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REVIEW ARTICLE

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Phonological awareness and reading outcomes in children with a history of otitis media: a review

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ABSTRACT
Objective: A review was conducted to investigate the current evidence for effects of otitis media (OM) on phonological awareness and reading skills in children under 12 years old.
Design: A review conducted in 2024 to identify articles between 1978 and 2024 related to OM and its impact on (pre-)reading skills.
Study Sample: An initial search across six databases provided 6808 research outputs. After screening, 27 articles were retained. Screening of the references on the selected articles provided an additional 6, giving 33 articles in the final review.
Results: The selected research papers did not all evaluate the same phonological awareness or reading skills. Of the studies, 20 identified that a history of OM impacted reading outcomes. Twelve studies found no significant impact while one study showed an impact which resolved with time.
Conclusion: The findings do not show a consistent association between a history of OM and phonological processing or reading skills. This is likely due to the wide range of methodologies employed and variability in the focus of the respective studies. Future research, including longitudinal studies, would be beneficial to infer the potential impacts of OM on phonological processing or reading skills.

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Introduction

Otitis media (OM) is a common condition of the middle ear that may result in temporary conductive hearing loss. OM-related hearing loss may impact children's language development and consequently their (pre-)reading skills, specifically, phonological awareness and/or reading ability. This review synthesises the current knowledge on the impact of OM on phonological awareness and reading.

Incidence of otitis media

OM occurs when fluid impedes middle ear system function, causing a temporary mild to moderate conductive hearing loss (CHL) (Rees, Mills, and Paatsch 2020). Left untreated it can progress to tympanic membrane perforation, chronic suppurative OM (CSOM) or a permanent hearing loss (O'Connor, Perry, and Lannigan 2009). Worldwide, approximately 28,000 deaths annually are caused by OM complications, with a further 65 to 330 million people suffering from CSOM (Monasta et al. 2012). There is a need to understand the impact of OM in children and its impact on early reading skills given that today Indigenous populations around the world experience OM that is longer in duration and more severe than in non-Indigenous counterparts (Coleman et al. 2018; Su et al. 2020a).

Effect of otitis media on the anatomy of the auditory system

OM may cause fluctuating auditory deprivation, potentially affecting the development of the auditory pathway. For instance, Clarkson, Antunes, and Rubio (2016) found alterations to the auditory pathway of rats post-exposure to a CHL and anatomical changes on the pre- and postsynaptic parts of the auditory nerve and auditory brainstem. Following 10 days of auditory deprivation, Auditory Brainstem Response (ABR) thresholds returned to normal only for frequencies below 8 kHz and not for the extended high frequencies. Other mice studies have reported similar effects on the cochlea and decreased innervation density of the lateral olivocochlear bundles, impacting binaural processing abilities (Liberman, Liberman, and Maison 2015). De-efferentation of the cochlea has also been shown to accelerate cochlear neuropathy (Liberman, Liberman, and Maison 2015). The findings of these animal studies, while informative, need to be considered with caution. Hearing loss caused by OM in humans is often transient and does not persist as long as the auditory deprivation in animal studies (Whitton and Polley 2011). Additionally, the effects of compensatory mechanisms due to language-enriched environments, auditory training and/or medical intervention are not considered in animal research.

A study investigating effects of OM on auditory processing in children has found similar results to the above animal studies. The auditory deprivation caused by OM can affect the size of the

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dendrite in the superior olivary complex, which alters the balance of the binaural auditory signal sent to the brain (Khavarghazalani et al. 2016). Children with a history of OM presented with poorer binaural hearing abilities and temporal processing. With extensive auditory stimulation, binaural abilities, but not temporal processing, improved (Khavarghazalani et al. 2016).

Plasticity of the auditory pathway is crucial in understanding whether fluctuating auditory deprivation, like that caused by OM, causes long-term alterations. Animal studies have shown the plasticity of the auditory cortex decreases with age, potentially due to reduced development of excitatory postsynaptic potentials (Kral and Eggermont 2007). Auditory deprivation during critical development periods can lead to cellular deficits in the auditory cortex, affecting the functioning of the Central Auditory Nervous System (CANS; Colella-Santos et al. 2019). Colella-Santos et al. (2019) found that a history of OM affected the brainstem, thus inferring that the lack of auditory stimulation caused by OM leads to a delay in the maturation of the CANS.

