forum acusticum 2026
8-12 September · Graz, Austria

FIRST STEP TOWARD A SOUND CATEGORIZATION REFLECTING AUTISTIC ATYPICAL AUDITORY PERCEPTION

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This paper is a revised version of the authors' submitted manuscript that was peer-reviewed by at least two anonymous reviewers.

Abstract

Autistic individuals exhibit specific positive and negative auditory experiences related to their atypical auditory perception, resulting in decreased or heightened reactivity to everyday sounds. Although negative auditory experiences substantially hinder their daily life, the sounds involved remain poorly characterized with respect to context-dependent factors (e.g., situation) and context-independent parameters (e.g., acoustic). To address this gap, a two-step methodology is proposed: (i) identifying the most reported sound items through a systematic literature review and (ii) categorizing the sound items through thematic analysis. A resulting structured categorization of sound items related to positive and negative auditory experiences is proposed. This categorization can guide the selection of ecologically relevant sounds in future research. The next research step involves validating the categorization with autism stakeholders.

Keywords: *Autism, Everyday sounds, Atypical auditory perception, Categorization*

1. Introduction

Autism is a neurodevelopmental condition with a worldwide prevalence of around one percent [1]. It is characterized by social and sensory issues [2]. Atypical auditory perception is widespread in autism, involving decreased tolerance to specific daily sounds in 50% to 70% of individuals (e.g., toilet flushing) [3] as well as atypical preferences for others (e.g., non-vocal sounds) [4]. Decreased sound tolerance can cause significant distress and limit access to everyday spaces [5].

While the causes of autistic atypical auditory perception remain largely unknown, psycho-acoustic and emotional features are involved [6]. At the psycho-acoustic level, difficulties include sound discrimination (e.g., between voices), modulation (e.g., under- and over-sensitivity), processing complex auditory scenes (e.g., speech in noise), and perceptual abilities (e.g., pitch differences) [6]. The emotional level refers to phonophobia (fear of sounds, e.g., barking), misophonia (aversion to specific meaningful sounds, e.g., mouth noises), and sensation-seeking (e.g., listening to music to self-regulate) [6], [7]. Thus, some auditory features depend on context while others are context-independent. This paper will refer to them as sound semantic contexts and sound parameters.

Given the diversity of sound items involved, the two existing types of auditory assessments - auditory exams and sensory profiles - remain ill-suited to assess such experiences [8], [9]. Auditory exams target specific psycho-acoustic features by measuring loudness discomfort levels using synthetic sounds (e.g., pure tones). However, their limited ecological validity may reduce reliability [8]. Sensory profiles rely on questionnaires, observations, and interviews to identify over-arousing sounds in light of their context [10]. However, they are conducted in non-ecological settings (e.g., care centers) with sounds heuristically selected by caregivers. Moreover, for 30% of autistic children who display minimal language [11], information is collected through proxies, leading to potential inaccuracies [9].

To investigate new auditory assessment methods, the most common sound semantic contexts and parameters associated with positive and negative experiences must first be identified and classified. While investigations of everyday sounds have been conducted with non-autistic populations for over thirty years [12], only two studies focus on autistic children [13], [14]. However, they focus on specific sounds linked to negative experiences and do not provide a detailed categorization. Nagib et al. [13] address sounds at home using interviews and a survey of families. Scheerer et al. [14] identified several sound semantic contexts and parameters through a survey of autism stakeholders.

To identify and categorize the most-reported negative and positive sound items among autistic children, this

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paper proposes a two-step methodology: (i) identifying the items through a systematic literature review, and (ii) categorizing them through thematic analysis. Validation with stakeholders is the next research step, and will be presented in future works.

2. Identification of the sound items

2.1. Method

2.1.1. Search strategy

Online queries were inspired by keywords used in previous reviews [6], [9]: ((autism OR ASD OR autism spectrum disorder OR asperger OR autistic) AND (child OR children OR paediatric)) AND (”audio disorder” OR ”auditory integration” OR ”auditory disorder” OR ”audio sensitivity” OR ”hypersensitivity to sounds” OR hyperacusis OR misophonia OR phonophobia OR “sound tolerance” OR ”sound sensitivity” OR tinnitus) AND (questionnaire OR classification OR clinical profile OR assessment OR evaluation OR treatment OR intervention OR training OR rehabilitation OR strategy OR therapy OR testimony OR desensitization). Online searches were conducted in June 2021 and June 2024, across various electronic databases: PubMed, Scopus, Web of Science, Google Scholar, and Journal of Autism and Developmental Disorders and Autism. Backward and forward snowballing sampling techniques were used to identify papers missed by our searches. Backward snowballing consisted of iteratively examining the reference lists of the identified papers until we could not find any new relevant papers. Forward snowballing involved searching for new papers citing those we had already identified. Finally, to also include sounds that caregivers commonly use during auditory assessments, a psychomotor therapist specialized in autism provided us with the auditory sections from five clinically validated sensory profiles (two of which are only in French).

