexia, and LD. The variance accounted for being at risk for SMD remained unimpressive with McFadden's rho = 0.02, df = 4. Prediction success decreased slightly to 54.0% (167 of 309 cases). Sensitivity and specificity values changed slightly to 0.20 and 0.91, respectively. Table 5 displays the regression coefficients, Wald statistics, odds ratios, and 95% confidence intervals for odds ratios for the remaining three predictors. According to the Wald criterion, only ADHD emerged significantly (z = 2.48, $p < .05$). The odds ratio of 2.75 indicated that when controlling for dyslexia and LD, the odds of subject's being at risk for SMD was 2.75 times higher for those with ADHD.

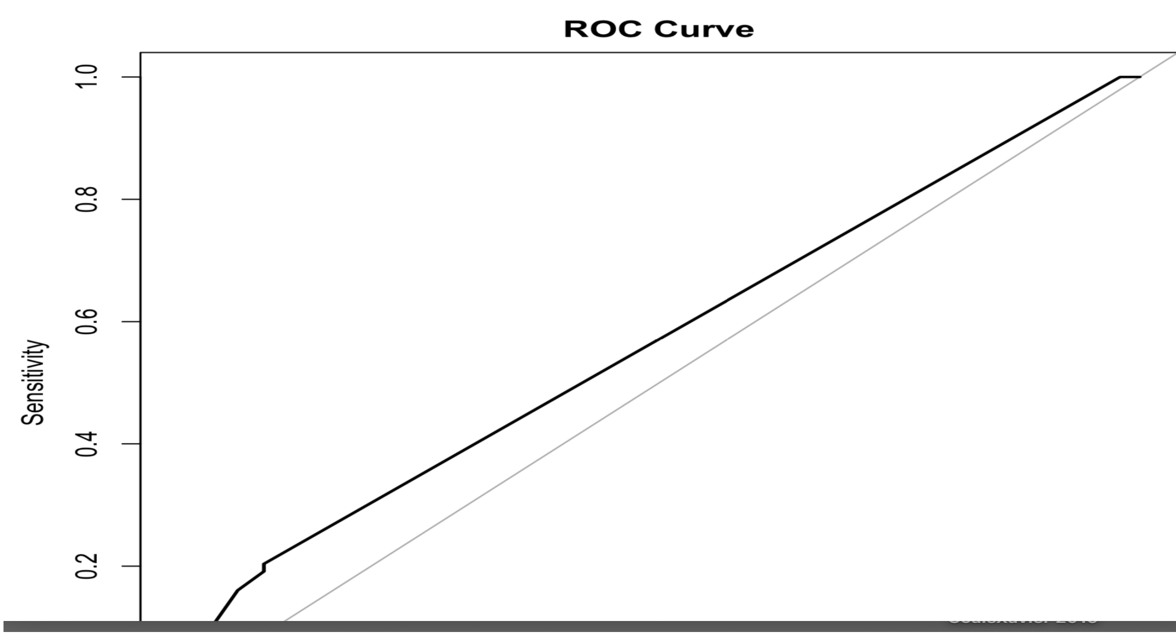
Table 5. Backward Stepwise Regression for "At-Risk" for Sensory Modulation Disorder (Model 1)

Variables	B	SE	Wald	Exp B	Sig	95% CI Lower	95% CI Higher
Intercept	-0.04	0.12	-0.30	0.96	.76	0.76	1.23
ADHD	1.01	0.41	2.48	2.75	.01*	1.28	6.45
Dyslexia	-1.78	1.04	-1.71	0.17	.08	0.02	1.26
LD	0.96	0.64	1.50	2.60	.13	0.81	10.43

B=Regression Coefficient, SE=Standard Error, Exp (B)= Odds Ratio, Sig=*p* value CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