Impact of otitis media on developmental outcomes

Hearing loss caused by OM can impact language acquisition, social development, educational outcomes, and is associated with higher rates of criminal activity in adolescent and adult life (Coleman et al. 2018). Typically, OM occurs within the first few years of life, coinciding with the rapid development of language skills (Niklas, Cohrssen, and Tayler 2016), which continues up to 12 years old (Gualtieri & Finn 2022). Hearing loss induced by OM may affect the ability to acquire language and, in turn, phonological awareness and reading outcomes (O'Connor, Perry, and Lannigan 2009).

Theoretical framework of literacy acquisition

Goswami (2000) and Ramus (2001) have proposed models of literacy acquisition emphasising the importance of sensory input in developing phonological representations. Ramus' study on children with dyslexia established the Magnocellular Theory to explain the link between phonological processing, literacy, and the auditory system (Ramus 2001). Populations with dyslexia experience sensory defects caused by abnormalities in the magnocellular pathway of the auditory system (Ramus 2001). In a normal functioning auditory system, auditory stimulus helps develop the phonological system; this system then provides a foundation to map phonemes to graphical (letter) representations (Ramus 2001). Impairment on this pathway leads to poorer phonological mapping and, in turn, poorer literacy outcomes (Ramus 2001). This is referred to as the phonological-deficit hypothesis. Goswami's framework further elaborates that phonological processing deficits arise from poor mapping of phonemes into distinct segments (Goswami 2000). This phonological mapping process reflects the child's language exposure. It can be inferred that if there is an auditory deficit, this impacts language acquisition abilities as the individual is not receiving the full auditory information to map onto their lexical categories (Goswami 2000). Impairment on the auditory pathway may lead to poorer phonological mapping and, therefore, poorer literacy outcomes.

The lexical restructuring theory further elaborates on this hypothesis, suggesting that phonological representations emerge from vocabulary development and change with the familiarity of phonemes (Goswami 2000). Introducing a graphical representation of phoneme information (letters and words) further develops the segmentation of lexical representations as the child has a visual to represent the previously acquired phonological information (Castles 2006; Goswami 2000). Graphical representation assists with literacy acquisition as phonemic information is mapped to its corresponding orthography, which the child then uses when "sounding out" new words (Goswami 2000). Goswami et al. (2001) furthermore highlighted the importance of auditory processing, specifically the analysis of temporal cues including loudness and the amplitude envelope, as a predictor for the development of phonological skills and literacy. These frameworks suggest that an impairment due to OM in the auditory system, which is the primary input for phonological information, causes lexical representations to be poorly defined, therefore impacting literacy outcomes.

Aim and hypothesis

To understand how OM can affect phonological awareness and reading outcomes in children under 12, a review was conducted to investigate the current evidence. By gathering and comparing the available literature, we can clarify whether there is any evidence of an impact of OM and consequent auditory deprivation on (pre-)reading outcomes in children and highlight any gaps in the published literature. This may reveal directions for future research to determine the effect of OM on literacy development, and to inform management practices, providing improved outcomes for children with a history of OM.

Method

Procedure

This review was completed in 2024 following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model.

Database searches

To identify relevant articles, six databases were searched (Academic Search Premier, CINAHL, EMBASE, Medline, PsychInfo, Scopus) from 1978 to 2024. The procedure for each search was identical, including pathology and education subject headings joined by "or" and pathology and education keyword strings joined by "or". "And" was used to connect the subject headings and keyword strings and no filters were used on the search.

The database search was performed by authors GO and MS. The pathology subject heading was: Otitis Media. Education subject headings were: Reading, Reading Disabilities, Reading Skills, Reading Achievement, Reading Readiness, Reading Ability, Reading Development, Language, Language Development, Speech Perception, Speech Disorders, Speech Delay, Speech Development. The pathology keyword string was Otitis Media. The education keyword string included: Prelitera*, Reading, Phonolog*, Language, Literacy, Speech.

Inclusion and exclusion criteria

Studies were included if they were written in English, published in peer-reviewed journals, and addressed OM and phonological awareness and/or reading outcomes in children. Studies excluded were not in English; were dissertations; focused on general academic outcomes (rather than reading outcomes specifically); did not include a measurement of hearing; or the pathology was not OM.

