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Differences in Perceptions of the Urban Acoustic Environment in Older Adults: A Systematic Review

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Abstract
Several policies have been developed to improve the quality of life for older adults in cities, with soundscape being one of the factors that most influence general comfort. This work aims to present a systematic review based on PRISMA methodology, of the existing scientific literature that identifies the differences in sensitivity, noise annoyance, acoustic comfort, and urban soundscape preference of the elders with the rest of the population. Soundscape evaluation is a complex issue, understood as the relationship between human beings and the acoustic environment, based on sound, environment, and people's perceptions of those. Among the personal variables, age is related to physiological, psychological, social, and cultural factors that lead to evaluate urban soundscape in a certain way. Our results show that the greatest difference among older adults and other age groups is presented on noise annoyance and the least differences were presented on sound level evaluation. More research is needed in this field, to achieve comfortable urban areas through soundscape design which should be pleasant and inclusive for all, including elders as a vulnerable group, and contribute to improving their health and quality of life.

Keywords Sound preference · Acoustic comfort · Noise annoyance · Aging · Older adults · Soundscape

Introduction

According to the World Health Organization (WHO), the increase in life expectancy and the low fertility rate, especially in the developed countries, will raise the percentage of older people, who in the 2050s are predicted to be around 20% of the world population (World Health Organization 2015a, b). Besides, in 2050, 70% of the world

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population is predicted to live in urban areas, and 22% of them are expected to be older than 65 years old (Arup, Help Age International, Intel, and Systematica 2015).

There has been a global awareness about the challenge of adapting cities to an aging population since the First World Assembly on Ageing in 1982 in Vienna, and then in 2002, the Second, which emphasized on the 'Madrid Plan of Action on Ageing' (United Nations 2002). The purpose of this plan was to establish 'the process of optimization of opportunities in health, participation, and security, to improve the quality of life for people as they get older' (World Health Organization 2007). Then, in 2010 the "WHO Global Network for Age-friendly Cities and Communities" was established as a WHO initiative, with the objectives of recognizing the diversity of the older adults, promoting a culture of inclusion, respecting their decisions and lifestyle choices, anticipate and respond in advance to their needs, facilitating an active, healthy and satisfying aging (IMSERSO 2017), up to the present time, this network is formed by 1000 cities in 41 countries.

Societies must face this demographic challenge in all its complexity, as chronological age is considered an indicator of being 'old' but can't be considered as a determinant, from a physiological point of view as 'human bodies' and natural changes and health affections that might have, but also from the psychological and sociological perspective as 'individuals and citizens', members of a community.

In terms of health, aging is defined as the consequence of the accumulation of molecular and cellular damage that leads to a gradual decrease of physical and mental capabilities, which would increase the risk of chronic and multiple diseases (World Health Organization 2015a, b). One of its characteristics is its diversity, as the state of health is not homogeneous in the older population, which may be due in part to genetic predisposition, lifestyle, or quality of life, which is also influenced by the social and physical environment (Organización Mundial de la Salud 2001). There is no international agreement on the chronological age to be considered as ¨older adult¨, it depends on the context including social and economic criteria such as life expectancy and retirement age. In most developed regions including Europe, it is considered from 65 years (Eurostat 2020), while in many developing countries it is related with an active contribution (Gorman 1999), for example, it is considered from 50 years in Africa (Peachey 2001). Nevertheless, the United Nations considers from 60 years old (United Nations 2013).

Vulnerability refers to exposure to stress situations and the difficulty of coping with them without harmful losses (Chambers 1989, 1). These risks are related to social, economic, or environmental factors and those could have effects on physical, psychological, physiological health. Therefore, a young person or a child could be equally vulnerable as an elder in some issues, nevertheless, most older people could face several of these risks at a time. There is no complete prediction model of vulnerability in the elderly because is not a homogeneous group, some of them might face a healthy and successful aging, defined by Rowe and Kahn (1997) as low probability of disease and disability, high cognitive and physical functioning, and active engagement with life (interpersonal relations and productive activity). In contrast with others who could be affected by pathologic aging, including slight cognitive impairment and cognitive-motor risk, multi-morbidity, frailty, etc. (Pickard et al. 2019) that are correlated with social relationships and participation (Duppen et al. 2019; Scharf et al. 2001). According to the study of Marengoni et al. (2011), there is a

50–98% prevalence of multimorbidity in people over 60 years old, with increasing prevalence over 80, women and people from lower social classes.

Acoustic Pollution and the Effects of Noise on Health

Until the 1980s noise studies were most related to health disorders at workplaces. Noise is defined as an unwanted sound that affects the normal development of an activity, WHO refers to environmental noise generically emitted by all kind of sources except occupational (World Health Organization 2018a; European Environment Agency 2020). Several international policy-makers have been concerned and laws have recognized noise as a risk factor for the health of the inhabitants, has developed some guidelines like 'Guidelines for community noise ' in 1999 (Berglund et al. 1999b), then in 2009 'Night Noise Guidelines for Europe' (Joseph 2009) and the latest 'Environmental noise Guidelines for European Region' with the main purpose of protecting human health from exposure to environmental noise originating from various sources (World Health Organization 2018a).

Noise pollution is constantly increasing in conjunction with the urbanization of cities since the main sources of noise come from human activities such as transportation, industry, wind turbines, leisure, and communication activities (World Health Organization 2018a). In Europe, the Environmental Noise Directive (END) 2002/49/EC (The European Parliament and the Council of the European Union 2002) was adopted in 2002, which requires member states to establish action plans to identify and control noise pollution levels and reduce the effects of noise exposure. The END refers to noise as high sound levels to which humans are exposed, including urban areas, near schools, hospitals, and other noise-sensitive buildings (European Commission 2020), created by human and industrial activity, embracing noise emitted by different means of transport (European Environment Agency 2020).

In 2012, about 100 million people were estimated to be exposed to road traffic noise (European Environment Agency 2020) above 55 dB Lden, with more than 32 million exposed to noise levels above 65 dB Lden from the European population (Blanes et al. 2016) and in western Europe, at least 1.6 million healthy years of life are lost as a result of road traffic noise (World Health Organization 2018a).

According to WHO, noise is a stressor and as such, expose ourselves to it can produce auditory and non-auditory effects on health, as a result, psychological and physiological effects (World Health Organization 2018a, b; Eriksson et al. 2018), some of them are hearing impairment; tinnitus; pain and auditory fatigue; sleep disturbance (Basner and McGuire 2018); cardiovascular effects (Eriksson et al. 2018; Münzel et al. 2018; Schnell et al. 2016; Van Kempen et al. 2002); impaired cognitive performance; provocation of hormonal responses and their consequences in human metabolism and immune system (Eriksson et al. 2018; Van Kempen et al. 2018; Maschke et al. 2000); psychosomatic diseases, interferences with social behaviour and interferences with oral communication, among others (Goines and Hagler 2007; Observatorio de Salud y Medio Ambiente de Andalucía OSMAN 2009; Stansfeld and Matheson 2003; World Health Organization Europe, and State Health Agency of Baden-Württemberg 2005).

Besides, although noise pollution is not considered as a cause of mental illness, it can intensify their development by contributing to adverse effects such as anxiety, stress, nervousness, nausea, headache, emotional instability, sexual impotence, changes in mood, increase in social conflicts, neurosis, hysteria, and psychosis (Centre for Renewable Energy Sources Goines et al. 2007). High-quality acoustic environments may contribute to a better quality of life and environmental health as a restorative mechanism as many studies have confirmed (de Kluizenaar et al. 2013; Hartig and Staats 2003; Lercher et al. 2016; Payne 2008; Szhambov and Dimitrova 2014; van Kamp et al. 2016).

In urban areas, the vehicular flow causes low-frequency sounds (the frequency ranges from about 10 Hz to 200 Hz) (Leventhall 2004) resulting in permanent background noise (Raimbault and Dubois 2005). There are more specific studies regarding the effect of traffic noise on health, showing that every year a million years of healthy life are lost due to noise-related to traffic in the western part of Europe (Khreis et al. 2016; World Health Organization 2018a, b). Maschke et al. (2000), their study reveals that there is an increased risk of ischemic heart disease whenever the traffic noise exceeds the equivalent sound level of Leq 65dBA per day. Also, Selander et al. (2009) establish that there is a high correlation between the increased risk of myocardial infarction and the long-time exposure to traffic noise. In addition, Jiménez and Gil (2015) relate traffic noise with daily mortality due to circulatory, respiratory, and diabetes causes in the group over 65 years of age in the city of Madrid, authors found that an increase of 1 dBA in daytime traffic noise levels is related to mortality from cardiovascular and respiratory causes in people over 65 years of age, being 6.6% in the former and 4% in the latter.

