STUDENT LEARNING, CHILDHOOD & VOICES | REVIEW ARTICLE

Academic benefits of wearing noise-cancelling headphones during class for typically developing students and students with special needs: A scoping review

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Abstract: Classroom noise impairs students’ cognition and learning. At a first glance, it seems useful to prevent the negative effects of noise on academic learning by wearing noise-cancelling (NC) headphones during class. The literature and guidelines emphasize the academic benefits of wearing NC headphones (decreased auditory distraction, increased concentration, learning improvement, and decreased distress). These benefits are particularly expected for students with special needs. None of the recommendations to wear NC headphones during class refer to any empirical studies, indicating a potential research gap and lack of evidence. Therefore, the question arises: Is there any empirical evidence supporting academic benefits of wearing NC headphones during class for typically developing students or students with special needs? A total of 13 empirical studies (quantitative and qualitative) were identified through a systematic scoping review of the existing literature. A wide range of outcomes (cognition, learning, academic performance, behaviour, and emotions) were reported related to the use of NC headphones. Most of the studies refer to specific groups of students with special needs (learning disabilities, autism, ADHD, etc.). In view of the limited number of studies, small sample sizes, and lack of replication studies, all studies give the impression of being pilot studies on the academic benefits of wearing NC headphones. The

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PUBLIC INTEREST STATEMENT

When deciding whether to provide students with NC headphones during class, teachers may be faced with the following questions: Are NC headphones conducive to learning? If so, for whom, under what learning and noise conditions, and for what types of tasks? The present scoping review is the first to summarize empirical findings on the academic benefits of wearing NC headphones during class for typically developing students and students with special needs. The current body of evidence does not meet the standards for evidence-based practices in both general and special education. However, the diversity of research approaches is a first step toward future research directions and theory building on the relationship between academic performance, classroom noise, noise cancellation, and special needs. Further studies are needed.

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practice of wearing NC headphones during class is an understudied topic. The current body of evidence does not meet the standards for evidence-based practices in both general and special education. Implications for educational practice and future research are discussed.

Subjects: Educational Research; Education Studies; Inclusion and Special Educational Needs; ADHD; Severe, Profound & Multiple Learning Difficulties; Autism; Emotional & Behavioural Difficulties; Learning Difficulties; Classroom Management & Organisation; Teaching & Learning

Keywords: classroom noise; academic performance; noise-cancelling headphones; special needs; scoping review

1. Classroom noise and academic performance

Noise and sounds in class are ubiquitous, such as due to paper rustling, throat clearing, or giggling. A certain sound level is therefore inevitable in the classroom, even during silent seatwork. However, there are many other sources of noise and sounds in classrooms. Differentiated instruction strategies such as learning stations and cooperative learning methods trigger students' activity (talking and movement), and this type of loud group activities of other students can disturb students’ independent learning. Conduct problems like rule-breaking behaviours are other sources of internal classroom noise (noise due to activities within the classroom). External noise such as traffic noise also affects everyday school life (Stansfeld & Clark, 2015). In addition, there are some concerns about noise levels in inclusive education classrooms. Such concerns arise from the assumption that individualized instruction (e.g., small group instruction by learning support assistants) for students with special needs distracts students not in need of additional support (Rose & Coles, 2002). There are also concerns about noise related to disruptive behaviour of students with emotional and behavioural difficulties in inclusive education classrooms (Ali et al., 2014). Self-stimulating sounds (e.g., humming) from autistic students educated in inclusive classrooms can also be perceived as annoying by other students (Wood, 2020). Regardless of classroom heterogeneity due to students with special needs, noise surveys have found sound levels in classrooms that can be considered harmful (Mealings, 2016). This kind of noise annoys children and adolescents and impairs students' cognition and learning (Klatte et al., 2013; Shield et al., 2010; Stansfeld & Clark, 2015; Van Reenen & Karusseit, 2017; Woolner & Hall, 2010). Hence, noise reduction and prevention are of interest to students and teachers.

2. Noise reduction and prevention measures in classrooms

There are different approaches to creating quiet or less noisy learning environments. This section offers a brief overview of noise reduction and prevention measures adopted in classrooms. First of all, classroom acoustics are improved by installing sound-absorbent materials on blank walls (Oberdörster & Tiesler, 2008). This reduces sound levels in classrooms through a reduction of reverberation time. In addition, educational interventions implemented by teachers can reduce sound levels in classrooms. For example, classroom behaviour management strategies such as the Good Behaviour Game reduce disruptive and challenging behaviours (Parsonson, 2012), which is, by implication, a reduction of the sound level. Compliance with acceptable sound levels can be a criterion for receiving a reward in the Good Behaviour Game (Radley et al., 2016), whereby sound is actually measured with a sound meter and students receive (visual) feedback on the appropriateness of the current sound level in class (Parsonson, 2012; Van Tonder et al., 2016), e.g., with a traffic light system. Relaxation training for students has also been shown to reduce noise in the classroom (Norlander et al., 2005). Furthermore, guidelines recommend that students wear noise-cancelling headphones to reduce auditory distractions during class (Baglieri & Shapiro, 2017; Bonner & Chen, 2019; DeHartchuck et al., 2019; Winter & O’Raw, 2010). Noise-cancelling headphones do not actually reduce sound levels in classrooms, but ambient noise is less audible to the
students wearing them (hearing protection). This phenomenon of wearing noise-cancelling headphones during class is described in more detail below.