Figure 1 shows the PRISMA article inclusion flowchart (Page et al. 2021). Initial title and keyword screening was conducted by two authors (MS, GO). If the titles were not clear, the abstracts were screened. The abstracts of the remaining publications were screened by all authors. 32 records were eligible for inclusion. Five of these were excluded as they a) were a dissertation, b) could not be located online on any database or in Macquarie University Library, c) were a proposal for a future study, or d) did not contain required information. This resulted in 27 relevant articles from the database search.

There was an additional search of the references of the final gathered articles and a further 6 relevant articles were found. Thus, a total of 33 papers were included in the final review.

Data extraction

For each record, the following data were collected: a) sample size, b) age range, c) diagnostic measures and criteria used, d) measures to assess hearing and academic achievement, e) outcomes related to academic achievement. Data extraction focused on participants with a documented history of OM.

Results

Twenty studies found a relationship between poorer reading outcomes and a history of OM, 12 reported no significant relationship, and one provided mixed results. There were 12 studies that used a history of OM as their participation criterion and 21 studies included those with active OM the day of assessment (Supplementary Figure 1 and 2).

Sample size

Sample sizes varied greatly, between 10 and 2,208 children with a history of OM. 12,156 children participated across the 33 studies. 36% of studies ($n = 12$) did not include controls (Hall, Maw, and Steer 2009; Lous 1993; Nittrouer and Burton 2005; Roberts,

