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Department of Speech-Language Pathology and Audiology

EXPLORING THE RELATIONSHIP BETWEEN REDUCED SOUND TOLERANCE, SENSORY PROCESSING DISORDER, AND AUDITORY PROCESSING DISORDER IN CHILDREN: A SCOPING REVIEW

In fulfilment of the requirements for the degree BA Audiology in the Department of Speech-Language Pathology and Audiology, Faculty of Humanities, University of Pretoria.

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ABSTRACT

Introduction: Reduced sound tolerance, sensory processing disorder (SPD), and auditory processing disorder (APD) can have significant adverse effects, particularly on communication in children. As a result, investigating the relationship between reduced sound tolerance and SPD, with a focus on APD, may lead to important discoveries that could contribute to the development of targeted intervention strategies.

Objective: The main purpose of this scoping review was to comprehensively explore the existing literature to allow for the determination of the relationship between these conditions, and identifying gaps in research.

Study design: A scoping review was used to conduct this study. A data extraction form was utilized to acquire information from articles that met the inclusion criteria set by the authors. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) were applied during a structured search for articles in five different electronic databases with information on reduced sound tolerance and sensory processing disorder in children. Keywords comprised of "Auditory Processing Disorder", "Sensory Processing Disorder", "reduced sound tolerance", "hyperacusis" and "children". The electronic databases were searched for relevant articles published from the 20th of June to the 25th of August. The opinion of two experienced researchers was used throughout the data collection process. All authors received identical library training to reduce discrepancies in data extraction. All four authors extracted the data and two researchers assessed the relevance and applicability of the data that was obtained. The data was analysed and key characteristics from each study were highlighted using a narrative synthesis approach.

Results: Seven articles were included in the review. All the studies provided information regarding reduced sound tolerance in children with APD or SPD. The studies highlighted a relationship between reduced sound tolerance and APD in children. APD and hyperacusis were seen to co-occur in three out of the seven studies found, with one study reporting a 70.9% prevalence of hyperacusis in children with APD. Another study indicated that speech in noise training might improve auditory processing and sound tolerance in children with SPD.

Conclusion: A notable overlap between reduced sound tolerance and SPD has been highlighted in the findings. This scoping review brought relevant information to light but also emphasized the gaps in the literature and the need for a more comprehensive analysis of the relationship between reduced sound tolerance and SPD, specifically focusing on APD.

KEY WORDS: Auditory Processing Disorder, Sensory Processing Disorder, Reduced Sound Tolerance, Hyperacusis, Children.

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1. INTRODUCTION AND RATIONALE

Sensory processing refers to the body's capacity to efficiently process and manage inputs of the sensory systems (e.g. vestibular, visual, proprioceptive and auditory) to guide appropriate responses within the environment (Baker, 2008). Sensory Processing Disorder (SPD) can be described as having difficulties in organizing, detecting, interpreting, modulating, and reacting to sensory stimuli and is found mostly in persons with neuro-developmental disorders (Passarello et al, 2022). SPD is estimated to affect approximately 60-90% of children with neuro-developmental disorders (Jussila, 2020), such as Attention Deficit Hyperactivity Disorder (ADHD), Learning Disability (LD), Autism Spectrum Disorder (ASD), and Auditory Processing Disorder (APD) (Bahramain et al., 2024).

Auditory Processing Disorder (APD) is characterized by a range of difficulties in perceiving and processing auditory information due to numerous factors affecting the central auditory nervous system (AAA, 2010). Although individuals with APD often have normal hearing sensitivity, they might find it challenging to recognize and comprehend sounds, particularly in difficult listening conditions. These challenges in processing auditory information can result in impairments in learning, speech, language, and other listening-related tasks (ASHA, 2005). In early childhood, signs such as hypersensitivity to sound or noise often become evident in children affected by APD (Geffner, 2019). Over-responsivity to auditory stimuli is common among individuals with sensory processing problems which is an important aspect of SPD (Ahmmed & Mukherjee, 2021). Misophonia and hyperacusis, which are hypersensitive reactions to sound, fall under the broader category of reduced sound tolerance (Raj-Koziak et al., 2021).

Hyperacusis is a condition characterized by an increased sensitivity to everyday sounds (Potgieter et al., 2020; Vernon, 1987). Baguley and Andersson (2007) describe hyperacusis can also be described as an atypical, reduced tolerance to acoustic stimuli. The underlying cause of hyperacusis may involve dysfunction in either the central or peripheral auditory system (Baguley et al., 2013a). Individuals with hyperacusis may perceive sounds as frightening, painful, or unpleasant (Coey & De Jesus, 2023). This increased sensitivity to normal sound levels can lead to significant

discomfort and adverse reactions to specific auditory stimuli. The subjective nature of the condition highlights the fact that individuals with hyperacusis may react to sound levels that are typically tolerable for the general population (Ahmmed & Mukherjee, 2021). Potential causes include viral infection, head trauma, jaw or face surgery, genetic predisposition, and excessive noise exposure (ASHA, 2015). It is important to note that hyperacusis does not exist in isolation among other auditory sensitivity disorders, but terms such as 'phonophobia' and 'misophonia' are also associated with reduced sound tolerance.

Phonophobia refers to both individuals who experience fear in response to certain acoustic stimuli (Jastreboff & Hazell, 2004) as well as those who suffer from migraines due to an increased sensitivity to sound (Baguley et al., 2013a). Misophonia, on the other hand, describes individuals who display an aversive response, typically characterized by strong negative emotional responses, toward specific sounds, often related to eating and respiration. It is important to note that the terminology in this field remains imprecise (Jastreboff & Hazell, 2004). Distinguishing between a heightened perception and an emotional response triggered by these stimuli presents considerable challenges especially among younger children (ASHA et al., 2010).