Presbycusis is one of the most common hearing loss problems in older people, it is bilateral and more marked at high frequencies. It is caused by cochlear aging that is given by some environmental factors such as loud noise long exposure, genetic predisposition, and greater vulnerability to physiological stress factors and modifiable habits. By 2018, approximately one-third of persons over 65 years were affected by disabling hearing loss (NIH 2016; World Health Organization 2018b). This interferes with the understanding of a normal conversation, therefore, can cause social isolation and loss of autonomy, accompanied by anxiety, depression, and cognitive impairment (World Health Organization 2015a, b). Also, hearing loss is related to a large number of frequent diseases in old age like dementia, depression, walking difficulties, falls, frailty, and even mortality (Díaz et al. 2015; Pichora-Fuller et al. 2015). Tinnitus is another frequent affection caused by prolonged exposure to loud noise (Tempest et al. 1976), it is presented as a continuous or intermittent ringing sensation in the ear and alter hearing sensitivity (World Health Organization 2015a), people with tinnitus complain of noise annoyance especially when background noise is low in frequency (Leventhall 2004; Heinonen-Guzejev et al. 2011).

Soundscape and Acoustic Environment

Sound must be studied from two approaches: physical and psychological, the first would be 'the acoustic environment' and the second would be 'soundscape' (Kang et al. 2016; International Association for Standardization 2014). The physical approach studies sound as a form of energy, while psychological refers to the perception people have of acoustic energy (Rodríguez Valiente 2015; Kang et al. 2016). Gaver (1993) describes that the route from the sound source (event) to the experience of listening, the sound is formative about the attributes if the source (size, shape, materials) and its location in an environment, this event could involve mechanical physics, fluid dynamics, acoustics, anatomy, and psychoacoustics.

The effects of noise exposure used to be assessed through physical focus policies and regulations established in cities represented by noise level maps focused on noise control; however, recent research shows that these actions are not representative of the people evaluation of acoustic comfort and sound perception, that might be also affected by psychological, physiological and personal characteristics of the listener including perception (Tempest et al. 1976, Ballas 1993, Gaver 1993, Berglund et al. 1999a, b, Dubois 2000, Raimbault and Dubois 2005, Yang and Kang 2005, Yang 2005, Kang 2006, Zhang and Kang 2007, Brooks et al. 2014; Farina 2014) or cognition as mental representation (Guastavino 2007; Morel et al. 2012) and emotional response (Russell 2003; Niedenthal et al. 1999) to the meaning attributed to the source and context (Guastavino 2007; Raimbault 2006). Some authors agree that reduction of noise levels is not the only way to improve people's quality of life, but rather the investigation of aesthetic principles related to the soundscape (Yu 2009; Kang 2011; Kang et al. 2016).

The first investigations on soundscape took place at the end of the 1960s. One of them was Southworth (1967), a student of Kevin Lynch who wanted to compliment his investigation by applying techniques of mapping to the perception of the urban sound in the city of Boston, he identified five main criteria for soundscape evaluation: sound delight, informational content or semantic relevance; the possibility of sonic interaction; the uniqueness and the auditory-visual correlation (Gokce 2009 p. 63). Subsequently, the studies of the musician Schafer (1977), who defined the sounds as keynotes (analogy to music), foreground signals/sounds, and sound marks (the sounds considered by a community). Soundscape research became most internationally popular when it was introduced at the International Congress on Acoustics in Seattle in 1998, attended by a wider community of noise and health researchers (Axelsson 2020).

Therefore, the soundscape is understood as the relationship between human beings and the acoustic environment, based on four elements: sound, space, people and the environment (Zhang and Kang 2007) and more recently defined by the International Organization for Standardization (2014) in ISO 12913-1 as 'the acoustic environment as perceived or experienced or experienced and/ or understood by a person or people, in context'. Today, the soundscape is recognized as one of the indicators of quality of life in a city (Szeremeta and Zannin 2009), some studies have shown that it plays an important role in the general comfort assessment of public space (Raimbault et al. 2003; Tse et al. 2012), because, as with other factors, it generates an emotional reaction, which could be pleasantness, exiting or relaxation (Nasar 1989; Cain et al. 2013). According to Raimbault (2006), there are two cognitive methods to evaluate soundscapes: descriptive and holistic. The first one refers to the identification of acoustic sources by the semantic process (the meaning of the sound), while the second assesses the soundscape as a 'whole' event.

Some authors agree on the complexity of soundscape evaluation due to the variety of factors apart from the physical features of sound that influence it, including physical stimuli such as thermal, lighting, and visuals (L. Yu 2009); psychological and physiological characteristics of the listener such as sound sensitivity, expectation, meaning, expectations of quality of life, memory, age and cultural context (Brooks et al. 2014; Bruce and Davies 2014; Irvine et al. 2009; Kang et al. 2016; Kang and Zhang 2010; Rodríguez Valiente 2015; Zimmer and Ellermeier 1999), activity and level of attention

(Stallen et al. 2008; Davies 2015). Davies (2015) stated the difficult task of evaluating a complex listener listening to a complex acoustic scene, the cognitive distinction would be due to exogenous and endogenous causation (Stallen 2008). Hence the differences in tolerance between individuals when exposed to the same sound level. According to Axelsson et al. (2010), three main factors intervene in the perception of the soundscape: 50% pleasantness, 18% eventfulness, and 6% familiarity.

Acoustic evaluation generally employs semantic differential analysis to assess some of those different factors as 'relaxation (comfort-discomfort, quiet-noisy, pleasant-unpleasant, natural-artificial, like-dislike and gentle-harsh), communication (social-unsocial, meaningful-meaningless, calming- agitating and rough-smooth), spatiality (varied-simple, echoed-deadly and far-close), and dynamics (fast-slow and hard-soft)' (Centre for Renewable Energy Sources 2004, p. 34).

Aletta et al. (2016) found that the most used methods for soundscape and acoustic environment evaluation are: sound-walks, laboratory experiments, behavioural observations, and narrative interviews. Conversely, several authors emphasize that due to the multiple factor interactions, it is not recommended to study soundscape in public spaces through recordings, laboratory tests, or simulations, and suggest that the most appropriate method is the on-site survey, to obtain the Real influence of all these aspects (Yang and Kang 2005; 2007; Zhang and Kang 2007). Although recent studies as Kang et al. (2016) advises the methodology of performing records of acoustic environments with binaural technology to analyse psychoacoustics parameters (loudness, roughness, sharpness, and fluctuation strength) that link both physical attributes and the perceptual approaches (Fastl and Zwicker 2007) as predicted human responses, nevertheless, those not necessarily represent how people perceive sounds, psychophysical approaches use to underestimate the impact of other environmental stressors by analysing sound isolated from their natural, ecological context (Raimbault 2006).

Otherwise, in the study conducted by Bruce and Davies (2014), the perception of the soundscape, both the real and the simulated, was affected by the expectation of the participants in several ways, they were supposed that a certain type of sound was present in a particular place, they make a difference between the possibilities of a sound that is expected or if it is pleasant, these results show that the expectancy of the soundscape is based on previous experiences. Similarly, in the studies of Ge and Hokao (2005), it was found that the quality of the soundscape was lower in the busy streets than in the silent ones. In both places people were bothered by the sound of traffic, however, it was more unpleasant for the people present in the silent street with natural and cultural elements than in the noisy and trafficked streets. In cities, traffic noise is taken for granted, while in areas far from the city, they are expected to be silent and affirm that personal factors such as age and hearing sensitivity are related to expectation. As in the study of Viollon et al. (2002) by audio-visual simulation environment, found that sounds that were influenced by vision of woods were judged as less pleasant and relaxing than in urban settings, the authors attributed it to the non-fulfilment of sound expectations created by natural setting.