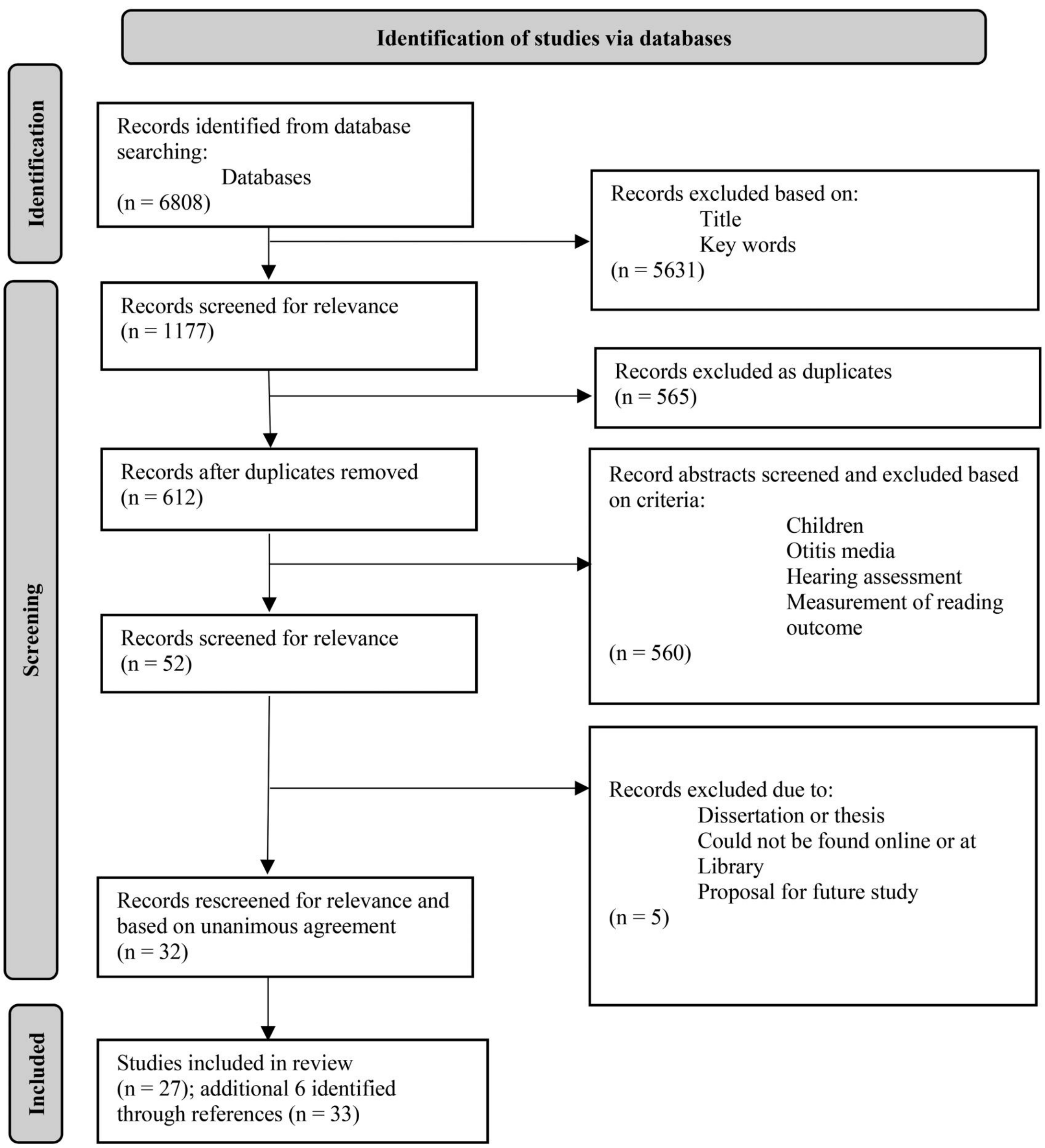

Figure 1. PRISMA flow diagram of publications completed in 2024.

Burchinal, and Clarke-Klein 1995; Roberts, Burchinal, and Zeisel 2002; Roberts et al. 1989; 2000; Share et al. 1986; Winskel 2006; Zinkus, Gottlieb, and Schapiro 1978; Zinkus and Gottlieb 1980). Of the studies that did include a control ($n = 21$), only 18% ($n = 4$) included an even split between control and experiment groups (Brandes and Ehinger 1981; Golz et al. 2005; Hutton 1983; Updike and Thornburg 1992).

Age range of population

Participants ranged in age from 3 to 18 years. Only 9% of studies ($n = 3$) included a teenage population (Bennett et al. 2001; DiSarno and Barringer 1987; Shapiro et al. 2009). 7-year-olds were the most commonly studied age group, included in 63% ($n = 21$) of studies (Brandes and Ehinger 1981; Breadmore, Halliday, and Carroll 2024; Golz et al. 2005; Hall, Maw, and Steer 2009; Hutton 1983; Lous 1993; Lous and Fiellau-Nicholajsen 1984; Peters et al. 1994; 1997; Schilder et al. 1993; Share et al. 1986; Sharma et al. 2020a, 2020b; Silva, Chalmers, and Stewart 1986; Timms et al. 2014; Updike and Thornburg 1992; Webster et al. 1989; Winskel 2006; Zinkus, Gottlieb, and Schapiro 1978; Zinkus and Gottlieb 1980).

Diagnostic measures

Presence of OM was typically determined via tympanometry (75% of studies, $n = 25$) or medical history documentation (57%, $n = 19$) (Supplementary Figure 1). Only one study did not include tympanometry or medical documentation in their diagnostic process (Su et al. 2020).

There were only three studies (9%) that did not include a hearing assessment such as Pure Tone Audiometry, Conditioned Play Audiometry or Visual Reinforcement Orientation Audiometry in their diagnosis of OM (Carroll and Breadmore 2018; Shapiro et al. 2009; Zinkus & Gottlieb, 1980). Seven studies used bone conduction thresholds to identify CHL (Brandes and Ehinger 1981; DiSarno and Barringer 1987; Golz et al. 2005; 2006; Su et al. 2020; Webster et al. 1989; Zargi and Boltezar 1992). CHL was verified by tympanometry in all but one of these studies. When bone conduction was not conducted, tympanometry alone was used to identify the type of hearing loss (52%, $n = 17$) (Bennet et al. 2001; Lous 1993; Lous and Fiellau-Nicholajsen 1984; Nittrouer and Burton 2005; Peters et al. 1994; 1997; Roberts, Burchinal, and Clarke-Klein 1995; Roberts, Burchinal, and Zeisel 2002; Roberts et al. 1989; 2000; Schilder et al. 1993; Share et al. 1986; Sharma et al. 2020a; 2020b; Timms et al. 2014; Updike and Thornburg 1992; Walker and Wigglesworth 2001). Speech audiometry was conducted in 9% ($n = 3$) of studies to confirm audiogram results (DiSarno and Barringer 1987; Golz et al. 2005; 2006). Golz et al. (2005, 2006) were the only studies that included specific inclusion criteria based on speech reception thresholds. For all these studies, it was not specified how the speech results were evaluated or the stimuli that were used.