2.1. Wearing noise-cancelling headphones during class
Noise-cancelling (NC) headphones (also called noise reduction earmuffs, noise-attenuating headphones, or the like) consist of moulded rigid cups that fit over the ears. Sound-absorbing foam within the cups provide the basic sound insulation. This type of physical hearing protection is known as passive noise cancellation. Headphones with active noise attenuation are known as active NC headphones: A miniature microphone detects the sound waveform and loudspeakers reproduce a cancelling anti-phase signal. Active NC headphones also contain sound-absorbing foam (passive noise cancellation) and can usually also reproduce sound, e.g., relaxing music or instruction. Some active NC headphones can fade in ambient noise (via a miniature external microphone) if noise cancelation is undesired; for example, teachers’ instruction can be faded in (comparable to the function of hearing aids). Passive and active noise cancellation is also available in the form of earplugs and in-ear headphones. Both active and passive noise cancellation do not offer complete noise insulation, but they attenuate the sound intensity to a certain degree. For an overview of NC headphones, see Peters et al. (2011).

2.1.1. NC headphones for typically developing students and students with special needs. As already stated, noise can irritate children and adolescents and impair cognition and learning in students. Guidelines for inclusive education emphasize these negative effects of classroom noise on academic learning and recommend wearing NC headphones for students distracted by ambient noise (Baglieri & Shapiro, 2017; DeHartchuck et al., 2019; Winter & O’Raw, 2010). This type of hearing protection is particularly recommended for young students with sensory sensitivity (auditory hypersensitivity, hyperacusis, and sensory processing disorder), as these children are often overwhelmed by noise (Humphries & Rains, 2012; Thompson & Raisor, 2013). Auditory hypersensitivity (AH) is common in students with autism spectrum disorder (ASD) and noise can cause distress in this population (McLaren & Page, 2015). To avoid this negative effect of noise, it is recommended that students with ASD also wear NC headphones (Laurent et al., 2018; McLaren & Page, 2015). With this in mind, manufacturers and vendors of NC headphones recommend the very same for students with ASD and/or AH (HamiltonBuhl, 2020; National Autism Resources, 2020). In addition, the manufacturers and vendors recommend NC headphones for students with attention deficit hyperactivity disorder (ADHD) and promise increased concentration in students with ADHD with the use of NC headphones (Honeywell, 2020; De Roode, 2016). The literature also recommends wearing NC headphones to reduce distractions from noise and to help students with ADHD to attend, focus, and learn better (Barkley, 2015; Bonner & Chen, 2019). In general, manufacturers and vendors of NC headphones promise increased concentration in all learners (regardless of special needs) (HamiltonBuhl, 2020; De Roode, 2016).

3. Potential research gap, research question, and aim
Classroom noise annoys children and adolescents and impairs cognition and learning in students. Thus, the literature, recommendations, and guidelines emphasize the academic benefits of wearing NC headphones during class (decreased auditory distraction, increased concentration, learning improvement, and decreased distress). These benefits of wearing NC headphones are particularly expected for students with special needs, for example, students with ASD, AH, or ADHD. However, none of the recommendations refer to any empirical studies on the academic benefits of wearing NC headphones during class, indicating a potential research gap and lack of evidence. Therefore, the question remains: Is there any empirical evidence supporting academic benefits of wearing NC headphones during class for typically developing (TD) students or students with special needs? Thus, the aim of the present paper is to identify and review empirical studies on the academic benefits of wearing NC headphones during class for students, especially students with special needs.
4. Method

None of the recommendations to wear NC headphones during class refer to any empirical studies, indicating a potential research gap and lack of evidence. It seems necessary to identify any empirical evidence and provide a comprehensive overview of the evidence on academic benefits of wearing NC headphones during class. For this purpose, a scoping review is an adequate tool to identify and map the available evidence, discover the types of evidence, and recognize and analyse knowledge gaps (Munn et al., 2018). To my knowledge, there is at present no systematic (scoping) review of the academic benefits of wearing NC headphones during class. The present scoping review will be conducted following the recommendations for systematic reviews in educational research by Newman and Gough (2020).

4.1. Selection criteria

The selection criteria will be broad in order to gather any empirical evidence on the academic benefits of wearing NC headphones for students, especially students with special needs. Any empirical study (quantitative or qualitative) will be included in the present review if it used headphones, earmuffs, or earplugs for noise insulation, cancellation, or attenuation in school-age children or adolescents (including preschool-age children) and if any school-relevant outcomes (cognition, learning, academic performance, behaviour, or emotions) were reported related to the use of the headphones, earmuffs, or earplugs. There will be no restrictions regarding study design. All types of study design will be included, such as intervention studies, quasi-experiments, observational studies, interview studies, single case studies, etc.

4.2. Search strategy

Two databases were selected for the literature search: Education Resources Information Center (ERIC) and PsycInfo. Search results from PsycInfo were narrowed by limiting the search results to relevant age groups (childhood, school age, adolescence, and preschool age). The following search string was used for both databases (date of search: 16 October 2020): (“sound*” OR “noise*”) AND (“headphone*” OR “earmuff*” OR “ear-muff*” OR “ear muff*” OR “earplug*” OR “ear-plug*” OR “ear plug*”). References in the papers meeting the inclusion criteria will be screened to identify further studies meeting the inclusion criteria. An unsystematic literature search on Google and Google Scholar will be the final step to ensure that no relevant study is overlooked.

4.3. Synthesis strategy

As the selection criteria are very broad, there will most likely be a variety of study designs (e.g., intervention and observational studies), data types (quantitative and qualitative), populations (TD students and students with different types of disabilities and impairments), settings (school types and grades), school-relevant outcomes (cognition, learning, academic performance, behaviour, and emotions), operationalization methods regarding the outcomes, and NC techniques (active and passive; in-ear and over-ear headphones). In view of this possible variety, statistical synthesis (meta-analysis) of the findings will most likely be inadequate. However, statistical synthesis is not the aim of a scoping review, but rather the identification and mapping of the available evidence, the exploration of the types of evidence, and the discovery and analysis of knowledge gaps (Munn et al., 2018). Therefore, the findings of the studies will be synthesized in narrative format to emphasize the variety of study designs, data types, populations, settings, school-relevant outcomes, operationalization methods regarding the outcomes, and NC techniques. This narrative synthesis will be helpful in assessing the empirical evidence on the academic benefits of wearing NC headphones during class for TD students and students with special needs.