Regarding the cultural differences that can affect sound preference, they can be related to culture, such as the study of Yang and Kang (2005), about noise annoyance caused by surrounded speech, it was found that 50% of those interviewed in a square in Greece considered it annoying, while in squares in Germany and Italy less than 1% considered the surrounding sound annoying and 45% considered it as a favourite (Yang and Kang 2005). Similarly, Yu and Kang (2014) obtained that the greatest noise annoyance at Sheffield sites was heavy traffic, while in Taipei people were more bothered by the sounds provoked by neighbours like conversations, music, and television. While, Yu (2009) found that both the sound of children playing and the sound of buses were more annoying for Chinese respondents than for the European interviewees.

Another important aspect in acoustic comfort is noise adaptation, as a mechanism that allows people to gradually incorporate it into their daily life to become part of their familiarity (Schafer 1977; Kang 2011; Ruíz and Lidia 2014). As evidenced in the study conducted by Ruíz and Lidia 2014) to the populations near an airport in Mexico, it was found that most of the people were adapted to the noise of the aircraft, this did not bother them, and they had learned to develop their lives around it. According to the author, learning to cancel a sound is an effect of habituation that is part of everyday life. Otherwise, Memoli et al. (2018) stated comparison of two types of survey methods one onsite with a short-term judgment questionnaire and the other by post to assess long-term perceptions survey. Additionally, the perceived height and size of planes with real acoustic measurements and aircraft tracking around Gatwick airport in London, founded that louder planes are perceived as lower and that planes different from the ¨average plane¨ influence the perception of overflown residents, generating annoyance more than the height of the most frequent plane.

Consequently, given the aging trend of the world population and the vulnerability to noise effects, the objectives of this study are a) to identify the main hearing physiological changes related to age; b) identify the differences in noise sensitivity, noise annoyance, acoustic comfort and sound preference among older adults and other age groups.

Methodology

A systematic review of the scientific literature attempted to assess all the empirical evidence about acoustic perception has been carried out, based on the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method, founded on a 27-item checklist and a four-phase diagram (Liberati et al. 2009).

PRISMA flow chart of the selecting process is presented in Fig. 1, after three selection stages, identification screening, and eligibility, just 34 articles met the established selection criteria. Databases such as Scopus, Web of Knowledge, Google Scholar, and Science Direct have been used, with the keywords: aging, acoustic perception, acoustic preference, acoustic tolerance, acoustic comfort, noise annoyance, noise sensitivity, elderly, seniors, soundscape, among others. Additionally, it included some bibliographic references quoted by the same articles to ensure the greatest possible number of studies. The final selection criteria were:

-Studies that evaluate soundscape, acoustic comfort, sound preference, noise annoyance, or noise sensitivity, contrasting and comparing between age groups including elders.

- Studies that evaluate soundscape, acoustic comfort, sound preference, noise annoyance, or noise sensitivity of senior citizens, both indoors and outdoors.

-No language restriction.

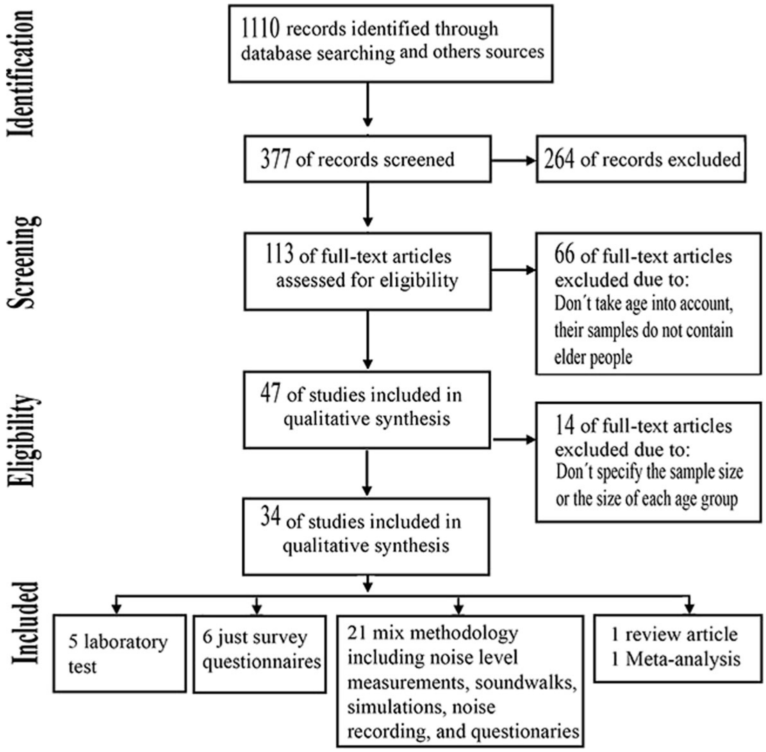

Fig. 1 Flow chart throw the selection process. Source: Own elaboration based on Liberati et al. (2009)

- Due to the lack of studies that relate these issues to elder people, no date limit has been established in the articles reviewed.

Subsequently, a complete reading of these articles has been made to identify their characteristics in terms of methodologies used, the objectivity of the sample, and results obtained, summarized in Table 1. In this case, just a systematic review was performed, due to the characteristics of each study, it can be seen that they are very heterogeneous in terms of sample size, criteria for selecting respondents, and the type of analysis they use. Therefore, according to the literature it is not recommended to perform meta-analyses when studies are so heterogeneous.

Results and Discussion

As it is shown in Fig. 1, 1110 articles were found with the selected in the identification phase, 377 articles were selected after screening on abstracts, some of them didn’t take account of older adults for their research. Subsequently, a complete reading of 113 articles has been carried out to identify their characteristics in terms of the methodologies used, the objectivity of the sample, and the results obtained, on this stage was found that 47 articles compare between age groups or refer to older adults, but 14 of them were excluded due to not specifying the total sample size or from each age group. Finally, 34 articles were selected for this review, a summary of these is presented in

Table 1 Summary of selected articles that assess sound perceptions by age groups, methodology, results and observations

N°	Author, year and reference	City, country	Space	Methodology	Index or scale	Subjective variables
1	(Zhang and Kang 2007)	Europe and China	Squares	Review, questionnaire Survey, noise level measurement, recordings and simulation	SP3P; SDT; ESL5P; AC5P	Sound preferences. Evaluation of sound level. Acoustic comfort
2	(Kang and Zhang 2010)	Sheffield, UK	Open public spaces: pool and a garden	Questionnaire Survey, sound walking, noise measurement and recording	SP3P; SDT; ESL5P; AC5P	Sound preferences. Evaluation of sound level. Acoustic comfort
3	(Yang and Kang 2007)	Sheffield, UK	Squares	Review, questionnaire Survey and noise level measurement	SP3P; ESL5P; AC5P	Sound preferences. Evaluation of sound level. Acoustic comfort
4	(Yang and Kang 2005)	Greece, Italy, UK, Germany, Switzerland	Squares	Questionnaire Survey and noise level measurement	SP3P; ESL5P; AC5P	Sound preferences. Evaluation of sound level. Acoustic comfort
5	(Schnell et al. 2016)	Tel Aviv, Israel	Community day center, streets and park	Questionnaire Survey, walk and noise level measurement		Acoustic comfort.
6	(Bauer et al. 2016)	Río Grande do Sul, Brazil	Homes	On site questionnaire Survey		Hearing perception
7	(Meister et al. 2013a, b)	Cologne, Germany	Laboratory	Laboratory test: Selective, divided attention tasks, neuropsychological test	Oldenburg sentence test.	Speech recognition
8	(Irvine et al. 2009)	Sheffield, UK	Green spaces		ESL5P Linkert scale	

Table 1 (continued)