Ahmmed and Mukherjee (2021) suggest a potential co-occurrence of APD and reduced sound tolerance in children, indicating a possible relationship between these two conditions Coey and De Jesus (2023) and the British Society of Audiology (2011) similarly note that individuals with hyperacusis and those with APD often face difficulties in social, occupational, and recreational activities. Both disorders profoundly affect an individual’s well-being, making it crucial to explore their potential relationship to optimize therapeutic approaches. Given the complexity of this relationship, further investigation is necessary.

While reduced sound tolerance is commonly reported in children with APD, the exact prevalence remains unclear. Several studies suggest a possible coexistence of APD and hyperacusis. A retrospective study by Ahmmed and Mukherjee (2021), analysing data from 282 children assessed for APD, revealed a 70.9% co-occurrence of hyperacusis and APD. This finding aligns with research by Bamiou et al. (2015) who also found that some patients diagnosed with APD had co-occurring hyperacusis.

Similarly, a study led by Spyridakou et al. (2012) demonstrated that individuals with confirmed APD scored significantly worse on hyperacusis questionnaires compared to those without APD, suggesting a higher symptom burden of hyperacusis in patients with APD, although the correlation was weak. Additionally, Vielmeier et al. (2016) reported elevated hyperacusis scores in some patients with APD, providing further support for a correlation between the two conditions. Comparing these studies reinforces the evidence that APD and hyperacusis may be linked. Schecklmann (2014) also reported a 40-55% prevalence of hyperacusis in individuals with chronic tinnitus, further suggesting overlapping auditory sensitivities. Despite this evidence, the exact prevalence and underlying causes of the co-occurrence of reduced sound tolerance and APD require further investigation.

Understanding this co-occurrence of reduced sound tolerance and APD is crucial for the effective management of these specific auditory difficulties. Identifying the coexistence of both these conditions in some children (Ahmmed & Mukherjee, 2021) could help clarify their relationship. However, distinguishing between these two conditions can be challenging due to overlapping symptoms and the complex nature of APD. Therefore, exploring the link and relationship between reduced sound tolerance and SPD, particularly APD will provide valuable insights into the underlying mechanisms and brain circuits involved, ultimately supporting the development of tailored intervention plans. By understanding these conditions, interventionists will be able to design individualized therapy plans that address specific needs, leading to improved outcomes, and the achievement of goals and milestones. Furthermore, researching the prevalence and co-occurrence of APD and reduced sound tolerance will contribute to the enhancement of public health initiatives and policies. It can also help to inform screening processes in schools, workplaces, and healthcare settings, promoting early identification and appropriate intervention for those with auditory processing issues (Moore, 2007).

Despite the growing body of research on SPD, specifically APD and reduced sound tolerance, a comprehensive synthesis and analysis of their co-occurrence remains lacking. To better understand the concurrent manifestation and interaction of these disorders, a thorough examination of the existing literature is essential. Therefore, this scoping review aims to systematically access the literature on the co-occurrence of reduced sound tolerance and SPD, specifically focusing on APD. By exploring the

relationship between these conditions, this review will also identify gaps in research, paving the way for future studies.

2. METHODOLOGY

2.1. Study aim

The aim of this study was to comprehensively explore the existing literature to allow for the determination of the relationship between these conditions and identify gaps in research.

2.2. Study design

To reach the objectives of this study, a scoping review was the most suitable design as limited research has been done in the field of study (Rumrill, 2010; Sürer Adanir et al., 2017). Arksey (2005), describes a scoping review as scrutinizing literature in a specific field of research to summarise all existing findings and mapping key concepts, this design enables researchers to systematically identify gaps in knowledge, which can guide future research efforts. Furthermore, scoping reviews allow for the exploration of a board research areas, assist with clarifying key concepts (Munn et al., 2018), are flexible, and help to inform future research and policy (Peters et al., 2015).

2.3. Protocol

This scoping review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (Tricco et al., 2018). The PRISMA-ScR provides a structured framework comprising 20 mandatory reporting elements, along with two additional reporting elements, to guide the reporting of scoping reviews. It serves as a foundation tool for organizing scoping reviews and streamlining decision-making processes. The goal of the PRISMA-ScR is to aid readers to better comprehend related terminology, fundamental concepts, and crucial components that should be included in scoping reviews (Tricco et al., 2018).

2.4. Eligibility criteria

The eligibility criteria for this scoping review are summarised in Table 1 below.

Table 1: Inclusion and exclusion criteria for the study selection.

Inclusion criteria	**Exclusion criteria**
Articles reporting on SPD; focusing on APD, in children (7-18 years).	Articles reporting on SPD in adults.
Articles reporting on reduced/decreased sound tolerance; hyperacusis, misophonia, or phonophobia.	Articles that do not refer to any form of reduced sound tolerance.
Peer-reviewed journal articles.	Non-peer-reviewed journal articles, grey literature in other formats.

Regarding the eligibility criteria (Table 1) mentioned above, it is essential to note that peer review serves as a filter to guarantee the use of high-quality research, specifically in respectable journals that investigate the studies' validity, credibility, importance, and originality. The search was performed from 20 June 2024 to 25 August 2024. This was due to the rapid developments in the fields of SPD and reduced sound tolerance over the past fifteen years (Passarello et al., 2022; Coey et al., 2023). It allowed the researchers to incorporate the most applicable literature in this review.