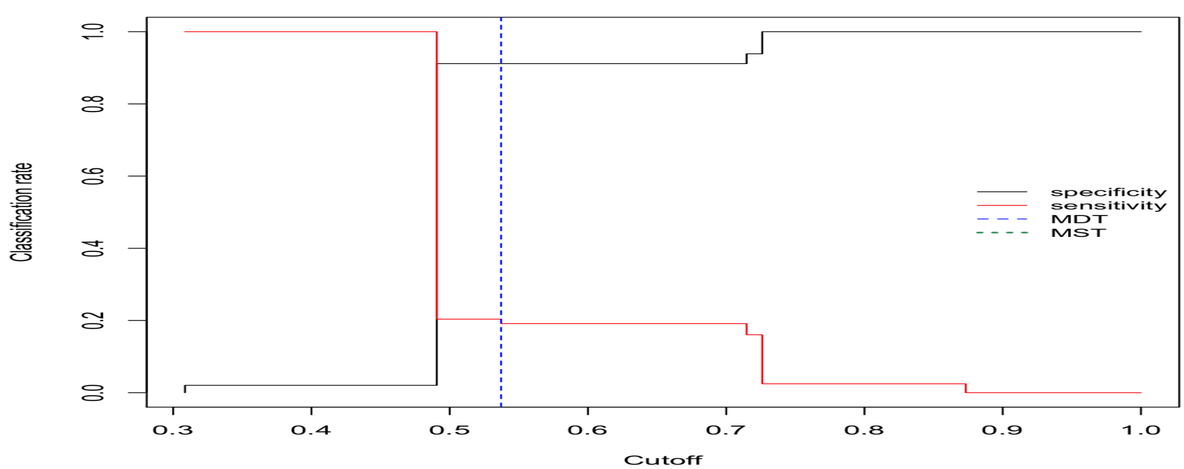
The three-predictor model was used to determine cut off points to create adequate sensitivity and specificity. Sensitivity is the probability that an individual that has a condition will test positive for the condition (Davidson, 2002). This is calculated by the true positive divided by the total calculation of true positive and false negative. Specificity is the probability that an individual that does not have a condition will test negative for the condition. This is calculated by the true negative divided by the total calculation of true negative and false positives (Davidson, 2002). A receiver operating characteristic graph (ROC), which has been shown to be a reliable technique for visualizing, organizing, and selecting classifications based on performance, is presented in Graph 1. Swets (1988) found that ROC analysis could be extended for use in visualizing and analyzing behavior of diagnostic systems and for determining accuracy of a test using the area under the curve. The ROC curve is the plot of true positive rate against false positive rate in order to determine possible cut points for having a condition, also known as a probability curve (Narkhede, 2018; Portney & Watkins, 2009). The Area Under the Curve (AUC) describes the degree the model distinguishes between classes (Narkhede, 2018). For the set of predictors, the area under the curve was found to be 0.567, which indicated a very poor accuracy classification for this at-risk behavior (Tape, 2015). Results are based upon 1.0 being the strongest classification to predict having the behavior and <0.6 being the weakest classification. Results from logistic regression, when taken in isolation of other statistics, should be generalized with caution when classifications are poor.

Graph 1. ROC curve for intent



In order to lessen error of misclassification of presence-absence of a condition, the calculation of threshold probability supports the modeling technique of prediction and improves the confidence of its accuracy (Jimenez-Valverde & Lobo, 2007). Minimized difference threshold (MDT) is calculated by the difference between sensitivity and specificity that is obtained from the AUC method (Goberville, Beaugrand, Hautekeete, Piquot, & Luczak, 2015). Using R to calculate MDT, it was found that 0.537 minimizes the absolute difference between sensitivity and specificity. The values of the sensitivity and specificity at 0.537 were 0.912 and 0.204, respectively. This method of prediction is considered better due to removing false positive presence (Goberville et al., 2015). Graph 2 shows the plot of model sensitivity and specificity for various cut points.

Graph 2. Plot of model sensitivity and specificity for various cutoffs



Prediction for APD (Model 2).

The next condition that was analyzed was being at risk for APD, identified as Model 2. Logistic regression was completed to predict the odds of being at risk of APD based upon the subject’s characteristics. Standard logistic regression analysis was performed on being at risk for APD as the outcome with eight predictor variables: age (AGE), gender (GEN), Attention Deficit

Disorder (ADD), Attention Deficit Hyperactivity Disorder (ADHD), Mood (MOOD), Autism Spectrum Disorder (ASD), Dyslexia (DYSL), and Learning Disorder (LD). After deletion of 40 cases with missing values for being at risk for APD, data from n = 269 cases were available for analysis: 253 (94.1%) subject's classified as not being at risk for APD and 16 (5.9%) subject's classified as being at risk for APD. Analysis was performed using R (R Core Team, 2015). Race, mother and father's education, and tubes were eliminated due to a high percentage of missing data and limited variation. Emotional Disorder and Other were eliminated due to an extremely high standard error.

A test of the full model with all eight predictors against a constant-only model was statistically reliable, χ^2 (9, N = 269) = 95.2, $p = .001$ indicated that the set of predictors reliably distinguish between those who were at risk for APD and those who were not at risk for APD. The variance in risk of APD accounted for was moderate with McFadden's Pseudo R Squared = 0.111, df = 9. Prediction success (using 0.5 as the threshold) was impressive with 253 of 269 cases (94.1%) accurately classified and predicted correctly with sensitivity and specificity values of 0.00 and 1.00 respectively.