Literacy and pre-literacy measures

There was inconsistency between the studies on the literacy measures used. All the studies included a measure of some reading or pre-reading outcome, and often had other academic achievement measures, such as spelling and numeracy skills. 28 studies (85%) included at least one reading assessment, but the tasks varied (Supplementary Figure 1).

Some studies also included a measure of phonological awareness (36%; $n = 12$; Supplementary Figure 1), but different tools were used, with 14 different phonological assessments applied (Supplementary Figure 1). Not all these measures were standardised, which limits the ability to compare results across studies.

Relationship between OM and literacy measures

Twenty studies reported an association between presence or history of OM and literacy outcomes when compared to normal hearing peers or normative data (Supplementary Figure 1) (Bennett et al. 2001; Brandes and Ehinger 1981; Breadmore, Halliday, and Carroll 2024; Carroll and Breadmore 2018; DiSarno and Barringer 1987; Golz et al. 2005; Hutton 1983; Nittrouer and Burton 2005; Peters et al. 1997; Roberts et al. 2000; Shapiro et al. 2009; Sharma et al. 2020a, 2020b; Silva, Chalmers, and Stewart 1986; Su et al. 2020; Updike and Thornburg 1992; Walker and Wigglesworth 2001; Winskel 2006; Zinkus, Gottlieb, and Schapiro 1978; Zinkus and Gottlieb 1980). Twelve studies found no significant association between OM and literacy outcomes (Golz et al. 2006; Hall, Maw, and Steer 2009; Lous 1993; Lous and Fiellau-Nicholajsen 1984; Peters et al. 1994; Roberts, Burchinal, and Clarke-Klein 1995; Roberts et al. 1989; Schilder et al. 1993; Share et al. 1986; Timms et al. 2014; Webster et al. 1989; Zargi and Boltezar 1992), although three of these papers found an impact on either spelling or oral reading fluency (Word Form Production Test) (Peters et al. 1994; Schilder et al. 1993; Webster et al. 1989). The remaining study showed a significant relationship between OM and literacy that resolved with time (Roberts, Burchinal, and Zeisel 2002).

Discussion

This review was completed in 2024 and included 33 papers from 1978 to 2024 that assessed the phonological awareness and reading skills of children under 12 years old with OM. The aim was to collate the available evidence to determine whether there was an association between OM and poorer phonological awareness and reading outcomes. Although some studies found an association between a history of OM and poorer (pre-)reading skills, we cannot decisively conclude that OM caused poorer outcomes. Critically, correlation does not equal causation. Several other factors such as the measures used to screen for OM, reading assessment used, the purpose of the study and whether an intervention group was included need to be considered when evaluating the evidence.

Review

This project began as a systematic review but, due to the variability between measures and populations across studies, only a general review could be completed. The phenomena under investigation were inconsistent across studies, with phonological awareness or reading abilities not always the primary focus. Therefore, it was difficult to combine the results of selected studies.

(Pre-)reading outcomes

Across studies that reported a negative relationship between OM and reading outcomes, performance of children with (a history of) OM was compared to that of children with no history. One study indicated a minimum 2-year delay in those with OM diagnosed with Type B tympanometry compared to normal-hearing peers (Bennett et al. 2001). Another study found a similar 2.4 grade level difference between children with OM and controls on reading assessments (DiSarno and Barringer 1987). Golz et al. (2005) found an error rate of 15.2% for the OM group on their reading assessment, compared to 5.8% for controls. Across these studies, a history of OM alongside tympanometry and Pure Tone Audiometry were used as the selection criteria, but prior history of OM was not considered. Having a documented medical history of OM would be beneficial to consider for future studies to ensure that children experiencing their only instance of OM at the time of testing are not included in the OM population. This is because multiple occurrences of OM are likely to cause longer term auditory deprivation, which in turn could impact auditory processing, and consequently phonological awareness and literacy development.