Nº	Author, year and reference	City, country	Space	Methodology	Index or scale	Subjective variables
				Questionnaire Survey, noise measurement and recording		Perception and evaluation of soundscape
9	(Tse et al. 2012)	Hong Kong, China	Parks	Questionnaire Survey and noise level measurement	Sounds preference by SP5P. Psychological response by sound PRS5P. Evaluation of sound level by ESL5P. Acoustic comfort by AC5P	Perception of soundscape, acoustic comfort, sound preference, psychological response to sounds
10	(Yu and Kang 2010)	Europe and China	Squares	Questionnaire Survey, noise level measurement and laboratory tests	Sound preference by SP3P	Sound preference
11	(Yu and Kang 2008)	Europe and China	Open public spaces	Questionnaire Survey and measurement	Evaluation of sound level ESL5P	Evaluation of sound level
12	(Alain et al. 2006)			Review		Noise sensitivity
13	(Miedema and Vos 1999)	Europe, North America and Australia	NS	Meta-analysis	Noise annoyance by NA5P	Noise annoyance, noise sensitivity
14	(Yu and Kang 2009)	Europe and China	City center, residential area, tourist spot, and railway station	Questionnaire Survey, noise level measurement and simulation	Acoustic comfort by AC5P. Evaluation of sound level by ESL5P	Sound level and acoustic comfort evaluation
15	(Sato et al. 2007b)	Tsukuba, Japan	Laboratory	Laboratory test, listening test	Test word list by Sakamoto. Listening difficulty by LDR4P	Listening difficulty. Word intelligibility
16	(Sato et al. 2007a)	Tsukuba, Japan	Anechoic chamber	Laboratory test, word intelligibility test	Test word list by Sakamoto. Listening difficulty by LDR4P	Listening difficulty. Word intelligibility

Table 1 (continued)

N°	Author, year and reference	City, country	Space	Methodology	Index or scale	Subjective variables
17	(Yang 2005)	Greece, Italy, Germany, Switzerland	Urban open spaces	Review, questionnaire Survey, noise level measurement and recording	Soundscape evaluation by ESL5P; Sound preference SP3P; Acoustic comfort AC5P	Soundscape evaluation. Sound preference. Acoustic comfort
18	(Champelovier et al. 2001)	France	Homes	Questionnaire Survey, noise measurement, recording and simulation	Noise annoyance by NA4P	Noise annoyance; self-rate noise sensitivity
19	(Yilmazer and Caliskan 2008)	Ankara, Turkey	Shopping mall	Questionnaire Survey, noise level measurement and simulation	Acoustic comfort AC5P; Noise annoyance by NA5P	Acoustic comfort; auditory perception; noise annoyance
20	(Fyhri and Klæboe 2006)	Oslo, Drammen, Norway	Residential areas (indoors)	Telephone questionnaire Survey, simulations	Noise annoyance by NA4P	Noise annoyance; noise level perception; self-rate noise sensitivity
21	(Rylander et al. 1972)	Scandinavia, Norway, Denmark	Indoors and Outdoors near airports	Questionnaire Survey, noise level measurement, laboratory	Noise annoyance by NA4P; 5-point Linkert scale	Noise annoyance
22	(Okokon et al. 2015)	Mainland, Finland	Residential areas (indoors)	Mail postal questionnaire Survey	Noise annoyance by NA5P. Noise sensitivity by Weinstein scale	Perceived noise sensitivity, noise annoyance
23	(Beaman 2005)	Reading, UK	Laboratory	Laboratory test	7-point Linkert scale	Sound effects, noise annoyance, acoustic comfort, speech susceptibility for distraction
24	(Michaud et al. 2008)	Canada	Residential areas (indoors)	Telephone Survey	Noise annoyance by NA5P.	Noise annoyance

Table 1 (continued)

N°	Author, year and reference	City, country	Space	Methodology	Index or scale	Subjective variables
25	(Abolhasannejad et al. 2013)	Biryand, Iran	Streets	Questionnaire Survey and noise level measurement	Noise sensitivity by Weinstein scale. Noise annoyance by 7-point Linkert scale	Noise annoyance and Noise sensitivity
26	(Michaud et al. 2008)	Canada	Residential areas (indoors)	Telephone Survey	Noise annoyance by NA5P.	Noise annoyance
27	(Li et al. 2012)	Hong Kong, China	Homes	Questionnaire Survey and noise level measurement, simulation	Noise annoyance by NA11P. Noise sensitivity by NS5P	Noise annoyance, noise sensitivity
28	(Bluhm et al. 2004)	Stockholm, Sweden	Residential areas (indoors)	Postal mail questionnaire Survey	NS	Noise annoyance
29	(Yu 2009)	Europe and China	Open spaces and laboratory	Review, questionnaire Survey, noise level measurement, recording, laboratory tests and simulation	Sound preference by SP3P and SDT; Evaluation of sound level by ESL5P; acoustic comfort by AC5P	Sound preferences. Evaluation of sound level. Acoustic comfort
30	(Song et al. 2018)	Jinan, China	Park	Soundwalks, questionnaire Survey, noise measurement and recording	Sound preference by SP5P	Sound preference evaluation
31	(Gozalo et al. 2018)	Caceres, Spain	Green spaces	Questionnaire Survey, noise measurement and recording	5 points Linkert scale	Noise annoyance, satisfaction, effects of noise.
32	(Zhou et al. 2014)	Habrin, China	Historical areas: streets, square, park	Questionnaire Survey and measurement	Acoustic comfort by AC5P	Acoustic satisfaction

Table 1 (continued)

N°	Author, year and reference	City, country	Space	Methodology	Index or scale	Subjective variables
33	(Nábělek and Robinson 1982)		Laboratory	Laboratory, listening tests	Modified Rhyme Test	Monaural and binaural speech perception
34	(Liu et al. 2019a, b)	Rostock, Germany	Green spaces (quiet areas)	Questionnaire Survey	Loudness by L3P Soundscape preference by SP5P	Perceived occurrences; loudness and preference of sounds

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
1	Age, gender	SPL (Laeq dBA), psychoacoustic indicators. Reverberation. Temperature, lighting, wind, view, humidity	9800	1100	8700	Older people were more favorable to sounds relating to nature, culture, or human activities and tend to be most satisfied.	11% of sample are >65. Study is part of RUROS project
2	Age, gender, education, occupation	SPL (Laeq dBA), visual, Temperature, lighting, wind, view, humidity	491	62	429	Older people were more favorable to sounds relating to nature, culture, or human activities.	Only results from stage 2 were considered. 13% of sample are >65
3	Age, gender, education, occupation, background	SPL (Laeq dBA)	1000	87	913	Older people were more favorable to sounds relating to nature, culture, or human activities. Older people sound preferences tend to be shaped by experience	Only 8.7% of sample are >65. Study is part of RUROS project
4	Age, gender, education, occupation, background	SPL (Laeq dBA), visual, Temperature, lighting, wind, view, humidity	1000	87	922	Only in acoustic comfort significant differences were found, older people were the most satisfied group	Only 8.7% of sample are >65 (just Sheffield study). Study is part of RUROS project
5	Age, use of medication	Noise level in Db. Thermal load, CO, social load, Heart rate variability	62	26	36 OS	Noise load increases stress in elders. Comparison between results for young subjectsstudied in Tel Aviv under about similar environmental conditions shows	Aging may be associated with depressed responses to environmental effects as they are measured by HRV. Elders represent 42% of the sample.

Table 1 (continued)

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
						that fluctuations in heart rate remain extremely low among elders	
6	Age, gender, ethnicity, income, social participation, education level, marital status		7167	7167		The chance of having hearing complaints increases with age: for every extra year of age there is an increase of 6% in the chance of hearing loss complaint.	There is a prevalence of approximately 30% of hearing loss complaints among the elders.
7	Age, gender, cognitive, linguistic abilities		26	14	12	Older listeners were less able to repeat sentences in a setting with two simultaneous voices than the younger group. Performance in older listeners was reduced as compared to the younger group in divided attention tasks.	Older interviewees represented 54% of the total sample.
8	Age, gender, ethnicity, income, frequency of visit	SPL (Laeq dBA), traffic load	70	9	61	No significant difference	Small sample, older interviewees is 12% of the total.
9	Self-rated auditory capabilities, purpose of visit, age, gender, residence, duration of stay	SPL (Laeq dBA)	595	263	332	Elders generally reported a lower auditory capability. Age did not influence individuals acoustic comfort evaluation.	44% of the sample were>60 yr. old, because was the larger group of park users.
10	Age, gender, occupation, education level, activity, residential status, frequency and reason of visit		9800	1100	8700	With Increased age people prefer natural sounds, and become slightly more annoyed by mechanical sounds	Age influence the sound preference significantly; it may vary with different types of urban spaces and sounds. 11% >65. Study is part of RUROS project
11	Age, gender, occupation, education level, activity, residential status, frequency and reason of visit	SPL (Laeq dBA)	9800	1100	8700	With increasing age, people tend to be slightly more tolerant.	11% of sample are >65. Study is part of RUROS project
12						Age-related changes in auditory perception include: impaired frequency and duration discrimination, impaired sound localization; difficulties in determining the	Hearing sensitivity diminisheswith age, especially in the high frequency range.