2.5. Information sources and search

PubMed, Scopus, Academic Search Complete, Taylor and Francis (Journals), and MEDLINE (Proquest) were the five electronic databases utilized to select applicable resources from June 2024 to August 2024. Key terminology was identified from the research question and used to search for relevant publications. Synonyms and abbreviations were used to guarantee the inclusion of all applicable research studies. Various combinations of the following terminology were employed throughout the study when searching the databases: "Auditory processing disorder" OR "APD" OR "Auditory Processing" OR "Central auditory processing disorder" OR "CAPD" OR "Sensory processing" OR "Sensory integration" OR "Sensory modulation") AND ("Sound intolerance" OR "Decreased sound tolerance" OR "Reduced sound tolerance" OR "Hyperacusis" OR "Misophonia" OR "Phonophobia" OR "Sound sensitivity" OR "Sound Aversion" OR "Auditory hypersensitivity" OR Noise sensitivity" OR "Sound

sensitivity syndrome") AND ("Child*" OR "Paediatric*" OR "School going child* OR "Kid*" OR "Teen*" OR "Minor*" OR "Adolescent" OR "Pediatric*".

2.6. Study selection and data charting process

All studies found while searching the abovementioned databases were searched for duplication and repetition before they were searched for further applicability. Initially, an abstract screening was performed to identify and exclude duplicate studies. Studies that were not relevant to the research topic were subsequently removed. Publications deemed potentially relevant then underwent a comprehensive full-text review, in accordance with the predefined inclusion and exclusion criteria established by the primary researchers. An extraction form was used to obtain applicable data from the remaining articles after all irrelevant articles were removed. This form was implemented to compare and analyse the data collected by the researchers. The researchers convened to deliberate decisions about the study's eligibility criteria to ensure consistency. Meetings were arranged during the initial, middle, and final phases of abstract reviews to deliberate any issues or variabilities related to study selection to ensure relevance and avoid potential ambiguity. Studies were only incorporated if they involved children aged 1 to 16 years with SPD and reduced sound tolerance and were published in the last 15 years (2009-2024). The data extraction form included article name, author, year of publication, study design, participants (number and criteria), findings on reduced sound tolerance, findings on auditory processing disorder, other related information (co-occurrence of other disorders or dysfunctions for example, tinnitus) and contradicting information (any indication of no co-occurrence or low prevalence of co-occurrence). The data was analysed and key characteristics from each study were highlighted using a narrative synthesis approach. All four primary researchers jointly executed all phases of the scoping review. Any discrepancies were discussed and resolved by the group throughout the analysis process. To deliberate findings and settle any disparities, the opinion of two experienced researcher was used throughout the data collection process. Any disagreements were addressed, as discussed by Levac et al. (2010). In addition, all authors received similar library training to minimize discrepancies in data extraction. Furthermore, all four authors extracted the data, and two researchers assessed whether the data was applicable and relevant (Shemilt et al., 2016).

2.7. Risk of bias across studies

Given the scoping nature of this review, a formal risk of bias assessment was not conducted. This decision aligns with the exploratory and expansive characteristics of scoping reviews (Tricco et al., 2018). The aim of this scoping review was to provide an overview of available literature, therefore critical appraisal of included sources was not applicable (Tricco et al., 2018).

2.8. Synthesis of results

A summary of the data was compiled for current methods of analysing sensory processing skills and capability to tolerate sound, and crucial findings using tables, narrative synthesis, and figures as per recommendation by Arksey and O'Malley (2005).

2.9. Additional analyses

By analysing the different domains pointed out by the research in each article, the researchers were able to discover gaps in the literature and pinpoint the domains that require further investigation.

3. RESULTS

3.1. Study selection

Figure 1 presents the step-by-step process employed to determine the eligibility of the articles for this scoping review. After the selected databases were searched, 90 articles were found. When duplicates were removed, 73 articles remained and were screened according to the title. The eligibility criteria (Table 1) were used to screen the abstracts of these articles. A full-text review was conducted for a total of 17 articles. Consequently, 10 of these articles were excluded as they did not meet the eligibility criteria (Table 1). Thus, seven articles remained and were included in the scoping review. The key characteristics of each article are summarised in Table 2 below.