Table 6 shows regression coefficients, Wald statistics, odds ratios, and 95% confidence intervals for odds ratios for each of the eight predictors. According to the Wald criterion, only ASD reliably predicted being at risk of APD, z = 3.05, $p < .01$. A model run with ASD omitted was not reliability different from a constant only model; however, this model was reliably different from the full model, χ^2 (1, N =269) = 8.29, $p < .01$ which confirmed that ASD is the only reliable predictor of being at risk for APD among the set of predictor variables. The odds ratio of 8.21 showed significant change in the likelihood of being at risk for APD based on being diagnosed with ASD. Variance Inflation Factors (VIF) values ranged from 1.06 (AGE) to 1.91

(DYSL), indicating that multicollinearity was not a problem. Examination of the significance levels of the additional predictors created by examining the interaction between each quantitative predictor (AGE) and the log of itself (Hosmer & Lemeshow, 1989) indicated that a linear relationship between the predictor variables and the being at risk of APD status may be assumed.

Table 6: Logistic Regression for "At-Risk" for Auditory Processing Disorder (Model 2)

Variables	B	SE	Wald	Odds Ratio	Sig	95% CI Lower	95% CI Upper
Intercept	-5.11	1.28	-3.99	0.006	.00***	0.000	0.065
Age	0.24	0.16	1.58	1.269	.11	0.944	1.718
Gender	0.61	0.64	0.96	1.847	.34	0.494	6.476
ADD	1.51	1.23	1.22	4.499	.22	0.200	39.291
ADHD	-1.10	1.10	-1.00	0.334	.32	0.017	1.967
Mood	-0.46	0.92	-0.50	0.630	.62	0.075	3.144
ASD	2.11	0.69	3.05	8.214	.00**	2.041	32.264
Dyslexia	2.58	1.67	1.54	13.174	.12	0.366	489.657
LD	-0.90	1.30	-0.469	0.406	.49	0.016	3.520

B=Regression Coefficient, SE=Standard Error, Exp (B)= Odds Ratio, Sig=*p* value CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

The standard logistic regression analysis was followed up with a backward elimination logistic regression analysis. Beginning with the full set of predictor variables, after 6 Fisher Scoring iterations, a statistically reliable reduced model emerged, $\chi2$ (3, N = 269) = 9102.2 $p <$ .001 with two predictors: AGE and ASD. The variance accounted for being at risk for APD remains unimpressive with McFadden's rho = 0.007, df = 3. Prediction success sensitivity and specificity values remained unchanged. Table 7 displays the regression coefficients, Wald statistics, odds ratios, and 95% confidence intervals for odds ratios for the remaining two predictors. According to the Wald criterion, only ASD emerged significant (z = 2.76, $p < .01$). The odds ratio of 5.12 indicated that when controlling for age, the odds of subjects being at risk for APD is 5.12 times higher for subjects with ASD.

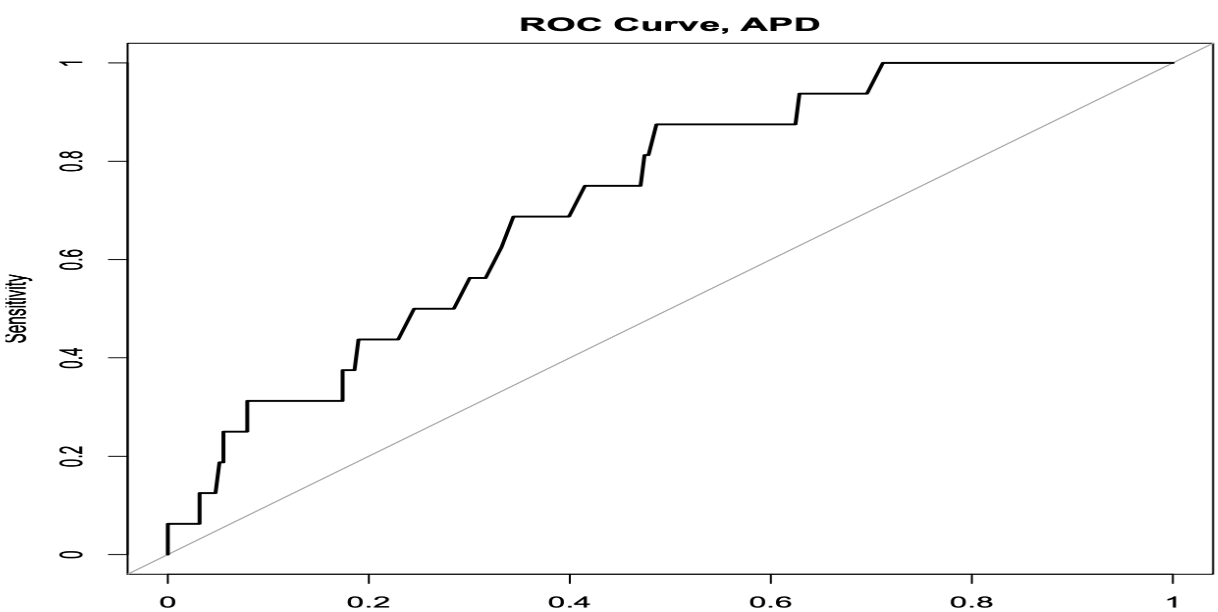
Table 7. Backward Stepwise Regression for "At-Risk" for APD (Model 2)