2.1.2. Inclusion and exclusion criteria

Searches were limited to four types of peer-reviewed studies, focusing on: i) auditory assessment or rehabilitation strategies, ii) room acoustics, iii) first and second-hand accounts, and iv) auditory sections from sensory questionnaires. Participants had to be aged 4 to 18 and have a confirmed autism diagnosis, determined by standardized tests (e.g., DSM-5 [2]). Studies on assessment or rehabilitation strategies had to include at least 50% autistic individuals and show positive outcomes. Studies without control groups were included due to the scarcity of controlled studies in this field. Studies on room acoustics had to include at least a third of autistic individuals since they often target multiple conditions (e.g., autism and attention-deficit/hyperactivity disorder). First and second-hand accounts included feedback from children or families. Auditory sections from sensory questionnaires refer to standardized tests used in clinical practice.

Papers from 2008 were included, as most research was conducted in the last decade [6]. Studies on auditory integration training were excluded due to a lack of evidence [15]. Only English studies were included (except for the questionnaires provided by the therapist). The following contributions were excluded: reviews, abstracts, notes, protocols, letters, editorials, reports, and master’s theses.

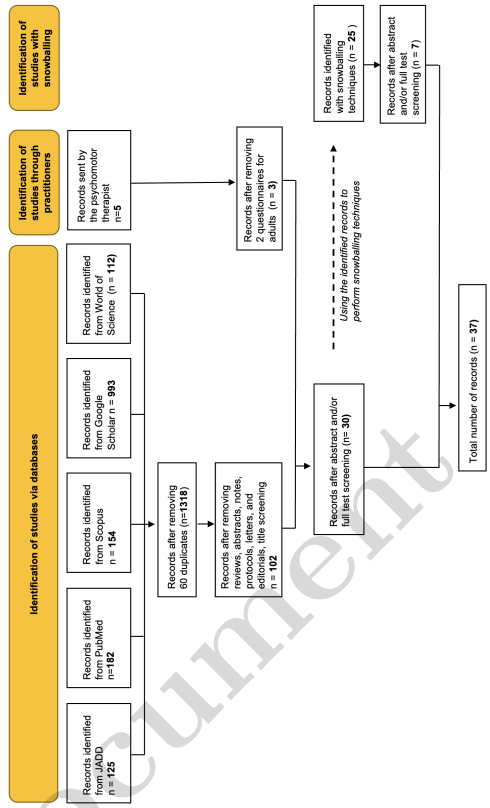

Figure 1: Flow diagram of the review selection process.

2.1.3. Screening process: identifying the items

The first and second authors searched and reviewed all the papers. For each paper, the title was first screened following our inclusion criteria, followed by the abstract and the full text. After a study was included, the sections on the method and findings were reviewed to identify the sound semantic contexts and sound parameters inducing positive or negative experiences. When such sound items were identified, we listed them using the same names as in the papers.

2.2. Results

The search yielded 37 articles, presented in Figure 1. The sound items identified in the papers were first divided into negative sound semantic contexts, positive sound semantic contexts, and parameters. The provenance of the items per paper is outlined in Table 1. In particular, nearly twice as many studies report negative semantic contexts (C-, n=26) compared to positive contexts (C+, n=13). Some sound items are sorted both as semantic contexts and parameters. For instance, the “clock ticking” [16] was set under the category “Home” (within the subcategory “Background sound”) and under the sound parameter “repetition” (being one of its most salient features).

3. Categorization of the sound items

3.1. Method

The first author used thematic analysis to build the categorization iteratively, adopting an essentialist paradigm [17]. A deductive approach was first used by grouping items into the categories identified in the papers. When items did not fit existing categories, an inductive approach was used to create new categories, with names reflecting descriptions found in the respective papers. Constant comparison ensured consistency between items and the emerging categorization. Some sound items appear in multiple categories to reflect situational effects on everyday perception (e.g., phones can ring at home or outside) [18]. A psychomotor therapist specialized in autism, with more than 10 years of experience working in both a day hospital and private practice, then reviewed the categorization.