The populations observed in two of the above studies were aged 11 to 18 years old (Bennett et al. 2001; DiSarno and Barringer 1987). The remaining study included 6.5 to 8.5-year-olds, followed up longitudinally at 10 to 11 years old (Golz et al. 2005; 2006). The longitudinal study found that reading results did not significantly differ between the OM recovered and control groups (Golz et al. 2006). However, reading outcomes were significantly poorer in those who still had OM compared to the resolved OM group. This study inferred that with the resolution of OM, reading outcomes matched their normal-hearing peers'. Furthermore, in another study, children with late onset OM did not significantly differ from normal-hearing peers in reading or phonological awareness, although the early-onset OM group performed more poorly on reading compared to both the control and late-onset OM groups (Shapiro et al. 2009). Studies varied in the age of the population observed. It may be beneficial to observe a younger age bracket, such as in the Golz et al. (2005) study, in future studies to better understand the relationship between OM and pre-reading outcomes.

In conjunction with these findings on reading, poorer phonological awareness (Carroll and Breadmore 2018) and dichotic listening skills (associated with phonological awareness) were observed in children with OM compared to age-matched controls (Sharma et al. 2020b). These findings support Ramus' (2001) claim that a deficit in auditory input impacts phonological mapping and, in turn, literacy outcomes. Furthermore, it supports studies that have shown that auditory deprivation affects the anatomy of the auditory system. Poorer results on dichotic listening tasks indicate reduced binaural processing abilities; this may be due to auditory deprivation altering the anatomy of the auditory system (Liberman, Liberman, and Maison 2015; Sharma et al. 2020b). The negative impact of OM on literacy outcomes was shown to increase access to educational support services in this population (Golz et al. 2005). An Australian study used the National Assessment Program – Literacy and Numeracy (NAPLAN) assessment to show an effect of OM on literacy abilities, writing and spelling (Su et al. 2020). All these studies investigated a similar age-group, spanning from 4.8 to 12 years old (Carroll and Breadmore 2018; Golz et al. 2005; Sharma et al. 2020b; Su et al. 2020). By observing a similar population, these studies provide consistent evidence of a relationship between a history of OM and poorer reading, writing, and spelling outcomes.

Conversely, Lous and colleagues found no statistically significant difference between control and OM groups in the Silent Reading Test (Lous et al. 1984). Lous (1993) similarly found a reported history of OM was not correlated with poorer silent reading abilities. Further to this, there was no significant difference between OM and control groups in academic achievement, as well as between OM treated and untreated groups (Schilder et al. 1993). Although, this study did indicate there was poorer phonemic segregation in those with OM than controls (Schilder et al. 1993). In another study, a teacher questionnaire revealed lower writing achievement in those with OM, although there was no significant difference in literacy assessments (Peters et al. 1994). These studies indicate no impact of occurrences of OM on (pre-)reading outcomes.

Papers also differed in the type and degree of hearing loss experienced by participants. Of the 33 studies, 21 included a population that had a hearing loss at the time of assessment (Supplementary Figure 1, 2). The remaining papers included participants who may have had a hearing loss in the past due to OM but did not have hearing loss at the time of testing ($n = 12$). It is unclear whether effects of OM on (pre-)reading outcomes differ when assessed during an acute phase of OM versus when OM is resolved as there were mixed results in the studies' outcomes (Supplementary Figure 1 and 2).

A history of OM may also be confounded with other risk factors for literacy difficulties, such as socioeconomic status. Of the studies that did show an impact of OM on (pre-)reading, there were only five which considered additional risk factors in their results. All other studies controlled for these factors. Three studies found socioeconomic status, gender, and maternal education did not have an impact on reading outcomes (Nittrouer and Burton 2005; Roberts et al. 2000; Su et al. 2020). One study found that girls outperformed boys on reading tasks, regardless of OM status (Updike and Thornburg 1992). Conversely, another study found gender did not impact results, but IQ, birth weight and prematurity, first language, and socioeconomic status had some impact on results (Peters et al. 1997). They further highlighted that the more risk factors the child had, the greater the chance of poorer outcomes (Peters et al. 1997). Therefore, other risk factors need to be taken into consideration, alongside hearing loss and acute or resolved OM, to predict a child's phonological awareness and reading outcomes.