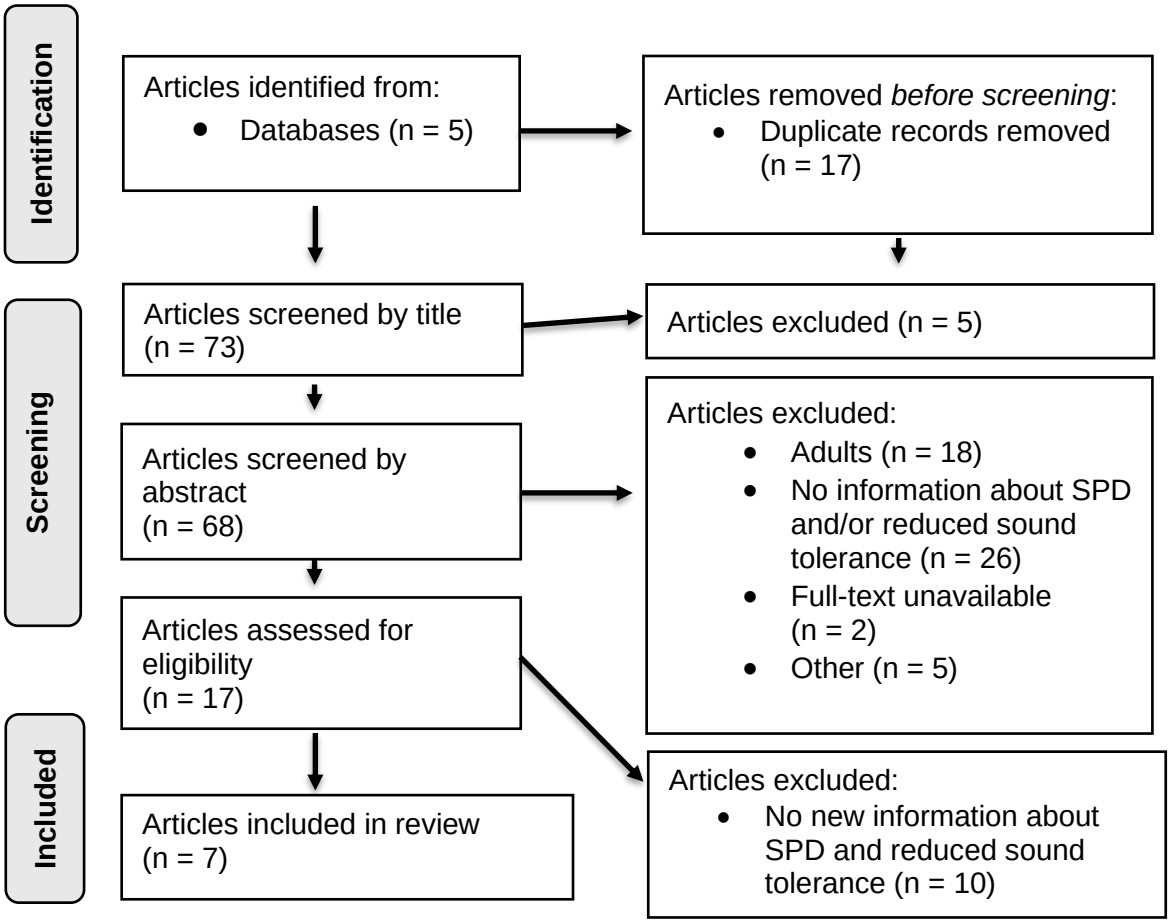

Figure 1 - PRISMA flowchart depicting the study selection process

Table 2: Key characteristics of included articles as these relate to reduced sound tolerance and SPD

Authors	Title	Study Design	Study Sampling (patient)	Assessment Measure (intervention)	Key findings
Myne & Kennedy (2021)	Hyperacusis in Children: A Clinical Profile.	Retrospective case review.	61 children aged 1 to 15 years presenting with hyperacusis.	Retrospective review of case notes, clinical presentation, hearing assessments, evaluation of middle ear problems, assessment of neuro-developmental conditions, and documentation of accompanying symptoms.	Language impairments and anxiety are non-auditory factors that can predict hyperacusis in children with APD. Different auditory processing domains such as temporal auditory processing, speech in noise, and dichotic listening do not seem to be affected by hyperacusis. ASD and ADHD tend to co-exist with APD and hyperacusis. There is a high co-occurrence of hyperacusis in children diagnosed with APD (exact number unclear).
Bahramian, Gohari & Aazh (2024)	Preliminary study on speech in noise training in children with SPD and hyperacusis.	Retrospective cross-sectional study.	28 children with a mean age of 8.7 years old who have been diagnosed with SPD and sound intolerance.	A standard assessment and management plan for APD problems.	The study found that speech-in-noise training may be effective in improving behavioural indicators of APD and decreasing hyperacusis symptoms. This is done by enhancing auditory skills and assisting with developing coping mechanisms.
Sürer Adanir, Gizli Çoban, & Özatalay (2017)	Increased hyperacusis with risperidone in an Autistic child.	Case presentation.	An eleven-year-old male with confirmed ASD complained of auditory hypersensitivity.	Case report, observation of medication effects, assessment of hyperacusis, and literature comparison.	New theories regarding the cause of auditory hypersensitivity may suggest that it is related to inhibitory processing decreasing. Hyperacusis was the most prevalent sensory processing problem found in children with ASD.
Ahmmed & Mukherjee (2021)	Auditory processing and non-auditory factors in children with auditory processing disorder.	Retrospective study.	282 children aged between 6 and 16 years diagnosed with APD.	Auditory processing assessments using SCAN-3 tests, and non-auditory assessments including language abilities (using Children's Communication Checklist or CCC-2), anxiety (using ASC-ASD), oppositional defiant disorder (using SNAP-IV) and ADHD.	A hyperacusis prevalence of 70.9% in children diagnosed with APD was reported in this study, however, the precise prevalence is still unknown. Some non-auditory factors that can predict hyperacusis in children with APD are language impairment and anxiety. Hyperacusis and APD frequently co-existed in children with ASD and WS. Children who have both APD and hyperacusis showed significantly poorer communication, higher rates of language impairment, anxiety, oppositional defiant disorder, and hyperactivity compared to children with APD only. It was found that the degree of APD impairment was not affected by hyperacusis.
Rashid, Mukherjee & Ahmmed (2018)	Auditory processing and neuropsychological profiles of children with functional hearing loss.	Retrospective study.	40 children aged between 7 and 16 years who were assessed for APD and functional hearing loss.	APD scanning using SCAN-3 and neuro-developmental condition scanning using SNAP-IV.	The results found that hyperacusis is more common in children without a FHL. 77.5% of the children were diagnosed with APD, resulting in an overlap between APD and FHL. The neuropsychological findings reported a higher prevalence of reduced sound tolerance and ADHD which suggests a possible connection between these disorders and APD.
Gundogdu, Aksoy & Eroglu (2023)	Sensory profiles, behavioural problems, and auditory findings in children with autism spectrum disorder.	Cross-sectional observational design.	46 children with autism spectrum disorder, aged 3 to 9 years.	DENVER-II Developmental Screening Test, the Wechsler Intelligence Scales, an audiological, head, and neck examination.	Hyperacusis might be due to inner ear dysfunction or central processing issues including auditory processing difficulties.
Kaf & Danesh (2012)	Distortion product otoacoustic emissions and contralateral suppression findings in children with Asperger's Syndrome.	Case control study.	36 boys (18 with AS and 18 healthy, aged 6 to 16 years).	Audiometric testing (otoscopy and pure tone audiometry), DPOAE measurements (including contralateral suppression effect).	Children diagnosed with ASD and AS frequently show challenges with processing speech in the presence of noise. This can be associated with central auditory processing problems. Additionally, these children commonly face issues with conditions like hyperacusis and tinnitus.