Variables	B	SE	Wald	Exp (B)	Sig	95% CI Lower	95% CI Higher
Intercept	-4.74	1.25	-0.38	0.009	.00***	0.001	0.089
AGE	0.21	0.15	1.46	1.237	.14	0.929	1.656
ASD	1.63	0.06	2.76	5.123	.00**	1.488	15.808

B=Regression Coefficient, SE=Standard Error, Exp (B)= Odds Ratio, Sig=*p* value CI=Confident Interval, * significant at .05 level; ** significant at .01 level; *** significant at .001 level

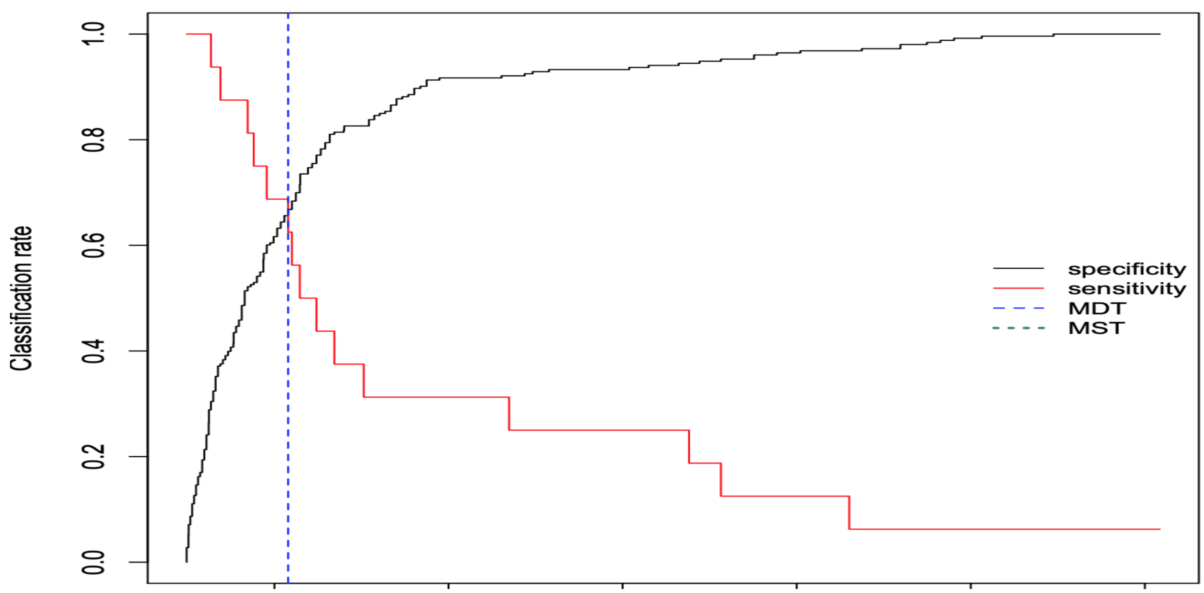
The two-predictor model was statistically reliable and used to determine cut points to create adequate sensitivity and specificity. A receiver operating characteristic graph (ROC), which has been shown to be a reliable technique for visualizing, organizing, and selecting classifications based on performance, is presented in Graph 3. Swets (1988) found that ROC analysis could be extended for use in visualizing and analyzing behavior of diagnostic systems and for determining accuracy of a test using the area under the curve. For the set of predictors, the area under the curve was found to be .721, which indicated a fair accuracy classification for this diagnostic (Tape, 2015).