5. Results

5.1. Study selection

Details of the search and screening process are shown in Figure 1 and Table 1 (see note to Table 1). The search led to 272 (ERIC) and 67 results (PsycInfo). The records (RIS files) are available as supplementary material. The total number of results was 329 after removing duplicates. Following
This, titles and abstracts were screened for meeting the inclusion criteria. This led to the exclusion of 320 results (reasons: non-empirical studies, studies with adults, or headphones were not used for noise cancellation, but to reproduce auditory stimuli). Hence, the number of results was nine. Following this, the full texts were screened for meeting the inclusion criteria. This led to the exclusion of one result (reason: non-empirical study). The references in the remaining eight papers were screened for further studies meeting the inclusion criteria. This resulted in the identification of another three relevant studies. The unsystematic literature search on Google and Google Scholar resulted in two more results. Consequently, the final number of papers was 13 (Table 1).
Table 1. Overview of studies

| Study                          | Participants/Population                  | Age in Years | Setting                  | Study Design/Noise Cancellation                                                                 | School-Relevant Outcome                                                                 | Comments                                                                                           |
|-------------------------------|-----------------------------------------|--------------|--------------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Rowe et al. (2011)*           | child with ASD and AH (N = 1)           | 11           | school (not specified)   | single case study (no headphones, headphones, no headphones): not wearing and wearing passive NC headphones during class | on/off-task behaviour (duration of attention to task)                                      |                                                                                                    |
| Pfeiffer, Stein Duker et al. (2019) | children and adolescents with ASD and AH (N = 6) | 8–16         | home, community, school  | single case study (baseline, headphones, washout, headphones): over-ear and in-ear headphones (active noise cancellation); not wearing and wearing headphones during loud activities or during aversive activities due to auditory stimuli (both everyday activities) | psychophysiological stress and anxiety: measurement of electrodermal activity               |                                                                                                    |
| Ikuta et al. (2016)*          | children and adolescents with ASD and AH (N = 17) | 4–16         | school, home             | single case study (baseline, passive NC headphones, active NC headphones or baseline, active NC headphones, passive NC headphones): not wearing and wearing headphones at home and at school | behavioural problems related to AH: Goal Attainment Scaling (Kiresuk et al., 1994)            |                                                                                                    |
| Study | Participants/Population | Age in Years | Setting | Study Design/Noise Cancellation | School-Relevant Outcome | Comments |
|-------|-------------------------|--------------|---------|---------------------------------|-------------------------|----------|
| Pfeiffer, Erb et al. (2019)* | parents (N = 10) and teachers (N = 5) of children and adolescents with ASD and AH (N = 15) | 6–12 | home, community, school | interview study with parents and teachers: over-ear and in-ear headphones (active noise cancellation); children and adolescents used headphones during everyday activities and at school (home, community, school) | participation, anxiety, stress, attention and focus, elopement (escape behaviour) |         |

**Students With ADHD (Attention Deficit Hyperactivity Disorder)**

| Study | Participants/Population | Age in Years | Setting | Study Design/Noise Cancellation | School-Relevant Outcome | Comments |
|-------|-------------------------|--------------|---------|---------------------------------|-------------------------|----------|
| Kollins (2020)# | children and adolescents with ADHD (N = 36) | 6–17 | N/S | randomized cross-over design (two within-subject conditions A and B): (A) no headphones (baseline), wearing active NC headphones (session 1), and wearing passive NC headphones (session 2) or (B) no headphones (baseline), wearing passive NC headphones (session 1), and wearing active NC headphones (session 2) while performing tasks (several days between experimental sessions); standardized noise that simulates classroom noise (probably reproduced using loudspeakers) | motor control, spatial working memory, stop signal reaction time, rapid visual information processing; Cambridge Neuropsychological Test Automated Battery for ADHD (Sandberg, 2011); mathematical calculation skills: Mathematics Fluency and Calculation Tests (Marbach, 2017); reading comprehension: Test of Silent Reading Efficiency and Comprehension (Johnson et al., 2011); concentration (self-experience with headphones) | * not yet published in peer-reviewed journal: study protocol, informed consent form, and initial results are available on the webpage clinicaltrials.gov (but this information is not sufficient to get the big picture) |
| Study | Participants/Population | Age in Years | Setting | Study Design/Noise Cancellation | School-Relevant Outcome | Comments |
|-------|-------------------------|--------------|---------|---------------------------------|------------------------|----------|
| Hooker (1985) | students with LD (N = N/S) | N/S | middle school: 5th grade | case study: not wearing and wearing passive NC headphones during class (within-subject); teacher instruction was given without the use of headphones | on/off-task behaviour, quantity of work, academic scores, talking among students, students’ support-seeking behaviour | • precise description of study design and measurement of outcomes (operationalization) is missing |
| Smith (2010) | students with LD (N = 4) | 9–10 | inclusive classroom: 5th grade | single case study (no headphones, headphones, no headphones, headphones): not wearing and wearing passive NC headphones during reading assessments in class | reading comprehension: Qualitative Reading Inventory (Leslie & Caldwell, 2006) | |
| Smith and Riccomini (2013) | TD students (N = 163), students with LD (N = 35), with other disabilities (N = 17), at risk for disability (N = 39) | N/S | elementary school: 3rd grade 4th grade 5th grade | randomized testing accommodations study (two within-subject conditions A and B): (A) wearing (t1) to not wearing headphones (t2) or (B) not wearing (t1) to wearing passive NC headphones (t2) during two different reading assessments in class (t1 and t2) | reading comprehension: Qualitative Reading Inventory (Leslie & Caldwell, 2006) | • Smith and Classen (2018) and Smith et al. (2018) used a sub-sample of this study sample, but used qualitative data (interview and observation) |
### Table 1. (Continued)