3.2. Study characteristics

The selected studies (n= 7) reported on 530 participants, ranging from 1 to 16 years of age. The sample sizes in the studies ranged from 1 to 282 children, however, APD was not confirmed in some participants. Various study designs were used, including three retrospective reviews, one cross-sectional observational study, one case-control study, one retrospective cross-sectional study, and one case presentation. Table 2 above provides the key characteristics of the included studies.

3.3. Synthesis of results

Sampling issues. The seven studies reviewed reported on 5 databases. The studies included children with APD, SPD, ADHD, and Asperger's Syndrome (AS). A total of 530 children were included across the studies, comprising 282 diagnosed with auditory processing disorder (APD), 47 with autism spectrum disorder (ASD), 28 with sensory processing disorder (SPD), 40 with functional hearing loss, and 18 with Asperger syndrome (AS). The mean age of participants was approximately 9 years. Some studies eliminated children with comorbid neurological or psychiatric conditions, while others, such as those by Gundogdu et al. (2023) and Bahramian et al. (2024), included participants with conditions like ASD, AS, and William's syndrome (WS) and ADHD, leading to diversity in the sample populations.

Reduced sound tolerance in children with APD. Four of the seven studies that made up this scoping review explored hyperacusis in children with auditory processing disorder (APD). Ahmmed and Mukherjee (2021) investigated the prevalence of hyperacusis in 282 children with APD, finding that 70.9% exhibited hyperacusis. No noteworthy differences were observed between gender or age in APD groups with and without hyperacusis. However, children in the "APD + hyperacusis" group revealed poorer first language profiles, particularly in in social and communicative skills. Hyperacusis was seen in 73.8% of the 248 children with language deficit, with the highest prevalence observed in those with pragmatic language impairments. In comparison to children who presented with APD alone, children with both exhibited higher levels of attention-deficit/hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD) symptom. Moreover, hyperactivity, impulsivity, and anxiety were more prevalent in children with hyperacusis. Myne and Kennedy (2021) further reported that more than 50% of children examined by clinicians in a clinical setting reported

experiencing hyperacusis. Upon assessment, many of these children had hearing thresholds within normal limits, although nearly half presented with middle ear pathologies. Additionally, Rashid et al. (2018) compared hyperacusis prevalence between children with functional hearing loss (FHL) and a control group with suspected APD. The control group had a significantly higher prevalence of hyperacusis symptoms (62%) compared to the FHL group (35%).

Reduced sound tolerance and APD in children with neuro-developmental conditions. Sensory processing challenges are frequently reported in the ASD population and may predict maladaptive behavior (Gundogdu, Aksoy & Eroglu, 2023). Myne and Kennedy (2018). reported that 46% of the children with hyperacusis, had an associated neuro-developmental condition, with ASD being the most prevalent. Similarly, in connection to this, Kaf and Danesh (2012) found that children diagnosed with ASD and AS frequently exhibit difficulties in speech processing, particularly in the presence of noise. This can be attributed to central auditory problems as a result these children frequently face challenges with conditions like hyperacusis (Kaf and Danesh, 2012). Among 212 children with hyperactivity, 159 (75%) also had hyperacusis. Children with Oppositional Defiant Disorder (ODD) also showed a higher prevalence of hyperacusis. However, it was found that the degree to which children struggled with APD was not impacted by hyperacusis (Ahmmed and Mukherjee, 2021). Additionally, Rashid, et al. (2018) discovered through neurophysiological findings that there was a high rate of reduced sound tolerance and ADHD in children with Functional Hearing Loss (FHL) suggesting a possible link between these conditions and APD. Finally, it was found that hyperacusis was present in approximately 90% of children with Williams Syndrome (WS) (Ahmmed and Mukherjee, 2021). Furthermore, it was detailed that children with WS scored poorly in the Children's Communication Checklist 2 (CCC-2) similar to children with APD and hyperacusis.

Test procedures. The studies described test procedures for different domains namely hearing assessments (Myne & Kennedy 2021; Gundogdu et al., 2023) Distortion Product Otoacoustic Emissions (DPOAE) measurements (Kaf & Danesh 2012), auditory processing tests namely the SCAN-3 and SCAN-IV tests(Ahmed & Mukherjee, 2021; Rashid et al., 2018) and the Auditory Figure Ground test (Rashid et al., 2018), assessments of hyperacusis such as the hyperacusis questionnaire and

Loudness discomfort level tests(Adanir et al., 2017; Rashid et al., 2018). Speech and language assessments such as the CCC-2 test (Ahmed & Mukherjee, 2021) and Developmental and cognitive assessments such as the DENVER-2 Developmental Screening Test and the Wechsler Intelligence Scales (Gundogdu et al., 2023) were also conducted.