3.2. Results

The resulting categorization is shown in Table 2. Semantic contexts were classified as positive (N=5) or negative (N=8), while sound parameters were not, as their appraisal is largely idiosyncratic. The psychomotor therapist deemed the resulting categorization representative. He highlighted the impact of children and baby cries, and mentioned two other positive sound semantic contexts: Autonomous Sensory Meridian Response (ASMR) sounds[1], and pushing on one's ears to create inner sounds. They are mentioned in the table within brackets as [PT].

4. Conclusion and Future Works

A structured categorization of sound items related to negative and positive experiences among autistic children was proposed through a two-step process: first, identification of sound items from a systematic literature review, and second, categorization of the items using thematic analysis (see Table 2). Unlike previous research [13], [14], both positive and negative experiences were considered, and a sound categorization was proposed. The resulting categorization, although preliminary, can guide the selection of ecologically relevant sounds in future research on atypical auditory perception in autistic children.

The papers identified in the systematic literature review tend to focus on negative auditory experiences, thus overlooking the positive experiences. Autistic individuals with minimal verbal abilities also remain underrepresented, which highlights the lack of knowledge for this population.

Limiting our review to works in English may have led to the exclusion of relevant papers and to the omission of specific sound items. This limit was partly mitigated by expert input from a psychomotor therapist during the categorization process. Papers related to the experience of autistic adults were excluded, despite potentially overlapping auditory experiences.

1 ASMR: A relaxation method using soft sounds (e.g., whispering) to generate a tingling feeling.

Table 1: Selected contributions and sound items (N=37). C-: Negative sound context, C+: positive sound context, P: souns parameter; ADHD: Attention-Deficit/Hyperactivity Disorder; Down= Down Syndrome; NA: Not Available; yo=years old

Ref.	Population	Items
Assessment or rehabilitation (N=12)		
[19]	3–6yo	P
[20]	2–6yo	C+; P
[21]	8–13yo	C-
[22]	ID;16yo	C-; P
[23]	16–19yo	C-; C+
[24]	6&15yo	C-; C+; P
[25]	4–11yo	C+; P
[8]	Hyperacusis; 2–17yo	C-; C+; P
[26]	8–11yo	C-
[27]	2&4yo	P
[28]	10–18yo	C+
[9]	6yo	C-
Influence of room acoustics (N=14)		
[29]	3–19yo	C-; P
[30]	age NA	C-; P
[31]	7–50+yo	C-; P
[13]	3–16yo	C-; P
[32]	6–9yo	C-; P
[33]	2–18yo	C-; P
[34]	age NA	P
[35]	5–8yo	P
[36]	5–8yo	P
[37]	Dyspr;13–20yo	P
[38]	5–8yo	C-; P
[39]	ADHD,Down;7–12yo	P
[40]	age NA	P
[41]	6–10yo	C-; C+; P
First and second-hand accounts (N=7)		
[14]	3–30yo	C-; P
[42]	3–7yo	C-; P
[43]	12–17yo	C-; P
[44]	4–13yo	C-; C+; P
[16]	12–16yo	C-; C+;P
[45]	7–18yo	C-
[46]	0–6yo	C-; C+
Sensory questionnaires (N=4)		
[47]	2–18yo	C-; C+; P
[10]	0–14yo	C-; C+; P
[48]	7–21yo	C-; C+; P
[49]	age NA	C-; C+; P

The next research step involves refining and validating the categorization with stakeholders - including autistic individuals, relatives, and caregivers - using an online questionnaire.

Table 2: Proposed sound categorization related to autistic atypical auditory perception: negative sound contexts, positive sound contexts, and sound parameters. Legend: Acous.: Acoustic; Back. = Background.; Cat. = Category; Crowd.: Crowded; Construct.: Construction; Domest. = Domestic; Prod.= Produced; Socio-emot.: Socio-emotional