Table 1 (continued)

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
						sequential order of stimuli; difficulties in processing novel or transposed melodies; and difficulties in understanding speech.	
13	Age, gender, education, occupation, household size, sensitivity, fear	SPL (Laeq dBA)	42,496	9774	32,722	To the same noise exposure, relatively young or relatively old peoples, feel less discomfort than intermediate ages.	23% of sample are >60
14	Age, gender, occupation, education level, activity, residential status, frequency and reason of visit	SPL (dBA); air temperature, relative humidity, wind speed, luminance aesthetics, sound sources	9800	1100	8700	There are differences in sound level evaluation, 13–18 age group will generally feel quieter than the age group >65. In acoustic comfort there are no differences.	Study is part of RUROS project
15	Age	Sound frequency (kHz); Sound pressure levels (dBA); reverberation time	264	142	122 OS	This means that hearing level affects the word intelligibility scores for the aged as much as those for the young. Listening difficulty ratings increase by aging	Sample of older adults represent 54%
16	Age	Sound frequency (kHz); Sound pressure levels (dBA); reverberation time	122	69	53	The minimum speech level to maximize word intelligibility scores for the aged was 45 dBA. The optimum speech level for the aged was 70 dBA, and it was higher than that for the young by 10 db.	Sample of older adults represent 57%
17	Age, gender, activity, background, occupation, education level, frequency of visit	SPL (dBA); air temperature, relative humidity, wind speed, luminance aesthetics, sound sources	9200	1100	8100	Significant differences among age groups in acoustic comfort and sound preferences, young people felt less comfortable than aged people, and the last are more favorable to nature, cultural and human activities sounds.	11% of sample are >65. Study is part of RUROS project. As people grow older, their sound preferences tend to be shaped by experience.
18	Age, gender, education, occupation, household size	SPL (Laeq dBA)	673	135	538	Older people were more annoyed by rail and road noise	20% of sample were>65
19	Gender, age, education level, duration of stay	SPL (dBA); reverberation time, sound frequency	80	19	61	There is a significant relationship between age and annoyance from noise during	Sample of older people is considered between 51 to 65 years old it is 23.8%

Table 1 (continued)

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
						conversation, older adults tend to be more annoyed and sensitive.	
20	Gender, age, number of children; marital status; income; occupation; education level	SPL (Laeq dBA)	16,007	3567	12,440	There is no influence of age in noise annoyance, only in noise level perception.	Sample of older people is considered between 60 to 70 years old it is 22.2%
21	Age, gender, marital status, income, education, number of children, type of housing, susceptibility, economic status, attitudes	SPL (dBA), spectral distribution, duration, frequency	2425	806	1619	People between 31 and 75 years old were more annoyed than the younger group.	Sample of older adults represent 23%
22	Age, gender, marital status, number of children, self-reported health, education, occupation	Noise level dB (A)	1112	446	666	Age was associated with annoyance and sensitivity only in bivariate models for age group (45–59).	The author states that older people are overrepresented in this study (40% age group 60–74)
23	Age, gender	Noise level dB (A); frequency	115	53	62	The elders felt less noise annoyed and less discomfort. The audio- metric tests were lower for elders than from the younger participants	Sample of older adults represent 46%
24	Age, gender		2532	419	2113	Age had statistical association with traffic noise annoyance. People between 25 and 44 were more annoyed by noise.	Sample of older adults represent 16.5%
25	Age, gender, years of residence, income, occupation, household occupation	SPL (Laeq dBA)	364	45	319	There was no difference in noise sensitivity and noise annoyance between age groups	80% of the sample were<50 years old.
26	Age, gender, self-reported health status, education, income, occupation		2565	308	2265	People 65 and over were the least annoyed by noise	

Table 1 (continued)

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
27	Age, gender, self-reported health status, education, duration stay at home, views	SPL (Laeq dBA), traffic parameters	861	60	801	Age was found to influence on noise annoyance. Older respondents were less annoyed than younger ones.	Just 7% of the sample were>60. Analyzes two age groups under and over 40.
28	Age, gender, education level, occupation, living conditions, general annoyance, sleep disturbance	SPL (Laeq dBA)	632	277	355	There was no difference in noise annoyance due to age	Older people were considered above 51 years old, they represented 44%
29	Age, gender, occupation. Education, residential status, frequency of visit, activity	SPL (Laeq dBA), psychoacoustic indicators, loudness and sharpness. Reverberation, temperature, lighting, wind, view, humidity	9856	1100	8812	With increasing age people tend to be slightly more tolerant. About sound preferences, with the increase of age, the sound preference for bird and insect sounds also increases. The age group 13–18 will generally feel quieter than the >65 age group	Study is part of RUROS project. People over 65 represented 11.16% of the sample
30	Gender, age, visitation frequency, satisfaction	SPL (Laeq dBA)	30	10	20	Older age indicated larger preference for nature sounds.	Relationship was shown between age and season with sound element preference. People >60 represent 33% of sample size
31	Gender, education level, age, occupation, activity	SPL (Laeq dBA), psychoacoustic indicators	182	38	144	Age tend to have significant relations with noise perception. Older people have higher annoyance with some sound sources.	Sample size of elder people is 20%
32	Gender, age, education level, occupation, income, visit frequency, duration of stay	SPL (Laeq dBA); temperature, humidity, wind, aesthetics, sound sources	580	58	522	Age have significant effect on acoustic satisfaction. The evaluation value of the interviewees older than 60 is significantly lower.	People >60 represent only 10% of sample size
33	Gender, age	SPL (dB) Reverberation time	60	20	40	Children and elders required from 10 to 20 dB higher sound pressure level than young adults.	Sample of older adults represent 33%

Table 1 (continued)

N°	Personal variables	Physical variables	N ° votes	VE	VO	Results and differences found between age groups	Observations
34	Gender, age, education level, occupation, income, visit frequency, duration of stay		400	80	320	Older people tended to perceive dog barking (lower frequency sound) louder, but they usually perceive surrounding speech and wind blowing not as loud as younger people.	People >60 represent only 20% of sample size

SP3P: 1. Favourite; 2. neither favourite nor annoying; 3. Annoying; SDT: Semantic differential technique; ESL5P Linkert scale: 1. very quiet; 2. quiet; 3. neither quiet nor noisy; 4. noisy; 5. very noisy; AC5P:1. very comfortable; 2. comfortable; 3. neither comfortable nor uncomfortable; 4. uncomfortable; 5. very uncomfortable; 5-point Linkert scale: 1. extremely quiet to 5. extremely noisy; 1. strongly disagree and 5. strongly agree; 1. extremely unpleasant to 5. extremely pleasant SP5P: 1. very much dislike; 2. dislike; 3. neutral; 4. like; 5. very much like; PRS5P: 1. very stressful; 2. stressful; 3. Neutral; 4. relaxing; 5. very relaxing; NA5P: 1. not at all annoyed; 2. slightly annoyed; 3. moderately annoyed; 4. considerably annoyed; 5. highly annoyed; PSQ5P: 1. very bad; 2. bad; 3. Neither good nor bad; 4. good; 5. very good; Weinstein scale: 21 elements and a 6-point scale that ranges from 1 'low noise sensitivity' to 6 'high noise sensitivity; ST5P: 1. very unsatisfied; 2. unsatisfied; 3. neither satisfied nor unsatisfied; 4. satisfied; 5. very satisfied; LDR4P: 1. no; 2. a little; 3. Fairly; 4. Extremely; NA4P: 1. Not annoyed; 2. A little bit annoyed; 3. Quite annoyed; 4. Very annoyed; NA4P: 1. Not annoyed; 2. A little bit annoyed; 3. Quite annoyed; 4. Very annoyed;5. Extremelly annoyed; NoiSeq: 0. strongly disagree; 1. slightly disagree; 2. slightly agree; 3. strongly agree; 7-point Linkert scale: 1- nota at all disruptive; annoying or uncomfortable to 7. very disruptive, annoying and uncomfortable; NA11P: 0. not at all to 10. Extremely; Self rate noise sensitive NS5P: 1-very sensitive to 5. not sensitive at all; OS: Other study sample; VE: votes from elders; VO: votes from other groups of age; NS: Not specified; SPL LAeq: Weighted equivalent sound pressure level