| Study                        | Participants/ Population                                                                 | Age in Years | Setting                                      | Study Design/ Noise Cancellation                                                                 | School-Relevant Outcome                                                                 | Comments                                                                                                                                 |
|------------------------------|------------------------------------------------------------------------------------------|--------------|----------------------------------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Smith and Classen (2018)     | TD students (N = 13), students with LD (N = 5), with other disabilities (N = 2), at risk for disability (N = 4) | N/S          | elementary school: 3th grade 4th grade 5th grade | interview study with students; not wearing and wearing passive NC headphones during reading assessments in class, see Smith and Riccomini (2013) | reading comprehension, distraction, concentration, calmness, enjoyment                    | students in this study are identical with students in the studies by Smith and Riccomini (2013) and Smith et al. (2018) |
| Smith et al. (2018)          | TD students (N = 13), students with LD (N = 5), with other disabilities (N = 2), at risk for disability (N = 4) | N/S          | elementary school: 3th grade 4th grade 5th grade | interview study and classroom-observation study (direct observation) with students; not wearing and wearing passive NC headphones during reading assessments in class, see Smith and Riccomini (2013) | students' reaction to the headphones                                                      | students in this study are identical with students in the studies by Smith and Riccomini (2013) and Smith and Classen (2018) |

**Students With Different Cognitive Abilities**

| Study                        | Participants/ Population                                                                 | Age in Years | Setting                                      | Study Design/ Noise Cancellation                                                                 | School-Relevant Outcome                                                                 | Comments                                                                                                                                 |
|------------------------------|------------------------------------------------------------------------------------------|--------------|----------------------------------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Sumter (1969)                | students with different cognitive abilities (N = 30)                                      | N/S          | technical high school: 11th grade 12th grade | randomized controlled trial: not wearing (control group) and wearing passive NC ear pads (intervention group) during learning in class between pre- and post-test; ear pads were used in combination with a privacy shield | test on electronics and computer programming (pre- and post-test)                         | it is not clear which test was used to assess cognitive ability (Sumter used the term mental ability) |

**Students With WS (Williams Syndrome) and AH (Auditory Hypersensitivity)**

(Continued)
| Study                  | Participants/Population | Age in Years | Setting | Study Design/Noise Cancellation | School-Relevant Outcome | Comments                                                                 |
|-----------------------|-------------------------|--------------|---------|---------------------------------|-------------------------|--------------------------------------------------------------------------|
| O’Reilly et al. (2000)| child with WS and AH (N = 1) | 5            | N/S     | single case study (no noise, noise, no noise, noise plus earplugs, noise, noise plus earplugs): not wearing and wearing passive NC earplugs during play time and playschool-task performance (both in the presence of the child’s mother; other children were not present); classroom noise reproduced using loudspeakers (audiotape) | problem behaviour, pain behaviour: scored by observers (partial interval recording) | • precise information about operationalization of problem and pain behaviour is missing |
|                       |                         |              |         |                                 |                         |                                                                          |
| Students With TE (Trauma Experiences) |                       |              |         |                                 |                         |                                                                          |
| McConnico et al. (2016)§ | TD students (N = N/S) and students with TE (N = N/S) and teachers (N = 12) | N/S         | preschool and elementary school: preschool 1st grade 2nd grade | pre-post design with no control group: passive NC headphones as part of a school-wide trauma-informed approach | emotional support, classroom organization, instructional support (dimensions of teaching): Classroom Assessment Scoring System (Piatora et al., 2008) | • evaluation (pre-post design) of school-wide trauma-informed approach • no direct evaluation of wearing NC headphones • no differentiation between TD students and students with TE • student outcomes were not measured |

Note: TD: typically developing; NC: noise-cancelling; *Results of screening references (see Figure 1); §Results of unsystematic search on Google (see Figure 1); †Result of unsystematic search on Google Scholar (see Figure 1); Non-peer-reviewed; ‡Another study is reported in this doctoral thesis, but the results of the second study were also published in peer-reviewed journals (Smith & Classen, 2018; Smith et al., 2018; Smith & Riccomini, 2013).
5.2. Narrative synthesis

5.2.1. Peer review
Nine papers were published in peer-reviewed journals. Non-peer-reviewed papers were two doctoral theses (Smith, 2010; Sumter, 1969), one short research report on the webpage clinicaltrials.gov (Kollins, 2020), and one paper published in a journal for educators (McConnico et al., 2016).

5.2.2. Study designs
A broad variety of study designs were used to evaluate the academic benefits of wearing NC headphones: five single case studies (Ikuta et al., 2016; O’Reilly et al., 2000; Pfeiffer, Stein Duker et al., 2019; Rowe et al., 2011; Smith, 2010), two randomized within-subject designs (Kollins, 2020; Smith & Riccomini, 2013), two interview studies (Pfeiffer, Erb et al., 2019; Smith & Classen, 2018), one interview/classroom observation study (Smith et al., 2018), one case study (Hooker, 1985), one pre-post-design study with no control group (McConnico et al., 2016), and one randomized controlled trial (Sumter, 1969).

5.2.3. Settings and age groups
Studies took place in different school settings (preschool, elementary school, middle school, and high school) and therefore covered a wide range of grade levels (1st-12th grades) and age groups (4-17 years old). Three studies (Ikuta et al., 2016; Pfeiffer, Erb et al., 2019; Pfeiffer, Stein Duker et al., 2019) also investigated children and adolescents outside of the school setting, namely at home and in the community environment. In two studies (Kollins, 2020; O’Reilly et al., 2000), the setting was not precisely defined.