Graph 3. ROC curve for intent



Graph 4 shows a plot of model sensitivity and specificity for various cutoffs. Using R and the minimized difference threshold (MDT) (Jiménez-Valverde & Lobo, 2007), it was found that 0.054 minimizes the absolute difference between sensitivity and specificity. The values of the sensitivity and specificity at 0.054 were 0.656 and 0.688, respectively.

Graph 4. Plot of model sensitivity and specificity for various cut points



Prediction for SMD and APD (Both) (Model 3).

Standard logistic regression was run for the final condition of being at risk of SMD and APD (both), identified as Model 3. Results indicated the statistics were unstable due to low cell count.

Summary of Results

This descriptive study reviewed 310 cases that met the inclusion/exclusion criteria in order to answer three objectives. The first objective addressed the number of children at-risk of sensory modulation deficits, at-risk of auditory processing deficit, or at-risk of both conditions. One case was removed due to missing SSP scores, with results of 162 cases (52.4%) being at-risk of SMD based upon the operational definition for this study (definite difference on the SSP composite score and definite difference on at least one of the auditory subtests). Forty-one cases were missing data leaving 269 cases with composite scores on the SCAN:C/SCAN-3: C. Sixteen cases (5.9%) were identified as being at risk of APD based upon the operational definition for this study (composite standard score that fell within the disorder range of 69 or below and a scaled score below 7 on two or more of the four diagnostic subtests). Lastly, a total of 268 cases had scores for both assessments, with 9 cases (3.4%) being at risk of both SMD and APD based upon the operational definition for this study.

The second objective for this study was to determine if there was a relationship between patient characteristics and being at risk of one or both of these conditions. The third objective was based upon these results in order to determine predictors of each condition. Results indicated that age was not statistically significant thus not related to being at risk of SMD, APD, or both of these conditions. Of all the characteristics examined in this study, results indicated that ADHD (p=.03) was related and significantly predictive of SMD. The odds ratio of 2.75 indicated that when controlling for dyslexia and LD, the odds of subject's being at risk for SMD was 2.75 times higher for those with ADHD. Results indicated that ASD (p=.00) was related and significantly predictive of APD. The odds ratio of 5.12 indicated that when controlling for age, the odds of subjects being at risk for APD was 5.12 times higher for subjects with ASD.

Discussion

The purpose of this study was three-fold. The first purpose was to determine the number of children at-risk of sensory modulation deficits, at-risk of auditory processing deficit, or at-risk for both. Secondly, to determine if there was a relationship between patient characteristics and being at risk of one or both of these conditions. Since warranted, predictors were determined for each condition. Results from this study may be used to support a clearer understanding of the relationship between these two pediatric conditions and strengthen the ability to screen and refer these children appropriately. Results also have the potential to support therapists to design and implement treatments that are specific to the characteristics of identified deficits and support future direction of research.

The clinical sample used in this study was based upon children referred to a pediatric clinic that specializes in sensory processing challenges in children and adults. Prevalence of children identified at risk of SMD tend to be significantly higher in this setting due to children being referred exhibiting behaviors indicating the need for this type of assessment. Results indicated that 59% (N=183) of the children referred for SPD scored in the definite difference range for being at risk of SMD with an additional 20% (N=63) that had probable difference. The additional 20% cases that had probable difference on the SSP, identified a group of children that would typically fall within Tier 2 of the Response to Intervention school model (Positive Behavioral Interventions & Supports [PBIS], 2019). Tier 2 includes educational supports for children that are not successful in the traditional educational approach (Tier 1) but deficits are not to the degree that require an Individual Educational Plan (IEP), which is Tier 3 (PBIS, 2019). Results of this study indicate that educational staff needs to understand characteristics of SMD that would benefit from supports within the Tier 2 system when screening results indicate probable difference in SMD that include deficits in the auditory subtests.

These results also indicated a high rate of appropriate referrals. The referral source was not examined in this study, but results may indicate a better understanding of behaviors that need evaluated by occupational therapists that specialize in sensory modulation disorder.