Only Bahramian, Gohari, and Aazh (2024) considered management strategies. Speech in Noise Training (SPINT) might improve decoding and phonetic skills, auditory short-term memory, and listening skills in children with APD, while reducing hypersensitivity to sound (Bahramian, Gohari, and Aazh, 2024). However, SPINT was ineffective in improving dichotic listening and auditory sequencing. This retrospective study also revealed that SPINT with white noise improved behavioral auditory processing and reduced hyperacusis symptoms in children with SPD. Word-in-noise perception also improved after SPINT. While these findings are promising, more studies are required to assess SPINT's effectiveness in treating hyperacusis. Moreover, when setting up appropriate management plans, Myne and Kennedy (2021) successfully highlighted the importance of understanding what underlying conditions are associated with hyperacusis as well as being able to identify the different ways in which it can present itself as this will lead to better outcomes in children.

4. DISCUSSION

This scoping review was carried out to explore the existing literature on the relationship between reduced sound tolerance, SPD, and APD in children. This review found the applicable literature but has shown a limited amount of research on the topic thus much research is still needed to understand the relationship between these disorders.

Consistent evidence from the limited available literature suggests a connection between reduced sound tolerance and sensory processing. Growing evidence suggests that APD and hyperacusis may co-occur in children (Ahmmed and Mukherjee, 2021). The study by Myne and Kennedy (2021) suggested that hyperacusis was a primary concern in the majority of children mentioned in the study, even when these children presented with normal hearing. Research also suggests that children with APD have hearing thresholds within the normative range (Alanazi, 2023). Myne and Kennedy (2021) used non-auditory characteristics to predict hyperacusis in

children with APD, while hyperacusis and poor attention was seen in children with APD (Rashid et al., 2018). The above-mentioned articles suggest a co-occurrence of hyperacusis and processing problems in children (Ahmmed and Mukherjee, 2021; Myne and Kennedy, 2021; Rashid et al., 2018).

Neuro-developmental factors are frequently observed in children with APD and are associated with conditions like ASD, ADHD, or LD. APD may also arise from a range of factors affecting the central auditory nervous system (AAA, 2010). Children affected by APD typically exhibit deficits in auditory discrimination, phonological awareness, and auditory memory (Moore & Hunter, 2013). Like APD, the notable prevalence of hyperacusis among children with neuro-developmental conditions, especially ASD and ADHD, highlights the necessity for tailored assessments and interventions that address the multifaceted nature of this sensory processing issue. (Bahramain et al., 2024; Gundogdu et al., 2023). Furthermore, the cause of hyperacusis has shown to either be due to a possible problem in the central or peripheral auditory pathways (Baguley et al., 2013a), which causes sounds to be perceived as frightening, painful, or unpleasant (Coey & De Jesus, 2023), as well as causative factors which include viral infection, head trauma, jaw or face surgery, genetic factors, and excessive noise exposure (ASHA, 2015). Newly discovered theories have also suggested that the cause of auditory hypersensitivity may be connected to inhibitory processing decreasing (Sürer Adanir et al., 2017), central processing issues including auditory processing difficulties, or even inner ear dysfunction (Gundogdu et al., 2023).

The studies included in this scoping review demonstrate a significant prevalence of hyperacusis in children with APD, though the precise prevalence remains uncertain. Ahmmed and Mukherjee (2021) reported that 70.9% of children with APD, also exhibited hyperacusis. Similarly, Ahmmed and Vijiyakumar (2024) found that out of 143 children diagnosed with APD, 107 presented with hyperacusis. Further supporting this high co-occurrence, research by Spyridakou et al. (2012) and Vielmeier et al. (2016) also reported a notable co-occurrence of APD and hyperacusis.

Moreover, children mentioned in the study by Ahmed & Mukherjee(2021) scored lower in language profile tests, specifically communication and social deviance. Children with APD and hyperacusis also showed higher levels of ADHD, oppositional defiance symptoms and anxiety (Ahmed & Mukherjee, 2021). In conjunction with the above-mentioned study, children who had suspected APD and significant hyperacusis had

poor attention (Rashid et al., 2018). Research clearly stated that children with hyperacusis and APD struggle in social situations and during recreational activities (Coey & De Jesus., 2023; British Society of Audiology, 2011). Individuals with ASD and WS were more susceptible to symptoms of hyperacusis and impaired auditory processing for example poor speech perception in noise and non-auditory systems, particularly pragmatic language dysfunction, behavioral problems and anxiety. It was recommended that the auditory and non-auditory symptoms might be connected to diminished temporal processing, abnormal sensory integration and neural adaptation (Ahmmed & Mukherjee., 2021). There was limited information regarding treatment options for the mentioned population, but Bahramian et al. (2024) found that speech in noise training may improve behavioral indicators of APD and may be effective in reducing hyperacusis symptoms.

Limitations

The limited amount of research on the relationship between reduced sound tolerance, SPD, and APD was highlighted through the findings of this scoping review. Additionally, the lack of standardized diagnostic tests may have introduced inconsistency and ambiguity, complicating the interpretation and comparison of the results. The relationship between reduced sound tolerance and APD has not been clearly defined in the literature, further complicating the analysis of the results. Despite a comprehensive search strategy, only seven articles met the inclusion criteria for this scoping review, which limits the breadth of the analysis. Additionally, the studies included relatively small sample sizes, which may elevate the risk of bias and result in false positives or negatives, affecting the overall reliability of the findings. The limited sample sizes also introduce variability in sampling methods, further compromising the generalizability of the results. Moreover, several participants in the included studies had comorbid conditions, such as neurological disorders, which may have influenced the results.