5.2.4. Types of NC Headphones
Children and adolescents used different types of NC headphones: over-ear headphones (passive and active noise cancellation) and in-ear headphones with active noise cancellation, but also simple earplugs or ear pads. Active NC headphones were used in four studies (Ikuta et al., 2016; Kollins, 2020; Pfeiffer, Erb et al., 2019; Pfeiffer, Stein Duker et al., 2019). In most studies, children and adolescents wore the NC headphones in the presence of naturally occurring sounds (classroom and/or environmental noise). In two studies (Kollins, 2020; O’Reilly et al., 2000), standardized classroom noise was reproduced using loudspeakers.

5.2.5. School-Relevant outcomes
A broad range of school-relevant outcomes were reported related to the use of NC headphones, such as reading comprehension, mathematical calculation skills, cognitive functions (focus, working memory, attention, concentration, etc.), behaviours (behavioural problems, on/off task behaviour), and emotions (stress, anxiety, enjoyment, etc.). Additional information on the operationalizations and measurement instruments used is available in Table 1.

5.2.6. TD students and students with special needs
Almost all studies refer to specific groups of children and adolescents with special needs: four studies with students with ASD and AH (Ikuta et al., 2016; Pfeiffer, Erb et al., 2019; Pfeiffer, Stein Duker et al., 2019; Rowe et al., 2011), one study with students with ADHD (Kollins, 2020), one study with students with different cognitive abilities (Sumter, 1969), one study with a child with Williams syndrome (WS) and AH (O’Reilly et al., 2000), one study with students with trauma experiences (TE) (McConnico et al., 2016), and five studies with students with learning disabilities (LD) (Hooker, 1985; Smith, 2010; Smith & Classen, 2018; Smith et al., 2018; Smith & Riccomini, 2013). Three of the studies with students with learning disabilities (LD) (Smith & Classen, 2018; Smith et al., 2018; Smith & Riccomini, 2013) also refer to students with other disabilities (miscellaneous), students at risk for disability (miscellaneous), and TD students. The study results on the academic benefits of wearing NC headphones are described below in more detail for each group of students with special needs (Table 1).
5.2.7. Main findings

5.2.7.1. Students with ASD and AH. In a single case study (Rowe et al., 2011), an 11-year-old student with ASD and AH (N = 1) showed more on-task behaviour when using passive NC headphones during class. The authors report that without the use of the headphones, the student more frequently turned his face away from the task, which was interpreted as off-task behaviour. Another single case study (Pfeiffer, Stein Duker et al., 2019) examined the effectiveness of active NC headphones (over-ear and in-ear) in children and adolescents with ASD and AH (N = 6). It was found that psychophysiological stress and anxiety (electrodermal activity) were caused by noise during everyday activities and that this effect can be counteracted with the use of headphones. Ikuta et al. (2016) found that the use of active and passive NC headphones at home and at school reduced behavioural problems related to AH in children and adolescents with ASD and AH (N = 17). In this single case study, individual behavioural goals (reduction of behavioural problems related to AH) were defined for each participant. Other participants (N = 4) refused to wear the headphones due to discomfort. Pfeiffer, Erb et al. (2019) provided children and adolescents with ASD and AH (N = 15) with active NC headphones (in-ear and over-ear) for everyday and school use. Following this, interviews were conducted with parents (N = 10) and teachers (N = 5) on their opinion on the use of the headphones by their children and students. Parents and teachers reported that the children and adolescents were able to participate in loud activities in school and everyday life without noise-related anxiety or stress. Furthermore, they reported that the children and adolescents were better able to attend and focus. Other reported benefits include an increased ability to stay calm and reduced elopement (escape behaviour). However, some parents and teachers have raised concerns about using the headphones. There were concerns that the students were perceived as different or that the over-ear headphones accentuated the students’ disability (stigmatizing effects of wearing headphones). Teachers and parents were concerned that the children and adolescents would become dependent on using headphones, and would not desensitize to noise or learn how to engage in loud activities without using the headphones. Some teachers expressed concerns that the students were not able to hear teachers' instruction when wearing the headphones and that the headphones prevented students from being able to hear and engage in conversations and activities. Some students refused to wear the in-ear headphones due to discomfort.
5.2.7.2. Students with ADHD. Children and adolescents with ADHD (N = 36) were randomly assigned to one of two conditions (Kollins, 2020): (A) no headphones (baseline), wearing active NC headphones (session 1), and wearing passive NC headphones (session 2) or (B) no headphones (baseline), wearing passive NC headphones (session 1), and wearing active NC headphones (session 2) while performing tasks (headphones as a testing accommodation; several days between experimental sessions). Other children were not present during task performance, but standardized classroom noise was reproduced (probably using loudspeakers). The tasks completed by the children and adolescents cover a broad range of domains and cognitive operations: mathematical calculation skills, reading comprehension, motor control, spatial working memory, stop signal reaction time, and rapid visual information processing (see Table 1 for details on operationalizations). This study is not yet published in a peer-reviewed journal. Study protocol, informed consent form, and initial results are available on the webpage clinicaltrials.gov, but this information is not sufficient to get the big picture regarding the effectiveness of NC headphones.