The clinical sample in this study was unique compared to other published studies because it looked specifically at the prevalence of SMD that involved auditory deficits. Fifty-two percent of the cases that had definite difference on the SSP involved deficits in the auditory system. Even though auditory concerns were significant enough to warrant screening for auditory processing disorder, this was not the reason for auditory deficits for the majority of children. A small percentage of children were at risk of APD, which was similar to the rates reported by AAA (2018). Co-morbidity of both SMD and APD was also very small indicating the uniqueness of auditory deficits specific to SMD. No other published studies were identified that compared the prevalence of co-morbidity of auditory impairment in SMD and APD. While the current study indicated that co-morbidity is small, additional research is needed. Results indicate that OT's need to ensure they evaluate for auditory issues within SMD and specifically address this sensory system in treatment when warranted. More OTs need to specialize in the auditory system within SMD to determine best practice. The development and future publication of the SP-3D (Schoen, Miller, & Sullivan, 2016) that identifies specific behaviors of auditory SUR, SOR, and SC will greatly contribute to identification of the specific area(s) of auditory deficits when evaluating children for SMD. The SSP does not measure each type of sensory modulation deficits in the area of auditory sensation, thus is limited in interpretation. Auditory filtering is a mixture of responses and the SSP combines visual and auditory over responsivity within the same subtest. The lack of published comprehensive tools for each type of SMD hinders identifying and treating the specific auditory SMD area. It also limits appropriate measurements for pre-post research studies to determine efficacy in treatment for SMD within the auditory domain.

It is unknown if there is a relationship between auditory SOR and auditory filtering within SMD. Eighty-one cases of the 309 had both SOR and AF deficits but as previously stated, the design of the SSP overlaps SOR, SUR, SC within the AF subtest and auditory SOR is combined with visual SOR. Only 2 of the 5 items of the subtest of visual/auditory sensitivity address auditory SOR. When looking specifically at the items in the auditory filtering subtest of the SSP, behaviors such as “distracted by a lot of noise”, “can’t work with background noise”, and “doesn’t respond when name is called but you know the child’s hearing is OK”, raise questions if SOR influences AF and how AF is different from auditory processing that is tested by audiologists. We do know that deficits in AF and SOR have the potential to negatively influence a child’s success in academics due to the complexity of the auditory environment in the school setting (Bradlow, Kraus, & Hayes, 2003; Shield & Dockrell, 2008). School is an environment that children spend the majority of their time, focusing on academics, social participation, and activities of daily living (eating & toileting). In the school setting, children are screened for peripheral hearing loss by nursing, but not screened for auditory deficits in the areas of APD or SMD (Ohio Department of Health, 2015).

A better understanding of the relationship between auditory filtering and auditory SOR would improve the identification and provision of a supportive learning environment for this population. Some schools are using Frequency Modulation (FM) systems within classrooms to encourage auditory attention (Reynolds, Kuhaneck & Pfeiffer, 2016). The FM system allows the teacher to speak into a microphone, which transmits their voice throughout the classroom through speakers (Kreisman & Crandell, 2002). The objective of this system is to improve the signal-to-noise ratio, thus supporting the teacher’s voice to be heard over background noise (Kriesman & Crandell, 2002). There are limitations in many of these studies, but overall a general body of evidence is growing indicating that FM systems support children with learning difficulties (Reynolds et al., 2016; Schafer, Mathews, Mehta, Hill, Munoz, Bishop & Moloney, 2013; Updike, 2006). The challenge of depending upon FM systems for school success is that they are not mandated as a universal design for public schools and the group of children with

SMD in the area of auditory deficits has not been directly studied to determine its efficacy with this population (Reynolds et al., 2016). In addition, school systems often use noise cancellation headphones to help children cope when they have auditory SOR. This is a compensatory technique that does not target remediating the cause of auditory SOR. In fact, the literature indicates that noise cancellation headphones may cause an increase in auditory SOR due to the gating system being activated less (Dozier, 2016; Frick, 2016). All treatment designed to address auditory SOR need to be studied for efficacy.

For the sample population in this study, children referred for testing due to behaviors of SMD and APD were primarily boys. Prior research has indicated boys have a higher incidence of both SMD and APD (Chermak & Musick, 1997; Schoen et al., 2018). This study further identified a higher referral rate of boys being at risk of processing difficulties within the auditory system.