When comparing the impacts of a transient hearing loss caused by OM to a permanent hearing loss, studies yielded similar results. Children with a minimal or mild sensorineural hearing loss, $\leq$30 dB HL, experience a similar level of hearing loss to the temporary conductive hearing loss associated with OM. Some studies have compared reading outcomes in those with permanent sensory impairment to their normal hearing peers. Walker et al. (2020) showed that the reading achievements of the hearing-impaired group were not significantly different to normal hearing peers. Moore, Zobay, and Ferguson (2020) found a difference in reading outcomes between children with minimal hearing loss (hearing thresholds 15-20 dB HL) and mild hearing loss (thresholds 25-40dB HL). This highlights the importance of considering the degree of hearing loss when evaluating reading outcomes. Having said that, a systematic review of the current literature on academic achievement in children with mild to moderate sensorineural hearing loss did not find a clear relationship (Zussino, Zupan, and Preston 2022). The current review has similarly found the association between OM, hearing loss and literacy outcomes to be complex.

The studies included in our review did not explore auditory processing deficits. Therefore, it is difficult to ascertain whether multiple instances of OM cause auditory processing deficits that in turn impact (pre-)reading outcomes. A study reviewing the current literature highlights that multiple instances of OM impact auditory processing abilities in children (Gyawali et al. 2024). Although, critically, auditory processing deficits can occur without the presence of OM (Alanazi 2023). Whilst it is possible that auditory processing impacts reading abilities, OM is not always responsible for that deficit. Further studies may explore the link between OM, auditory processing and (pre-)reading outcomes.

Other outcomes

Some studies assessed the impact of OM on other areas of academic achievement. In several studies OM had a negative impact on numeracy abilities (Roberts, Burchinal, and Zeisel 2002; Roberts et al. 2000; Su et al. 2020). However, two studies conversely reported no relationship between OM and numeracy skills (Zinkus, Gottlieb, and Schapiro 1978; Zinkus and Gottlieb 1980). Due to the lack of consistency between measures used and the diversity of the populations assessed, it is difficult to determine whether OM impacts numeracy outcomes. In addition, some studies found poorer spelling results for those with a history of OM (Bennett et al. 2001; Brandes and Ehinger 1981; Hutton 1983; Su et al. 2020; Timms et al. 2014; Walker and Wigglesworth 2001; Zinkus, Gottlieb, and Schapiro 1978; Zinkus and Gottlieb 1980). Peters et al. (1994) contradicted these findings, showing no impact of early childhood OM on spelling abilities.

Receptive and expressive language abilities of those with OM were also assessed in some studies. From 6 months to 2 years old there was a delay in expressive language outcomes in those with OM, although this diminished over time, with these children performing no differently to their normal-hearing peers by 7 to 8 years old (Roberts, Burchinal, and Zeisel 2002). The verbal comprehension of those with OM was not found to be impaired when compared to controls (Schilder et al. 1993).

Teacher reports identified greater behavioural issues in those with OM at 7 and 8 years old, but no impact on reading outcomes (Hall, Maw, and Steer 2009). However, another study failed to observe a statistically significant difference between OM and control groups in behaviour (Silva, Chalmers, and Stewart 1986). It seems that there may be a perceived impact of OM on behavioural outcomes by teachers.

Considerations for future studies

OM incidence: For prospective studies, it is critical to define OM and whether a history of recurrent OM is included in the participant criteria, or whether a single instance is enough. Following Ramus' framework on deprivation of the auditory system, including a population that has experienced multiple instances of OM, would provide insight into the link between *persistent* auditory deprivation and literacy abilities. In this review, there were 19 studies (57%) that included a history of recurrent OM in their selection criteria. Having rigorous testing criteria to establish a history of OM would allow for more consistency in the populations investigated across studies. To confirm auditory deprivation, multiple audiograms would need to be obtained to indicate a prolonged hearing loss caused by OM.

Future studies may also consider including related or synonymous diagnoses when searching the literature to provide a fuller picture of impacts of OM. In preliminary searches for this review, the terms "middle ear" plus "disorder", "effusion", "infection" and "fluid" identified medically-focussed papers including syndromes and hence these were not included in further searches. However, some databases (Medline and Embase) automatically included "middle ear infection" under the OM subheading; and the OM subject heading and keyword also included middle ear disorders. We therefore anticipated that our OM search term would identify relevant papers including middle ear disorders more broadly. Nevertheless, it is recommended that future studies consider additional search terms that may capture other literature focusing on middle ear conditions similar to OM.