5.2.7.3. Students with LD. Hooker (1985) gave lessons to a group of fifth-grade students with LD (n = N/S). Students’ performance and behaviour were observed in two consecutive phases: not wearing and wearing passive NC headphones during class. A precise description of the study design and measurement of outcomes (operationalization) is missing in this case study. However, Hooker (1985) made some interesting conclusions based on his observations. He reports that half of the students had difficulty adjusting to the headphones and that the headphones were a greater source of distraction than ordinary noise in the room. For 28 percent of the students, the headphones eliminated the number of off-task behaviours and actually doubled the quantity of work. For the other students, the behaviours were the same, but the output of work increased significantly. Academic scores were not affected. Talking among the students diminished while they were wearing headphones. Students’ support-seeking behaviour increased (hands were raised for help when the students were wearing their headphones). Results of a single case study with fifth-grade students with LD (N = 4) are reported in a doctoral thesis by Smith (2010). Students performed better on a reading comprehension test during class when they wore passive NC headphones. Another study is reported in the doctoral thesis. However, the results of the second study were also published in peer-reviewed journals (Smith & Classen, 2018; Smith et al., 2018; Smith & Riccomini, 2013) and are described in more detail subsequently. A group of elementary students (3rd–5th grades) were randomly assigned to one of two conditions (Smith & Riccomini, 2013): (A) wearing (t1) to not wearing headphones (t2) or (B) not wearing (t1) to wearing passive NC headphones (t2) during two different reading comprehension tests in class (t1 and t2). It is important to note that students wore the headphones during reading and while giving answers on the written reading comprehension test (headphones as a testing accommodation). The sample consisted of TD students (N = 163), students with LD (N = 35), students with other disabilities (N = 17), and students at risk for disability (N = 39). TD Students did not benefit from wearing the headphones (d = 0.00), but the students with LD (d = 0.32) and those at risk for disabilities (d = 0.19) did. So did the students with other disabilities, but the reported effect size (d = 0.59) is not plausible in view of the reported parameters (M<sub>headphones</sub> = 3.71; M<sub>no headphones</sub> = 3.12; SD<sub>headphones</sub> = 1.96; SD<sub>no headphones</sub> = 2.00). A smaller effect size is more plausible (d = [3.71–3.12]/(1.96 + 2.00)/2] = 0.30). After using the headphones during the reading comprehension test, interviews were conducted with some of the students (Smith & Classen, 2018). The sub-sample for the interviews consisted of TD students (N = 13), students with LD (N = 5), students with other disabilities (N = 2), and students at risk for disability (N = 4). Students reported that the headphones reduced auditory distractions and increased reading comprehension, concentration, calmness and enjoyment of the task. Some students reported that the headphones made them feel strange (too much silence). Other interview results (Smith et al., 2018) on the same sample emphasize students’ positive attitude towards the use of headphones. Smith et al. (2018) also report that they observed students’ enjoyment of wearing headphones during reading comprehension tasks, but specific information about the observation criteria is missing.
5.2.7.4. Students with different cognitive abilities. The study by Sumter (1969) is a randomized controlled trial, in which high school students (N = 30) were randomly assigned to one of two groups: not wearing (control group) or wearing passive NC ear pads (intervention group) during learning in class between pre-and post-test (ear pads were used in combination with a privacy shield). The students were first pre-tested (test on electronics and computer programming), then they studied the learning unit and were subsequently post-tested. It is important to note that the students in the intervention group took the pre- and post-tests without using ear pads. Sumter (1969) concluded that students who studied using the ear pads did not perform better than the students in the control group (no ear pads). The same holds true for students with different cognitive abilities (no benefits of using ear pads for students with different cognitive abilities), but specific information about the levels of cognitive ability is missing and it is not clear which test on electronics and computer programming was used. It is also not clear which test was used to assess cognitive ability (Sumter used the term mental ability).

5.2.7.5. Students with WS and AH. In a single case study (O'Reilly et al., 2000), a 5-year-old girl with WS and AH (N = 1) showed fewer problem and pain behaviours when using passive NC ear plugs during play time and playschool task performance (both in the presence of her mother). Other children were not present, but standardized classroom noise was reproduced using loudspeakers.

5.2.7.6. Students with TE. Passive NC headphones were implemented as part of a school-wide trauma-informed approach for young students (McConnico et al., 2016). This school-wide trauma-informed approach was evaluated using a pre-post design (with no control group) to examine teachers' (N = 12) teaching styles (emotional support, classroom organization, and instructional support). The study examined the multidimensional school-wide trauma-informed approach overall, and the use of headphones was not evaluated directly. The study did not differentiate between students with TE (N = N/S) and TD students (N = N/S). Student outcomes were not measured. Therefore, no conclusions can be drawn on the academic benefits of wearing NC headphones for students with TE or TD students.

6. Discussion
The aim of the present scoping review was to identify and review empirical studies on the academic benefits of wearing NC headphones. To my knowledge, the present scoping review is the first to summarize empirical findings on the academic benefits of wearing NC headphones during class for TD students and students with special needs. Finally, a total of 13 empirical studies were identified through the systematic literature search. TD students (along with students with LD, students with other disabilities, and students at risk for disability) were examined in a few studies. Most studies refer to specific groups of children and adolescents with special needs. The examined groups were students with ASD and AH, students with ADHD, students with LD, students with different cognitive abilities, one student with WS and AH, and students with TE (although the corresponding study did not differentiate between students with TE and TD students). The samples of students with special needs are rather small (sample size N ranges between 1 and 39), which is certainly due to the single case nature of most studies. In view of the limited number of studies (n = 13), small sample sizes, and lack of replication studies, all studies give the impression of being proof-of-concept studies, pilot studies, or explorative studies on the academic benefits of wearing NC headphones during class. Given this scattered evidence, conclusions about the academic benefits of wearing NC headphones should be treated with caution and it does not seem to be an overstatement to say that the practice of wearing NC headphones during class for TD students and students with special needs is an understudied topic. The current body of evidence does not meet the standards for evidence-based practices in both general and special education (Council for Exceptional Children, 2014; What Works Clearinghouse, 2020). Further replication studies are needed, especially methodologically sound group comparison studies and single case research. At any rate, the current diversity of research approaches (different study designs,
operationalizations of school-relevant outcomes, and populations) offers broad insights from different perspectives (e.g., interviews with teachers, students, and parents) and is a first step toward future research directions and theory building on the relationship between academic performance, classroom noise, noise cancellation, and special needs. However, many studies lack a precise description of the study design, participants, and measurement of outcomes (operationalization). In light of the sparse evidence, the relevance of noise cancellation for TD students and students with special needs as well as implications for future research and educational practice are discussed below in more detail.