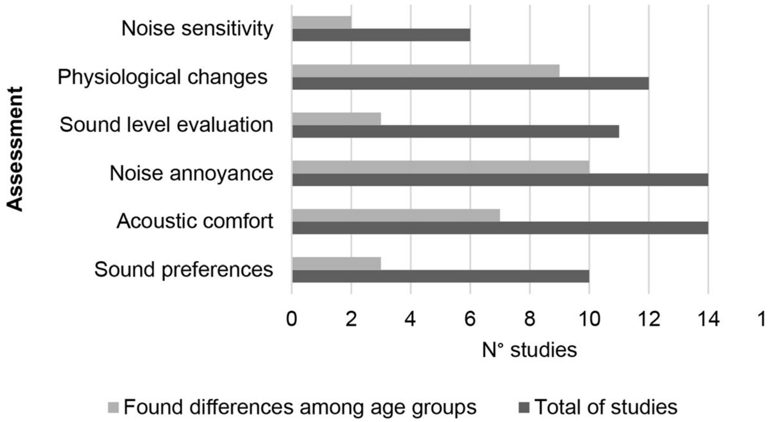

Fig. 2 Reviewed studies that found differences among age groups

Table 1. The selected articles were very diverse in terms of methodology, sample size, and results, so meta-analysis is not appropriate in this case. Besides, there are also differences in the base age to consider the group of older people, 4 studies consider it from 50 years; 2 from 55 years; 9 from 60 and 15 studies from 65 years.

In terms of methodology, four main groups are identified: (I) reviews from these, one is a meta-analysis; (II) mixed methodology including quantitative sources as sound level measurements, audio recordings, and qualitative data from questionnaire surveys, sound-walks, focus groups or auditory tests; (III) laboratory throw simulations or test and (IV) only questionnaire survey.

Regarding the type of soundscape evaluated 9 of the studies refer to inside buildings including home and shopping malls and 18 to outdoor spaces as streets and parks.

Only 3 of the selected studies analysed psychoacoustic parameters such as loudness, sharpness, roughness, fluctuation, and fluctuation strength, which are physical magnitudes that describe the psychological effect of sound on a listener (Gozalo et al. 2018; Yu 2009; Zhang and Kang 2007).

Among the selected articles 8 of them are part of taking the European Commission Project, RUROS (Rediscovering the Urban Realm and Open Spaces) and some compare with cases from China (Yang and Kang 2005; Yang 2005; Yang and Kang 2007; Yu 2009; Yu and Kang 2008, 2009, 2010; Zhang and Kang 2007). This project was an extensive analysis of open spaces in the urban environment, combining most indicators of the physical environment as microclimate, thermal, visual and audible comfort, urban morphology, etc. with user's satisfaction, through a mixed methodology, including microclimatic monitoring and modelling of open spaces, combined with field questionnaire surveys with users of those spaces. RUROS was carried out across seven cities in Europe (Athens, Thessaloniki, Milan, Fribourg, Cambridge, Sheffield, Kassel) in two open spaces in each city. The overall data set contains over 10,000 records. Regarding soundscape, this project applied a methodology for describing the soundscape in urban open spaces, that includes the 'characteristics of each sound source, the acoustic effect of space, social and other aspects, along with simplified models for sound propagation in urban squares' (Centre for Renewable Energy Sources 2004).

Table 1 Summary of selected articles that assess sound perceptions by age groups including elders, methodology, results, and observations.

Three articles found no difference between age groups (Abolhasannejad et al. 2013; Bluhm et al. 2004; Irvine et al. 2009), stated that it could be due to a small representation of older people in the sample size (Abolhasannejad et al. 2013; Irvine et al. 2009). Conversely, some authors found differences among age groups related to: to physiological changes as listening difficulty (Sato et al. 2007a; b; Meister et al. 2013; Bauer et al. 2016; Schnell et al. 2016; Tse et al. 2012; Liu et al. 2019; Náběłek and Robinson 1982; Alain et al. 2006); to sound preference (Yang 2005; Yu 2009; Kang and Zhang 2010; Yang and Kang 2007; Yu and Kang 2010; Zhang and Kang 2007; Song et al. 2018); to acoustic comfort (Beaman 2005; Fyhri and Klæboe 2006; Yang and Kang 2005; Wei Yang 2005; Yu 2009; Zhang and Kang 2007; Yu and Kang 2008, 2009; Zhou et al. 2014); to noise sensitivity (Bauer et al. 2016; Champelovier et al. 2001; Miedema and Vos 1999; Okokon et al. 2015); to noise annoyance (Beaman 2005; Gozalo et al. 2018; Li et al. 2012; Michaud et al. 2005; Michaud et al. 2005; Miedema and Vos 1999; Okokon et al. 2015; Rylander et al. 1972; Yilmazer and Caliskan 2008; Champelovier et al. 2001). Some of those differences are reviewed below, it should be noted that some studies are part of the RUROS project, in this case, for accounting purposes, the studies that analyse the same sample are counted as one in Fig. 2, which presents the number of studies that evaluate each indicator and those that have found differences between age groups.

Age-Related Physiological Changes in the Auditory System

People with normal hearing can detect sounds between 16 and 20,000 Hz. Along with aging, there are losses of sensory functions that vary from one person to another, including the peripheral and central auditory system undergoing large changes. (Alain et al. 2006). The most common changes in auditory perception related to aging are Alteration of frequency and duration discrimination (Abel et al. 1990; Liu et al. 2019), altered sound localization (Abel et al. 2000), difficulty ordering sequential stimuli (Trainor and Trehub 1989; Meister et al. 2013), difficulties in understanding speech (Duquesnoy 1983; Gordon-Salant and Fitzgibbons 1993; Yilmazer and Caliskan 2008; Meister et al. 2013).

Some hearing tests and sound identification are based on standards such as ISO 7029, this norm specifies the expected median value of hearing thresholds concerning the median hearing threshold at age of 18 in ontologically normal persons between 18 and 80 years old under monaural earphone listening conditions for frequencies between 125 Hz to 8000 Hz. (International Organization for Standardization 2017).

The present research found twelve studies that assess physiological changes among age groups and nine of them identified differences. All those have between 30% and 60% of older adults' representation on their samples. Those findings show that elders generally reported a lower auditory capability (Tse et al. 2012). Some studies analysed listening difficulty ratings and found that those increase by aging. Sato et al. (2007a) identified that sound levels above 2 kHz significantly affect both word intelligibility scores and listening difficulty ratings for the aged. Other authors stated that children and the elders need between 10- and 20-dB higher sound pressure than young adults for maximizing word intelligibility and this difficulty increased with increased reverberation time (Nábělek and Robinson 1982; Sato et al. 2007a; b). Meister et al. (2013) attribute it to the decline of the frontal lobe functions (working memory and fluid intelligence) that influence speech recognition.

Conversely, Beaman (2005) found that the audio- metric tests were lower for elders than from the younger participants and Bauer et al. (2016) found that 28% of the elder interviewees complained of hearing loss, this author states that for each year of age the possibility of having hearing problems increases by 6%. The average age of the elders without hearing ailments was 69.44 years old, while those of auditory discomfort corresponded to 72.8 years. Additionally, some socio-demographic factors such as education level, marital status, income participation, health care access, and gender. Older people with hearing complaints had around 4.48 fewer years of education than the others, single and widowed subjects had most hearing complaints, and men were 19% more likely to have hearing problems than women, which could be attributed to past occupational noise exposure of most of the men (Tempest et al. 1976). Furthermore, 50% of older people who stated not leaving their homes due to communication difficulties had hearing affliction.