Framework and outcome measures: Inclusion of Ramus and Goswami's frameworks will assist in defining the outcome measures relevant to literacy development and hence contribute to the literature in a systematic manner. In the surveyed literature there were a variety of assessments used that did not ultimately measure the same skills. This may stem from variation in the motivation of the research and the theoretical basis for how OM impacts phonological awareness and/or reading. For example, of the studies reviewed, 12 included a measure of phonological awareness, motivated by theoretical accounts of the role of phonological awareness in literacy development (Breadmore, Halliday, and Carroll 2024; Carroll and Breadmore 2018; Hall, Maw, and Steer 2009; Lous 1993; Schilder et al. 1993; Shapiro et al. 2009; Sharma et al. 2020a; 2020b; Timms et al. 2014; Walker and Wigglesworth 2001; Webster et al. 1989; Winskel 2006). However, other studies have not measured phonological awareness, and other measures have been included. For instance, previous research has evaluated reading comprehension, spelling, numeracy, and word recognition. As mentioned previously, the greatest limitation of these studies is their use of differing diagnosis and measurement outcomes. Therefore, it is difficult to make a clear comparison between the studies to infer conclusively if there is an impact on literacy outcomes in those affected by OM.

Age Range: The 33 studies included children ranging from 3 to 18 years of age. The differing age ranges restricted the ability to determine whether there was an impact of OM at specific ages only or throughout childhood, and contributed to inclusion of different outcome measures, given that some outcome measures were only appropriate for certain age groups. For instance, Walker and Wigglesworth (2001) reported the phonological awareness of 5 to 6-year-olds with OM was below the mean, contrasting with Webster and colleagues' (1989) assessment of 7- to 10-year-olds. Webster et al. suggested that the lack of association in their study could be due to participants' increasing ability to utilise "bottom up" and "top down" processes as they gain more exposure to reading and language, therefore mitigating the effect on reading outcomes as they grow older. They further stated that there was a complex, interactive relationship between reading outcomes, OM, and other factors such as socioeconomic status and teaching environment. If the impact of OM on phonological awareness and literacy is via sensory deprivation, future studies could focus their investigation on 3- to 6-year-olds, as in research by Lous and Fiellau-Nicholajsen (1984), Hall, Maw, and Steer (2009), and Silva, Chalmers, and Stewart (1986). This age range encompasses the foundational development period for phonological awareness skills, where it has been hypothesised that sensory deficits such as those caused by OM, make it challenging for those individuals to match their typically-developing peers (Wildová and Kropáčková 2015). It would be beneficial to follow participants longitudinally to determine both whether a relationship is observed and if the impact of OM is mitigated with age.

Sample Size: Statistical power is impacted by the number of study participants. Studies such as Bennett et al. (2001) included 952 participants, which provided greater power and thus a greater likelihood of detecting a statistically significant result. These high participant numbers were also seen in Su et al. (2020), which included 2208 children with OM. This study reported an association between hearing loss, measured by Pure Tone Audiometry, and poorer writing and spelling scores. However, it is important to note that correlations were not predictive, therefore we cannot definitively state whether OM impacts literacy skills purely from this data. To address this limitation, including an intervention population, such as in Hall and colleagues' (2009) study, or a randomised control trial would be appropriate. Future research could include many participants, as in the studies mentioned above, to improve statistical power, in conjunction with an intervention population or a randomised control trial to define the cause-and-effect relationship between OM and pre-reading skills.

Conclusion

Of the 33 papers identified, 61% showed an association between OM and (pre-)reading outcomes, which supports the need for further investigation in this space to ensure timely intervention and support for children at risk of ongoing OM. Although we did not find overwhelming evidence that OM impacts (pre-)reading outcomes, the weight of evidence is in favour of an impact. In future, increased reference to theoretical frameworks of reading and use of longitudinal studies may allow for connections to be drawn between auditory deprivation due to OM and phonological skill impairment which, in turn, may affect reading. By localising the source of reading difficulties in this population, we will be better equipped in future to implement effective interventions to improve literacy outcomes for children with OM.

Disclosure statement

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