6.1. Relevance of noise cancellation for TD students and students with special needs: implications for future research and educational practice

In order to answer the question of whether wearing NC headphones during class is conducive to learning, it must first be clarified to what extent noise actually affects learning and cognition in students. There is some consensus on the negative effects of noise on academic learning. Given this consensus, it seems useful to prevent these negative effects of noise on academic learning by wearing NC headphones during class. However, the assumption of academic benefits from wearing NC headphones is questionable, as some of the research on the relationship between noise and academic performance is inconclusive and contradictory (Woolner & Hall, 2010). Some studies show mixed results, fail to show the negative effects of noise, or even show beneficial effects of noise on learning and cognition in students. For example, aircraft and road traffic noise impaired recall, while train and verbal noise did not affect recall (noise played through loudspeakers in classrooms) (Hytte, 2003). These results suggest that some specific types of noise may have no negative effect on recall. In those cases where specific types of noise do not interfere with cognitive processing, noise cancellation may be redundant (no benefits from wearing NC headphones). This appears to be the case in the study (Smith & Riccomini, 2013) showing that TD students did not benefit ($d = 0.00$) from wearing NC headphones during reading comprehension tasks. A possible explanation for the ineffectiveness of the NC headphones for TD students is that the specific types of noises that occurred during the tasks did not interfere with reading comprehension in TD students. At the same time, the very same types of noise probably interfered with reading comprehension in students with special needs, which is likely why students with LD, students at risk for disabilities, and students with other disabilities benefited from wearing the headphones. However, the different groups of students with special needs benefited to varying degrees ($d = 0.32$; $d = 0.19$; $d = 0.30$) from wearing the headphones, which in turn indicates that the effectiveness of NC headphones may depend on individual differences (i.e., types of special needs). Further, the effectiveness of NC headphones may also depend on different types of academic tasks. This assumption is supported by a study (Dockrell & Shield, 2006) showing that TD students and students with special needs benefited from noise during task performance (babble plus environmental noise played through loudspeakers in classrooms during written spelling and reading comprehension tests). The beneficial effect was even more pronounced for students with special needs than for TD students (differential effect as a function of individual differences). This beneficial effect of noise was not the case during a test of information processing speed. Babble plus environmental noise impaired information processing speed in both TD students and students with special needs. These results suggest that a specific noise condition can have a beneficial effect on a certain type of academic task and at the same time a negative effect on another type of academic task. It certainly would make no sense to wear NC headphones during the occurrence of a beneficial noise condition. To summarize the research on the relationship between noise and learning in students, Woolner and Hall (2010, p. 3259) emphasize that the interplay between different noise conditions, individual differences, and different types of academic tasks is an understudied topic:

> From these experimental studies, however, it is not possible to know the limits of such improved performance over time, different tasks and noises, or across differing learners. Much work does not differentiate between individuals in their reactions to noise or between
different sorts of noises. Where individual differences are investigated, there is a body of evidence that some individuals might be more sensitive to noise than others […]’ (p. 3259)

All this can be transferred to research on the academic benefits of noise cancellation: The academic benefits of wearing NC headphones may depend on

- different noise conditions (sound level, environmental noise, irrelevant speech, etc.),
- individual differences among students (age, types and severity of special needs, abilities, etc.), and
- types of academic performance (recall, reading comprehension, task difficulty, form of learning, etc.).

These three aspects (see also Sikström & Söderlund, 2008; Van Reenen & Karusseit, 2017; Zentall, 2005) must be considered in future research (Figure 2). Accordingly, when deciding whether to provide TD students and students with special needs with NC headphones during class, teachers may be faced with the following questions: Are NC headphones conducive to learning? If so, for whom, under what learning and noise conditions, and for what types of tasks? The current evidence regarding these questions is far from certain. It would be interesting to gather some representative data on the current practice of using NC headphones in schools. So far, there does not seem to be any studies on the status quo of the application of NC headphones during class. Therefore, it is hard to judge whether wearing NC headphones is a frequent or rare phenomenon in general, inclusive, and special education. In that regard, many questions remain open: How often are NC headphones used in schools? Which students (with special needs) are provided with NC headphones and in which noise and learning conditions? What are teachers’ and students’ beliefs about the academic benefits of wearing NC headphones during class? In general, a possible explanation for academic benefits could be an immediate increase of self-efficacy in students: “If I wear my headphones, I can solve this task easily.” Most of the research identified in this scoping review has investigated the immediate effects of NC headphones on learning and behavior (NC headphones as a testing accommodation). An exception (Sumter, 1969) is first learning using NC headphones and then testing academic achievement while not wearing the headphones (medium-term effect after taking off NC headphones). So far, the short-term, medium-term, and long-term effects of wearing NC headphones as well as learning processes after taking off NC headphones remain uninvestigated.