Noise Sensitivity Differences among Age Groups

Individual noise sensitivity is related to physical and mental health, as well as personality traits and attitudes such as extroversion and introversion, neuroticism, or negative feelings (Yang and Kang 2005; Schreckenberg et al. 2010). It has been shown that it is a precedent of the nuisance caused by noise in each person, as in the case of Ellermeier et al. (2001) where the sensitivity to individual noise explains 10.2% of the variation in nuisance reactions to noise from a given sound source, compared to 17.6% of the variation explained by the noise exposure measures.

Some authors question the difference between noise sensitivity and noise annoyance, therefore, Taylor (1984) explains the independence between these two concepts: sensitivity is a psychological feature that refers to a predisposition to perceive noisy events, while annoyance is an attitudinal dimension that indicates to what extent noisy events are evaluated unfavourably, nevertheless, Taylor (1984) also found that noise sensitivity has a significant effect on annoyance.

Six of the reviewed studies assessed noise sensitivity (Abolhasannejad et al. 2013; Champelovier et al. 2001; Fyhri and Klæboe 2006; Li et al. 2012; Miedema and Vos 1999; Okokon et al. 2015). Most of the authors agree that this diminishes with age, especially in the high-frequency range (Alain et al. 2006; (Miedema and Vos 1999; Liu et al. 2019). Miedema and Vos (1999) in their meta-analysis found that younger and older respondents were the least sensitive to noise and also who reported being less annoyed, there was a difference in the annoyance of about 11 dB between noise levels between non-sensitive and highly sensitive people. Likewise, Okokon et al. (2015) found that age was associated with sensitivity only in bivariate models in the age group of 45–59 years old.

Differences in Noise Annoyance among Age Groups

The sensation of annoyance due to sound is considered one of the first reactions to environmental noise. According to Ouis (2001), this has two components, one cognitive, that has to do with the expectation of people regarding the idea that sound helps improve the environment; while the other is emotional, and has to do with the change of mood as an answer to sound.

According to noise annoyance, ten of fourteen studies found differences, most of them have a representation of about 20% of older people in their sample. To evaluate noise annoyance, most of the studies use a 5 or 4-point scale (1. not at all annoyed; 2. slightly annoyed; 3. moderately annoyed; 4. considerably annoyed; 5. highly annoyed). On one hand, Miedema and Vos (1999) found that at the same noise exposure, relatively young or relatively old people feel less annoyed than intermediate ages, and that has an effect of 5 dB Leq day, the authors stated that one of the reasons for the least sound annoyance in the elders could be due to impairment of senses, most of the findings from the studies reviewed agreed with this (Beaman 2005; Li et al. 2012; Michaud et al. 2008; Michaud et al. 2008; Miedema and Vos 1999; Okokon et al. 2015; Rylander et al. 1972). Additionally, it was found that some attitude variables such as noise sensitivity and 'fear to the noise source' (aircraft, road traffic, and railway) were related to noise annoyance, and this is associated with age (Miedema and Vos 1998).

In another study about the effects of sea and greenery views on noise annoyance at home, Li et al. (2012) found that age was related to noise annoyance, although, this study separated age groups into two under and over 40 years old. And predicts that a person has a 60% chance to present low noise annoyance if he stays longer at home, (more than 12 h) and between 55% and 69% chance if a person has sea and greenery views respectively. In this study the relationship between age and hours of stay at home was not analysed, however, it would be interesting, since it is known that older people, especially retired people stay most of their time at home, so these variables could be related.

On the contrary, other studies found that the correlation between age and noise annoyance shows that older adults tend to become more sensitive than younger adults, as they were less satisfied (Champelovier et al. 2001; Gozalo et al. 2018; Yilmazer and Caliskan 2008), for their part Yilmazer and Caliskan (2008) found that during conversation older adults tend to be more annoyed by noise.

Differences in Sound Preference among Age Groups

According to Schafer (1977), soundscapes reflect human activities divided into four categories: mechanical sounds, human sounds, social activities sounds, and spatial effects that give information about the environment. Related to this, Zhang and Kang (2007) identified two kinds of sounds: active and passive, the first came from human activities, and the second belongs to the environment, like water fountains.

Differences in sound preferences are related to three levels essential, cultural, and personal (Yang and Kang 2003).

Sound preference is evaluated in ten of the selected studies, from those, seven found differences among age groups, and those authors agree that older adults express a preference for natural sounds. Five of them are part of the RUROS project (Yang 2005; Yu 2009; Yang and Kang 2007; Yu and Kang 2010; Zhang and Kang 2007), on those studies the representation of elders is around 11% of the sample. Meanwhile, the study of Song et al. (2018) had the same findings but the representation of elders is 33% of the sample.

Table 2 Soundscape evaluation factors related to age found in reviewed studies. Source: Own elaboration based on (Zhang and Kang 2007)

Factors that influence soundscape evaluation			Reference study
Source	Sound pressure level		5,11,13,14,15,16,17,19,20,21,27,29,30,31,33,34
	Spectrum		7,12
	Frequency		12,13,16,31,33,34
	Temporal conditions	Variation (hour, day, season)	10,11,12,18,19,27,30,31
		Duration	7,11,12,15,16,27,33,34
		Impulsive characteristics	12
	Location		12,13,24
	Source movement		13,29
	Psychological and social characteristics	Meaning	1,3,11,12,13,17,23,31,34
		Natural, artificial, mechanical sound	1,2,3,4,10,13,17,18,20,21,22,24,26,29,30,31,32,34
		Relation to activities	1,2,3,7,11,13,19,23,29,31, 34
		Soundmark	3
		Descriptive or holistic	31
Space	Reverberation		12,15,16,33
	Reflection pattern and/or echogram		12,15
	General background sound		7,12,31
	Sounds around the space		5,12,17
People	Social-demographic-cultural characteristics of the users		1,2,3,6,7,10,11,13,14,17,20,24,25,26,27,29,32, 34
	Acoustic condition at users' home and work, experience, etc.		1,3,10, 11,13,17,20,22,23,24,26,27,29,31
	Physiological changes: loss of sensory function; hearing loss; tinitus, memory, cognitive impairment, etc.		6,7,9,12,13,15,16,17,22,23,33,34
Environment	Temperature, humidity, lighting, etc.		5
	Visual, landscape, and architecture characteristics		3,5,10,11,12,27,31,34

References Numbers: 1 (Zhang and Kang, 2007); 2 (Kang and Zhang, 2010);3 (Yang and Kang, 2007); 4 (Yang and Kang, 2005); 5 (Schnell et al., 2016); 6 (Bauer et al., 2016); 7 (Meister et al., 2013); 8 (Irvine et al., 2009); 9 (Tse et al., 2012); 10 (Yu and Kang, 2010); 11 (Yu and Kang, 2008); 12 (Alain et al., 2006); 13 (Miedema and Vos, 1999); 14 (Yu and Kang, 2009); 15 (Sato et al., 2007b); 16 (Sato et al., 2007a); 17 (Yang, 2005); 18 (Champelovier et al., 2001); 19 (Yilmazer and Caliskan, 2008); 20 (Fyhri and Klæboe, 2006); 21 (Rylander et al., 1972); 22 (Okokon et al., 2015), 23 (Beaman, 2005); 24 (Michaud et al., 2008); 25 (Abolhasannejad et al., 2013); 26 (Michaud et al., 2008); 27 (Li et al., 2012); 28 (Bluhm et al., 2004); 29 (Yu, 2009); 30 (Song et al., 2018); 31 (Gozalo et al., 2018); 32(Zhou et al., 2014); 33 (Nábělek and Robinson, 1982); 34(Liu et al., 2019)

To evaluate sound preference, some of the studies include in the questions of their survey based on the semantic differential technique of Osgood (1976) to connect the feelings of the user regarding the linguistic and psychological levels and sources of sounds in public spaces (Zhang and Kang 2007; Kang and Zhang 2010) and most of them use a 3-point scale (1. Favourite; 2. neither favourite nor annoying; 3. Annoying).