Cat.	Subcat.	Sound items identified
		Negative sound contexts (C-)
Human prod.	**Mouth noise**	Eating [8], [14], breathing [8], [16], snoring [8], sniffing [14], whistling [14], [16], humming [14], squealing [16], coughing [46]
	Cries	Crying/shouting [8], [14], [16], [21], [22], [23], [26], [43], [45], [46], [48, PT], fighting [21]
	Voice	Laughter, nagging, songs, background voices[8], [13], [14], [16], [23], [31], [44], [47], [48]
	Presence	Typing on a computer [16], audible steps [47]
School	**Alarms**	School bells [8], [14], [26], [30] and alarms (e.g., fire drill) [8], [14], [21], [46]
	Classroom	Noise [8], [14], rustling paper [26], air conditioner[10], [32], [33], [38], plumbing[30], [45]
Crowd. space	**Venues**	Applause [26], [46] whistle/buzzers [14], [44], acoustical feedback [46], sport venues [22]
	Hum. dens.	Party [8], shops [22], restaurant [9], crowd [8], [14], church [9], transports [45]
	Alarms	Alarms [13]: Checkout till [26], phone ringing [10], [16]
	Music	Background music in public spaces [30]
City	**Explosions**	Fireworks [8], [21], [22], [26], [42], [44], [46], gunshot [44], balloon burst [44], oth. [31]
	Traffic	Noise [8], [13], [14], [16], [26], [33], [47], plane [16], car engine [8], [21], train [26]
	Construct.	Drilling [14], hammering [14], [26]
	Sirens	Fire engine, police, ambulance [8], [10], [14], [22], [23], [26], [42], [47]
Domest. space	**Household appliances**	Robots, kettle, vacuum cleaner [8], [13], [14], [44], [46], [48], washing machine, dish-washer [8], [14], blender [8], [14], [30], [44], lawn mower, leaf blower [8], [14], other [13]
	Toilets	Hand dryer [8], [16], toilet flushing [14], [44], [46], [48]
	Hair care	Hair dryer [8], [10], [14], [21], razor [49], hair clipper [9], [49], scissors [49]
	Back. sounds	Devices on [47], lamps [13], [29], [30], [41], [47], branches on windows [16], clock [10], [16], [30], [47], far church bell [47], humming [10], rumbling [31]
	TV	TV [8], [10], [14], [16], [46], [48]
	Toys	Sound toys [10], [42]: cars [47], objects with triggers [47]
	Other	Door slamming [26], furniture moving [47], dishes rattling [14], [26], door ringing [13]
Nature	**Elements**	Thunder [22], [49], water flowing [14], [25], [49], rain [13], wind [25]
	Animals	Sounds/calls [31], [49]: dog barking [10], [14], [22], [26], [46], birds [25], [26], [47]
Music	**Music**	Music [14], [44], piano [16], other (e.g. toys) [47]
		Positive sound contexts (C+)
Music		Music [28], [41]: cello and clarinet melodies[25], piano [20], classical music [28], favorite song [16], [22], [46], children singing[20], other instruments (e.g., tambourine) [47]
ASMR		Various sounds [PT]: paper torn apart/rustling [10], white noise [8, PT]
Nature		Water (stream, waves, rain), [8], [20], animals (birds, cats, frogs), trees rustling [8], [20]
Self-prod.		Inner sounds [10] (e.g., push on one's ears [PT])
Other		Idiosyncratic preferences (e.g., heart beat, car roaring) [8], [10], [44], [47], [48], [49]
		Sound parameters (P)
Acous.	**Intensity**	Negative: loud [8], [10], [13], [14], [22], [29], [30], [31], [32], [33], [34], [35], [38], [41], [42], [43], [44], [46], [47], [48], [49], quiet [10], [14], [47]; Neutral [48]; Positive: fluctuation strength [20]; Varied: sound-dependent [20]
	Pitch	Negative: high-pitch (e.g., harsh, shrill) [14], [16], [25]; Positive: low-pitch [14], [16], [25], [44] (e.g., car roaring [44], cello [25]); Varied: idiosyncratic [20] (e.g, honking).
	Duration	Varied: Long sounds can be perceived negatively or positively [47]
	Repetition	Varied: Repetition perceived negatively [14] or positively [16], [49]
	Combinat.	Negative Ambient noise [14], [30], [31], [32], [35], [36], [38], [39], [41], [42], infiltrating noise [30], [33], [34], [36], [38], [39]; complex noise [20]
	Reverb.	Negative: echoes, reverberation [13], [29], [30], [31], [32], [33], [34], [37], [40], [41]; Positive: kitchen/bathroom sounds [49], auto-stimulation with echoes/reverberation[41]
	Musicality	Positive: melody-dependent, rhythmic, soothing, cheerful [20], fast tempo, high-pitch, consonant, percussive, high event density, smooth attacks [19]
Socio emot.	**Suddenness**	Negative: unexpected/unfamiliar [10], [13], [14], [16], [20], [30], [35], [40], [42], [43], [44], [46], [48]; Positive: expected/familiar [20], [47]; Neutral [48]
	Social	Negative: social sounds[22]; Positive: non-social sounds [47], social sounds [27]

5. Acknowledgments

We thank the therapist A. D'Ignazio who participated in this study. This work was supported by a MESRI doctoral funding from Université Paris-Saclay, the funding from the Fondation John BOST pour la Recherche, and partly supported by French PIA Equipex+ CONTINUUM project (ANR-21-ESRE-0030) and the ANR PEPR Ensemble/CATS (ANR-22-EXEN-0002).

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