Identifying deficits and providing intervention for children as early as possible has the potential to lessen the severity of impairment into adulthood (Rice et al., 2014). The mean age of children referred and identified at-risk for the stated conditions in this study was at the second-grade level of education or 7-8 years old. The inclusion criteria of the study were based upon the age range of the SCAN-3: C, which starts at age 5. Shapiro (2016) reported that children are typically referred for APD testing at age 7 or 8 years old but believes this should occur at a much younger age. Typically, children are identified with SMD during the early years of school when the demands of a multi-sensory environment impede school function. This study was able to determine the mean age of children referred for SMD in a clinical setting based upon the inclusion criteria of 5-11 years old, ages used by the SCAN-3: C. In the general population, the mean age may be younger due to availability and widely used tools that measure SMD in the infant and toddler age group (Dunn, 2008). It is important to acknowledge that Ahn et al. (2004) identified 5.3% of the kindergarten population met the criteria for SMD using the SSP as a screening tool. The current challenge is providing adequate screening for all auditory deficits for children at the birth to 5-year-old period of development, thus increasing family and teacher education and intervention for children prior to the childhood demands of school. In 2009, Part C (Early Intervention program) served 2.67% of the general population of birth to three-year-old children (National Early Childhood Technical Assistance Center, 2011). Based upon stated data, up to 13% of this age group met the criteria for service, yet those families did not choose to participate in the program (National Early Childhood Technical Assistance Center, 2011). Screening tools are available to capture infants, toddlers, and preschoolers that are at risk of SMD but tools are lacking to adequately screen this age group for being at risk of APD. Since the SCAN-3: C starts at age 5 and is a commonly used screening tool among practitioners, it becomes a challenge for early identification of the at-risk population of APD. Identifying at-risk behavior of APD during the preschool years has shown promise using neural coding of speech in noise and phonology but that is not common practice (White-Schwoch et al., 2015). Affordable and reliable assessments needs developed to capture preschoolers at-risk of APD and improved multi-disciplinary team approach that have an understanding of auditory deficits in the younger population.

The second purpose of this study was to determine if there was a relationship between patient characteristics and being at risk of one or both of these conditions. Results indicated a relationship between being at risk of SMD and ADHD at a significant level. This was not surprising based upon the growing body of evidence indicating co-morbidity among SOR and ADHD (Lane & Reynolds, 2019). In fact, one study used the SSP, controlling for overlapping characteristics of AF and sensory seeking among SMD and ADHD, with results still indicating co-morbidity. Yet, ADHD and SMD did occur alone, as distinct conditions independent of each other (Miller et al., 2012). The current study was unable to control for behaviors similar to attention deficits and may have inflated the result. However, it is important to note that the outcomes in the study by Miller et al. (2012) still demonstrated AF deficits in cases with SMD, ADHD, and both conditions compared to typically developing children.

The relationship between APD and the identified characteristics were examined indicating a relationship between autism spectrum disorder (ASD) and APD. Co-morbidity of APD and ASD has been reported throughout the literature (Brandwein et al., 2015; Danesh & Kaf, 2012; Demopoulos et al., 2015; Denman, Banajee, & Hurley, 2015; DePape, Hall, Tillmann, & Trainor, 2012; Kozou, Azouz, Abdou, & Shaltout, 2018; Linke, Keehn, Pueschel, Fishman, & Muller, 2018; Lortie et al., 2017; Ocak, Eshraghi, Danesh, Mittal, & Eshraghi, 2018, and Otto-Meyer, Krizman, White-Schwoch, & Kraus, 2018.) When reflecting on the diagnostic criteria of ASD including language delay and social pragmatic deficits, it is not surprising that results indicated a relationship between APD and ASD. The results of this study did not identify a relationship of being at risk of SMD with ASD, which is surprising. Literature has repeatedly identified auditory sensitivity in individuals with autism (Bhatara., Quintin, Fombonne, & Levitin, 2013; Danesh & Kaf, 2012; Linke et al., 2018; Matsuzaki et al., 2017). The nature of the assessment (SOR in both auditory and visual SOS combined and only 2 of 5 items addressing SOR) used in this study may not have been able to determine the relationship of SMD and ASD. Additional studies using assessment tools measuring auditory SOR in individuals with ASD needs completed.

The current study expands the body of knowledge indicating that the odds of children with SMD having ADHD is 2.72 times higher than being at risk of one condition alone. Knowing that the auditory items of the SSP overlap with the diagnostic criteria of ADHD may have inflated the odds of having both conditions, yet based upon the results of the study by Miller el al., (2012), auditory filtering scores indicated clinical impairment for both SMD and ADHD using an inclusion criteria that controlled for in-attention. Miller et al., (2012) also suggested that children referred for ADHD should be screened for SMD. The screening, evaluation, and treatment of children at risk of SMD and/or ADHD should include auditory specific testing and appropriate treatment based upon the emerging evidence.

The probability of having APD and ASD was at a very high rate (5.12) in this study. Individuals with ASD have significant deficits in communication and social pragmatics, which are based upon the DSM-5 diagnostic criteria (Center for Disease Control and Prevention, 2019). Children with ASD should always be screened for APD and treated accordingly. Evaluating this population can be challenging but having a complete understanding of all areas of APD is important for appropriate treatment.