Strengths

To the researchers' knowledge, this is the first scoping review that discusses the scope and composition of studies on reduced sound tolerance and SPD focusing on APD in children. The inclusion of four separate researchers for data extraction, abstract review talks to address any concerns or variables connected to study selection, and

the ongoing consultation of seasoned researchers during the analytic process all contributed to the scoping review's enhanced strength.

5. CONCLUSION

Research to date pointed out the possible co-occurrence of reduced sound tolerance, SPD and APD in children. A notable overlap between these two conditions was identified in this scoping review. Currently, the exact number of children who present with APD and reduced sound tolerance together with the underlying mechanisms is still unknown. As mentioned, some therapies such as SPINT have been tested to alleviate hyperacusis and APD symptoms however this review emphasized the need for more information on this and other therapies to aid in managing this population. This review made it clear that due to the complex nature of these conditions as well as the often-co-occurring neuro-developmental conditions, it is essential that a multidisciplinary team approach be used when setting up a management plan for these children. In addition, a clear and concise diagnostic criterion focusing on children, could have the potential to transform possible treatment outcomes, resulting in a better quality of life, social and communication skills for children affected by these conditions. Researchers and clinicians are encouraged to collaborate to further investigate the relationship between reduced sound tolerance, SPD and APD in children.

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Appendix A: Ethical clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100. Since 1919

Department of Speech- Language Pathology and Audiology

7 March 2024

Dear Researchers,

Project:	Reduced sound tolerance and tinnitus in children with APD: A scoping review
Researchers:	Andanani Mapholi (17090432), Anneke Snyman (21569992), Bianca Prinsloo (21439304), Idaishe Wazara (21660507)
Supervisors:	Prof Lidia Pottas, Prof Talita le Roux
Department:	Department of Speech-Language Pathology and Audiology
Reference Number:	SLPA2024/10

Thank you for the application submitted to the Research Committee of the Department of Speech-Language Pathology and Audiology, Faculty of Humanities. We have the pleasure of informing you that the above application was approved on 7 March 2024.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal.

We wish you success with the project.

Sincerely

Prof Lidia Pottas
Chair: Departmental Research Committee

Prof J van der Linde
HEAD: DEPARTMENT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY
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Appendix B: Turnitin Report

turnitin

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

Submission author:	B (Bianca) Prinsloo
Assignment title:	Turnitin report
Submission title:	2024 KMP481 Mapholi, Prinsloo, Snyman, Wazara.pdf
File name:	2024_KMP481_Mapholi_Prinsloo_Snyman_Wazara.pdf
File size:	706.29K
Page count:	29
Word count:	7,018
Character count:	44,142
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UNIVERSITEIT VAN PRETORIA
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Department of Speech-Language Pathology and Audiology

EXPLORING THE RELATIONSHIP BETWEEN REDUCED SOUND TOLERANCE, SENSORY PROCESSING DISORDER, AND AUDITORY PROCESSING DISORDER IN CHILDREN: A SCOPING REVIEW

In fulfilment of the requirements for the degree BA Audiology in the Department of Speech-Language Pathology and Audiology, Faculty of Humanities, University of Pretoria.

Student name	Student number
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Aanalea Snyman	21688982
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Supervisor: Prof L Pottas
Co-supervisor: Prof T le Roux

Date: October 2024

Appendix C: PRISMA-ScR checklist

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

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Appendix D: Data Extraction Form