6.1.1. Potential adverse effects of wearing NC headphones during class
A discussion of the academic benefits of wearing NC headphones during class also implies a consideration of possible adverse effects (Figure 2), especially as the studies identified do indicate some potential adverse effects. For example, the over-ear headphones are eye-catching because of their size. There were concerns that the students were perceived as different or that the headphones accentuated the students’ disability (stigmatizing effects of wearing headphones). Stigmatization due to the headphones might even lead to peer exclusion. Moreover, using the headphones, students can miss out on relevant information or conversations. Students may also become dependent on using headphones, and may not desensitize to noise or learn how to engage in loud activities without using the headphones. Some students refused to wear the NC headphones due to discomfort or had difficulty adjusting to the headphones. Other students reported that the headphones made them feel strange (too much silence). Potential adverse effects of NC headphones can also be considered from a developmental perspective. In general, there is maturation of auditory development well into the teenage years (Litovsky, 2015). For example, the ability to parse out various sound sources and assign meaning to appropriate sound sources (auditory scene analysis) develops in childhood and infancy (Leibold, 2012; Litovsky, 2015). In addition, the ability to filter out irrelevant auditory information (irrelevant sound effect) is more pronounced in older than in younger individuals (Elliott, 2002), indicating a developmental process. Exposure to noise and sounds is most likely a prerequisite for developing such auditory abilities.
One can only speculate that excessive avoidance of exposure to noise by using NC headphones (over-protection) can hinder or even impair the development of the auditory system in children (potential reason for developmental delay or impairment). For example, Vernon (2002) assumes that over-protection of the ears will progressively exacerbate AH. He emphasizes sound-desensitization therapy as an alternative to noise cancellation. Given this long list of possible adverse effects, future research on the effectiveness of NC headphones must also consider potential adverse effects. Accordingly, the potential advantages and disadvantages must be reflected on when providing students with NC headphones during class. The question of whether or not noise cancellation is indicated and potential limitations and advantages of noise cancellation are discussed below in more detail for each group of students with special needs.

6.1.2. ASD and WS

AH is common in students with ASD as well as students with WS and noise can cause distress in these populations (Gothelf et al., 2006; McLaren & Page, 2015), which is certainly not a good prerequisite for learning and everyday school life. In addition to NC headphones, other noise control measures for students with ASD and AH are discussed in the literature (Kanakri et al., 2017; McLaren & Page, 2015), namely sound-absorbing materials in classrooms or quiet places where students can escape if they are overwhelmed by noise. However, there are some doubts about whether there are physiological differences in auditory systems of individuals with ASD and TD individuals (Stiegler & Davis, 2010), indicating that the reason for AH in individuals with ASD is not necessarily physiological, but rather psycho-emotional (phonophobia and misophonia: fear of sounds and emotional reaction to sound). Stiegler and Davis (2010) assume that over-protection of the ears will progressively exacerbate these problems (phonophobia/misophonia) and that sound-desensitization therapy is a lasting alternative to noise cancellation, as individuals with ASD can learn to react to noise in less stigmatizing, more effectively self-regulating ways. Phonophobia also appears to be the case in children with WS (Gothelf et al., 2006), however there is some uncertainty about the effectiveness and appropriateness of sound-desensitization therapy for individuals with WS (Gothelf et al., 2006; Pereira et al., 2016), indicating that sound-desensitization therapy may cause hearing loss in individuals with WS.

6.1.3. ADHD

Barkley (2015, p. 786) points out that noise cancellation, in theory, could be conducive to learning in students with ADHD: “Some have found that headphones or earplugs can reduce distractions from noise. These modifications of the setting, in theory, might help the student with ADHD to attend, focus, and learn better.” However, the assumption of attaining academic benefits while wearing NC headphones is questionable, as the evidence regarding the question of whether noise and sounds impair learning in students with ADHD is mixed (for an overview, see Sikström & Söderlund, 2008; Söderlund & Sikström, 2012; Zentall, 2005). Some studies show mixed results, fail to show negative effects of noise, or even show beneficial effects of noise and sounds (especially music) on learning and cognition in students with ADHD, which has even resulted in recommendations to induce moderate levels of noise and sounds during class, such as running a fan or playing some music (Carbone, 2001). Recently, the benefits of listening to white noise during task performance for students with ADHD were discussed (Bajot et al., 2016; Cook et al., 2014, 2015; Helps et al., 2014). Such hypotheses about the effectiveness of white noise in students with ADHD are grounded in theories of arousal and increased information processing. Recommendations for ADHD students to wear NC headphones during class (Barkley, 2015) and to induce moderate levels of (white) noise during class (Carbone, 2001; Sikström & Söderlund, 2008) are somehow conflicting, as is the evidence regarding the question of whether noise impairs learning in students with ADHD. Given this equivocal evidence, there are several factors to consider when examining the benefits of NC headphones or when providing students with ADHD with NC headphones (Zentall, 2005, p. 824): “The specific effects of sound appear to depend upon a number of factors, including task complexity and the type, intensity, and meaningfulness of that sound as well as the age, experience, and abilities of the child.”
6.1.4. LD
It is well documented that students with LD have poor speech-in-noise perception (for an overview, see Bradlow et al., 2003). However, NC headphones would not improve this situation, as the headphones aim to block out all sounds including speech. Nevertheless, noise is hazardous to the attention and performance of students with LD, although additional studies are needed to identify subject-specific levels of noise that can affect attention and cognitive function (Bhang et al., 2018). Further studies are needed to examine the interplay between noise, academic performance, LD, and noise cancellation.

6.1.5. TE
Symptoms of sensory sensitivity, such as hypersensitivity to sounds, touch, and movement are common in children with TE, causing flight, fight, or freeze (Koomar, 2009). These reactions may be triggered by specific sounds associated with impending abuse or neglect (Dwyer et al., 2012; Koomar, 2009). Therefore, measures of sound reduction and prevention are considered as part of trauma-informed approaches (McGruder, 2019). Further studies on the sensitivity to sounds of students with TE and the effectiveness of noise cancellation in this particular group are needed.

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