Limitations

Data were collected at one clinic that specialized in SPD, lacking diversity as seen in the general population. Results can be applied to this specific clinic but needs repeated using a more diverse population in order to generalize the results. Another limitation is how the data were collected. A retrospective study uses data obtained from several therapists and over a period of several years. There was no ability to determine the accuracy of administration of the assessments, the environment during administration, and how the parent and child felt at the time of being evaluated. It is noted that the clinic has a reputation of high-quality therapists and services. Lastly, there were limitations in the assessments used. The Short Sensory Profile is a parent report inventory thus lacked behavior-based administration in order to determine accuracy of responses. The auditory items on the SSP did not separate SOR, SUR, SC and combined vision and auditory SOR on one subtest, which limited the ability to identify the auditory subtest according to recent publications of SMD (Miller et al., 2007).

Clinical Relevance and Future Research

This study provided data comparing characteristics of children that were referred for an evaluation based upon sensory deficits that included auditory deficits with no peripheral hearing loss. Results indicated that the majority of children with auditory difficulties were at risk of SMD involving auditory deficits versus APD. Clinically, auditory deficits are complex, and a multi-disciplinary team needs to be involved that specializes in this area of practice. Health care professionals need a better understanding of symptoms of auditory deficits in order to make appropriate referrals. There also needs to more research exploring the relationship of AF and SOR in order to treat appropriately.

This study determined being at risk of SMD using the SSP that included two criteria, composite score of definite difference and definite difference on at least one of the auditory related subtests. Additional studies are needed that separate the three auditory areas, that include auditory under-responsivity, auditory over-responsivity, and auditory sensory craving in order to guide best method of evaluating and treating SMD with specific auditory involvement. This is especially needed in the area of over-responsivity. There is a growing body of literature among various professions that are exploring auditory over-responsivity (Danesh & Kaf, 2012; Otto-Meyer et al., 2018). Occupational therapists evaluate and treat functional impairment, such as coping strategies to attend events that are noisy or sound based treatment targeting the ability to lessen the sensitivity to specific tones when flushing the commode or drying hands in the bathroom. Further research is needed to understand auditory SOR and determine the effectiveness of treatment used by occupational therapists and their ability to improve functional outcomes.

Based upon the results of this study, children with a diagnosis ADHD should be evaluated for SMD and children with ASD should be evaluated for APD due to being at a greater risk of these conditions. Pediatricians needs to understand the probability of co-morbidity of these conditions in order to make appropriate referrals. Therapists need to understand the difference in these conditions in order to treat appropriately.

Additional studies are needed beyond screening for SMD and APD by comparing the characteristics and neurology of children using diagnostic testing. There continues to be a gap in the literature that identifies the neurological difference between SMD and APD. Preliminary research has explored non-classical auditory pathways (Moller, Kern, & Grannemann, 2005); vagal modulation to auditory stimuli (Cruz, Ferreira-Santos, Oliveira-Silva, Ribeeriro, Goncalves, & Sampaio, 2017); P300 (Ubiali, Sanfins, Borges & Colella-Santos, 2016), and electro- and magnetoencephalography methods of the auditory pathway (Orekhova et al., 2012), yet there is so much that is unknown when considering the underlying neurology of these two disorders.

In conclusion, there is a growing body of literature that has explored auditory pathways, auditory behaviors indicating dysfunction, how symptoms overlap among various diagnoses, yet some symptoms are unique for some conditions. This study contributes to the growing body of literature in several ways. First, auditory deficits in children at risk of SMD is not the same as the auditory deficits in children at risk of APD. Having appropriate referrals made by pediatricians and therapists knowledgeable of auditory impairment in SMD can guide appropriate evaluation and treatment process for these children. Second, children at risk of ADHD should be evaluated for SMD and vice versa. Families, physicians, and other professionals that are in the position to make referrals or determine what needs to be evaluated should keep this in mind. The same is true for children at risk for ASD. They should be assessed for APD and vice versa. When specific symptoms are identified, specific treatment can be formulated, increasing the likelihood of an improved quality of life for the children and their families.

Lastly, occupational therapists are taught the inter-relationship of the individual, the occupations or activities that the individual engages in, and how context and environment influences performance (AOTA, 2014). Our unique holistic approach can provide valuable information to the team when working with individuals with auditory dysfunction that impairs life. Being consumers and participants of research in the area of auditory deficits can insure our presence on the team.

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