Article Name	Author	Year of publication	Study design	Participants (number & criteria)	Findings on decreased sound tolerance	Findings on Audiotory Processing disorder	Other related information (co-occurrence of other disorders or dysfunctions for example tinnitus)	Contradicting information (any indication of no co-occurrence or low prevalence of co-occurrence)
Hyperacusis in children: A clinical profile	Shibani Myne, Veronica Kennedy*	2018	retrospective case review	61	Possible mechanisms for hyperacusis in children include • Immature but normally developing auditory system • Temporary auditory deprivation • Disorder within the auditory system • Disorder of sensory processing	One child reported difficulties with listening despite normal peripheral hearing and was suspected to have auditory processing disorder (APD). While further assessments were planned to investigate APD, the child did not attend subsequent appointments	hypercusis	None
Preliminary study on speech in noise training in children with sensory processing disorder and hyperacusis	Bahramian, E., Gohari, N. & Aazh, H.	2024	Retrospective cross-sectional study	28 children with sensory processing disorder and sound intolerance	-Several theories explain that hyperacusis is caused by increased neural synchrony of the tonotopic structure of the auditory cortex + problems with the limbic system and auditory pathways. -Hyperacusis can cause listening difficulties in b/g noise	None	Over-responsivity for auditory stimuli (similar to hyeracusis) can be viewed in individuals with sensory processing disorder -SPD prevalent among individuals with APD	None
Increased hyperacusis with risperidone in an Autistic child	A. Sürer Adanir, Ö. Gizli Çoban and E. Özatalay	2017	Case study	11-year-old boy with ASD	1) ASD is found to be related to Hyperacusis. 2) Hyperacusis' severity increased risperidone (for hyperactivity and behavioral problems) was prescribed. 3) He was particularly disturbed by the voice of children and electric appliances - High Freq sounds? 4) The cause of auditory hypersensitivity remains unknown. Recently, it has been thought to be associated with decreased inhibitory processing, possibly resulting from the dysfunction of inhibitory interneurons or an abnormal sensory gating system - two cited references for this that we can look at.	1) In addition to these core features of ASD, sensory processing (SP) abnormalities such as auditory hypersensitivity have been frequently reported and may be a predictor of maladaptive behavior - Cited article possibly with more info. 2) Researchers have reported differences in auditory processing in ASD patients compared with typically developing controls.	1) The underlying medical condition cannot be found, but it can be related with some diseases, syndromes, and developmental and mental disorders - There is an article cited that might have more information. 2) Sensory processing abnormalities were added to the diagnostic criteria for ASD. 3) The reported coincidence of SP abnormalities in ASD is 42-88%. Among them, auditory hypersensitivity is the most common sensory impairment, interrupting behavioral adaptation.	none
Auditory processing and non-auditory processing factors associated with hyperacusis in children with APD	Ahmmed, A.U. & Mukherjee, D.	2021	Retrospective study	282 (165 males and 117 females) children with APD aged 6-16 years	-Anxiety and language impairment= non-auditory factors that predicted hyperacusis in children with APD. -Hyperacusis= symptom in children with APD, but the exact prevalnece is unknown. -Proportion of hyperacusis significantly higher in children with either pragmatic or intermediate language impairment compared to either typical or structural language impairment. -In addition to speech in noise and temporal auditory processing, dichotic listening ability in children with hyperacusis., but the presence or absence of hyperacusis did not influence auditory processing impairment in different domains in children with APD.	-High prevalence of hyperacusis in APD -APD is associated with "general auditory processing", "working memory and executive attention" + "sensori-motor processing and alerting attention". All these are affected in different neurodevelopmental conditions (ASD, ADHD etc).	-Prevalence of hyperacusis greater inn ASD and ADHD (these also commonly exist with APD), thus we should expect a higher prevalence of hyperacusis in children with APD. -In conditions such as ASD and WS, hyperacusis co-exists with symptoms of auditory processing impairment (e.g. poor speech perception in noise) and non-auditory symptoms such as anxiey and externalizing behaviour. These non-auditory symptoms may be related to impaired temporal processing, atypical sensory integration and neural mal-adaptation. -Children with APD and hyperacusis suggested to have significantly higher hyperactivity/impulsivity and opposition/defiance compared to those with APD only. --"A significant number of children with APD and hyperacusis had a high prevalence of pragmatic language impairment, combined sub-type of ADHD, anxiety and	-6/32 children with APD had hyperacusis (Dawes et al., 2008) - Future research in evaluating auditory processing in children mainly presenting wth hyperacusis suggested. -"There were no differences in the auditory processing profiles of the two groups of children with APD, one with and the other without hyperacusis."

Auditory processing and neuropsychological profiles of children with functional hearing loss	Rashid, SKMU., Mukherjee, D. & Ahmmed, A U.	2018	Retrospective study	40 children between the ages of seven and sixteen. One group with a history of functional hearing loss and the other with suspected APD without functional hearing loss.	The study found that 35% of children in the FHL group exhibited hyperacusis, which was significantly lower than in the control group (62%)	Children who had suspected APD had poor attention and significant hyperacusis.	While hyperacusis is typically linked to language impairments , the FHL group appeared to have fewer attention problems and less hyperacusis although presenting with high levels of language impairment.	Children with FHL had significantly fewer attention problems (45%) compared to the control group (82.5%) This lower prevalence of attention issues this could explain the lower incidence of hyperacusis, as ADHD and sensory sensitivities, including hyperacusis, often co-occur
Sensory profiles, behavioural problems, and auditory findings in children with autism spectrum disorder.	Ummugulsum Gundogdu, Ahmet Aksoy, Mehtap Eroglu	2023	This study utilized a cross-sectional design focusing on the relationship between sensory processing differences, behavioral problems, and auditory findings in children with autism spectrum disorder (ASD).	The study involved 46 children diagnosed with ASD, aged 3 to 9 years. Participants were selected from those attending a child and adolescent psychiatry outpatient clinic. The study excluded children with comorbid neurological (e.g., cerebral palsy, epilepsy) and psychiatric (e.g., anxiety, depression, psychosis) conditions and those on psychiatric medication.	The study identified that terms like auditory hypersensitivity, hyperacusis, and decreased sound tolerance are commonly used interchangeably. Some children with ASD displayed discomfort towards certain sound frequencies, suggesting decreased sound tolerance. However, audiological test results did not clearly correlate with sensory processing differences observed in parental reports.	the study found that auditory processing differences in children with ASD, such as difficulties in sound perception and discrimination, were associated with lethargy. These children might show hypoactivity due to decreased auditory processing abilities. Despite this, standard audiological tests often failed to detect these auditory processing issues.	The study also reported associations between sensory processing differences and behavioral issues like hyperactivity, stereotypy, and irritability. Behavioral problems in children with ASD were linked to sensory processing domains, including auditory processing. Hyperacusis might stem from inner ear dysfunctions or central auditory processing differences.	he study found no significant differences in behavioral problems between children who passed or failed the audiological tests, indicating a potential mismatch between objective auditory test results and parent-reported sensory processing issues.
Distortion-product otoacoustic emissions and contralateral suppression findings in children with Asperger's Syndrome.	Wafaa A. Kafa, Ali A. Danesh	2013	Case control study	18 boys with AS and 18 age-matched control subjects	1. Central auditory processing in the temporal lobe, limbic system and autonomic nervous system may be involved in the generation of hypersensitivity to sounds and difficulty understanding in noisy environments in children with AS. 2. Children with AS and ASD exhibit problems with sensory input, learning, psychosocial function, tinnitus and/or hyperacusis.	The reverse pattern in our study may reflect abnormality at the level of the MOCB or at proximal level in the central auditory pathway suggesting central processing disorder in children with AS.	None	None