In the study of Zhang and Kang (2007) in two squares in Sheffield, the differences between the age groups in terms of preference were significant, 93% of people over 65 years old scored the songbirds as a favourite, while only 46.4% of young people between 10 and 17 years old did it and 14% considered it annoying. Younger people were more favourable towards music and mechanical sounds, for example, concerning music from stores, 77% of people over 65 considered it as annoying and 36.6% of younger people rated it as a favourite, while the only sound in which they all agreed as neutral, was surrounding people's speech. Yu and Kang (2010) also found an increased preference for natural sound with age, and a less common relationship between human sounds like speaking, footsteps, and children shouting with age, this is varied among cities, authors suggest the possible effects of cultural factors. Additionally, Zhang and Kang (2007) found that people chose to attend the squares according to their preferred sounds, thus soundscape preferences influence the choice of public space and this might be related to age. According to the authors, a possible reason for this difference in evaluating sounds is that the preference of sounds of older people tends to be formed by memory or experiences and cultural background (Yang and Kang 2007), while older people feel more emotional with some sounds of the environment (Russell 2003; Farina 2014).

Other studies found that with increasing age people prefer 'quiet and natural sound environments' while 37.6% of people between 10 and 17 years prefer soundscapes with a mixture of 'natural and artificial sounds' (Yang 2005).

Yu and Kang (2010) performed an in-depth analysis about the influence of various social, demographical, physical, behavioural, and psychological factors on the sound preference, including age, considering that some factors´ relationships, may be affected by their other variables. Authors found that 'age generally has strong correlations with physical/behavioural/psychological factors, in 55.6% of the sites in terms of the time of day, 47.4% of the sites in terms of frequency of coming to the site, and 50.0% of the sites in terms of the site preference '(Yu and Kang 2010, p. 632). While Yu and Kang (2008), Yu (2009), and (Liu et al. 2019, b) analysed the relationship among social and demographic factors, they found a significant correlation between age with education level and occupation.

Differences in Acoustic Comfort and Sound Level Evaluation among Age Groups

Human perception of the environment is multisensorial (Viollon et al. 2002; Raimbault 2006), that might include or not an interaction with acoustic comfort, because of the psychological adaptation and meaningful or meaningless of the content of a sound in a perceived soundscape (Centre for Renewable Energy Sources 2004). For Yu (2009), the perception that people have of an acoustic environment is not a unique sensory process, it is also determined by the perception of other physical stimuli, such as thermal, lighting, visual, geographic, social, psychological, and cultural aspects (Kang et al. 2016; Raimbault 2006). Similarly, Zhang and Kang (2007) found that the most important factors in general comfort were: temperature, sunlight, brightness and wind represented 22.8%, followed by the visual and auditory, 17.5%, and the humidity and wind factors were 14.8%, and it was assumed that the percentage that was missing is the influence of cultural and social factors.

From the articles assessed in this paper, from fourteen studies which analyses acoustic comfort evaluation, seven found differences among age groups, most of them found that older people were the most satisfied group (Yang and Kang 2005; Yu and Kang 2008; Beaman 2005; Yang 2005; Zhang and Kang 2007), as is the case of Yang (2005), and Yang and Kang (2005), they found that teenagers felt less satisfied in terms of acoustic comfort, while people over 55 were the most satisfied group. Meanwhile, Yu (2009) in a park in Sheffield where the acoustic comfort and noise level evaluation in two age groups were compared using prediction maps by simulations, it was found that the age group of 13 to 18-year older generally felt more comfortable than the age group older than 65 years. Similar findings had Zhou et al. (2014) in their study in historical areas in China. Nevertheless, only Beaman (2005) had a high representation of older people (46%) on the sample size, while the rest of the studies had around 10%. Conversely, Tse et al. (2012) performed a study in urban parks in China, with a sample of 595 people, and 44% of them were older than 60, as authors stated those were the largest group pf park users, through a model for predicting acoustic comfort evaluation, age was not found to influence it, only individuals' residency status affected it, people not living in the neighbourhood tend to state higher acoustic comfort evaluations.

To evaluate acoustic comfort most of these studies use a 5-point scale (1. very comfortable, 2. comfortable, 3. neither comfortable nor uncomfortable, 4. uncomfortable and 5. very uncomfortable). Meanwhile, for sound level evaluation, most of them use a 5-point scale (1. very quiet; 2. quiet; 3. neither quiet nor noisy; 4. noisy; 5. very noisy).

Regarding the sound level, eleven studies evaluated it but only 5 authors found differences among age groups (Fyhri and Klæboe 2006; Liu et al. 2019; Yu 2009; Yu and Kang 2008, 2009), and three of them are part of the RUROS project (only 11% of elders in the sample).

In the RUROS project developed in squares in Europe and China, only 4 from the 19 study cases, showed significant correlations between age and the sound level evaluation, people between 13 and 18 years old felt quieter than the older than 65 years old people (Yu and Kang 2009; Yu 2009; Yu and Kang 2008). Authors state that older people tend to be more tolerant in open public spaces like parks, it might be due to the function of recreation and relaxation attributable to (Yu and Kang 2008). In addition, some authors state that reduced expression of annoyance might increase physiological stress (Maris et al. 2007), and this could be affecting elderly health. Age was found related to occupation and education and those factors were correlated to sound level evaluation, similarly, between behaviour variables, it was found that activities like reading/writing; watching, moving activities show a little difference in sound level evaluation, being watching the most significant and all those were related to age (Yu and Kang 2008).

In the study of Liu et al. (2019) in Germany, with a representation of 20% of older people in the sample, those tended to perceive some sounds louder, for example, dog barking (lower frequency sound), but they usually perceive surrounding speech and the wind blowing not as loud as younger people. This could be explained by presbycusis which is more marked at high frequencies and affects most older people. Additionally, it was found a relationship between age and visit motivation to green spaces, and among the length of stay and sound perception, authors stated that older people tended to visit those places for relaxation and stay longer, while younger people perform more physical activities.

Conclusion

Although the study of the soundscape has increased in recent years, only limited attention has been given to environmental noise risk on vulnerable populations such as the elderly. In this paper, 34 studies were assessed due to their focus on differences in noise perceptions such as preference, acoustic comfort, noise annoyance, and noise sensitivity, considering age groups. The most common age-related changes in auditory perception are associated with hearing loss, like alteration of sound frequency and localization, difficulty ordering sequential stimuli, and difficulties in understanding speech, among others that affect and difficult elder people's daily life. Results show that the greatest difference between older adults and the rest of the age groups was found on noise annoyance followed by acoustic comfort, meanwhile the least differences were found concerning the noise sensitivity and evaluation of sound level. While about sound preferences, it was found that generally, the elders prefer natural and cultural sounds, some authors have found older adults as more sensitive to noise and less satisfied, while others found the elders as the most tolerant and satisfied age group.

Soundscape evaluation is a complex issue, understood as the relationship between human beings and the acoustic environment, based on the sound source, space, environment, and people characteristics. Table 2 presents a summary of all these factors that were found related to age in the reviewed studies.

Table 2**.** Soundscape evaluation factors related to age found in reviewed studies. Source: Own elaboration based on (Zhang and Kang 2007).

Some of the reviewed studies found that among demographic variables, age, occupation, education level, marital status, and residential status are the most influential over the sound perception. However, just a few of them make a cross-analysis among those social/demographic variables, it was found that age is related to occupation, education, and marital status. Older people tend to be retirees, maybe widowers, and depend on the group of reference and gender could be more or less educated. Besides, the research found a strong correlation between physical/behavioural/psychological characteristics with age and soundscape evaluation, like those related to physiological changes, experiences, memory, attitude, culture, etc. Given the complex relationships between all the different variables, it is difficult to develop prediction models to integrate the effects of multiple factors in soundscape evaluation, but should be taken into account.

Studies reviewed in this paper showed heterogeneous results, maybe due to the different types of methodologies, as well as different sample size and the proportion of older adults in it, since most studies do not focus on age as the main variable and there is a lack of analysis about demographic and social variables.

Additionally, some studies found that people chose to attend open public spaces according to their preferred sounds, so a more aesthetically appealing soundscape would attract more older users to an urban square. This should be taken into account to attract older people to public open spaces encouraging more active and healthy aging, avoiding situations of social isolation and loneliness. It can be concluded that more research is still needed in this field, to achieve comfortable spaces through soundscape design which should be pleasant and inclusive for all age groups and contribute to improving their quality of life, as a measure to adapt cities to an aging population, this design might take into account the sensitivity and preferences of older people in particular as a vulnerable group.

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Declarations

Conflicts of Interest/Competing Interests The authors declare that they have no conflict of interest.

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