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Research paper

Evaluation of the main sensitivity drivers in relation to indoor comfort for individuals with autism spectrum disorder. Part 1: Investigation methodology and general results

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ABSTRACT

The present study applies an approach to analyze the stress induced on people on the autism condition. Dedicated questionnaires were prepared, in order to guarantee an inclusive participation and then applied by means of two different surveys in living and extended care unit environments. Results permit to highlight that: (i) the four comfort domains show similar sensitivity trends, with acoustics having the greatest impact on people with autism spectrum disorder (ASD), while thermo-hygrometric, visual and IAQ sensitivity decreases as the stress scale increases; (ii) Severity of autism influenced the acoustic sensitivity, while age and the considered environment influenced thermo-hygrometric, visual and IAQ sensitivities. The proposed approach can be applied to well-being studies involving people with other types of conditions which could alter their perception of the built environment.

1. Introduction and background

Buildings are designed to provide a suitable living and working environment for humans. Indoor comfort is necessary in different types of buildings, such as living, learning, working and healing environments. Good environmental quality is important as it affects health, comfort and productivity (European Committee for Standardization, 2007, 2019), significantly impacting on psychological and physiological aspects. Typical and traditional design criteria are based on a prescriptive approach and focus on comfort requirements. For instance, EN 16798-1 is related to thermal, acoustics and indoor air quality (IAQ) (European Committee for Standardization, 2007, 2019) and EN 12464-1 to lighting (European Committee for Standardization, 2011), specifying suitable ranges of indoor conditions.

However, the same reference could not be suitable in environments dedicated to individuals with special needs, since they might diversely experience environmental stimuli and have an individual perception. Wang et al. (2018) highlighted that there are several studies confirming the dependence of thermal comfort on gender, age, circadian rhythm, physical disabilities and fitness. For these reasons, specific studies are necessary to ensure comfort to users with special needs (Wang et al., 2018; Cena and De Dear, 2001; Chappells and Shove, 2004; Del Ferraro et al., 2015; Kumar and Mahdavi, 2001; Zaniboni et al., 2020; Heylighen et al., 2008; Devos et al., 2018). It has been demonstrated that neuroatypical individuals offer diverse responses to indoor environmental stimuli, in comparison with neurotypical ones.

One standard approach, usually followed to conduct comfort research, is constituted by field studies; in these, physical measurements of objective parameters, such as temperature, relative humidity, mean radiant temperature, illuminance, clothing insulation or even metabolic rate are associated with subjective responses. These responses are generally collected by means of questionnaires, which have been used in several field surveys regarding thermo-hygrometric, visual, acoustic and indoor air quality comfort (Carpino et al., 2019). Measurements taken in specific environments combined with subjective surveys results are then used to generalize the preferred ranges of the investigated environmental parameters, which are then reported in reference standards and literature. Indeed, people on the spectrum (especially featuring high severities of autism) are acknowledged as neurodiverse (Kapp et al., 2013) and thus identified by the Declaration of World Medical Association (1991) as individuals to be protected by testing for aim of research (Schüklenk, 2000). For this reason, the importance of an indirect approach is the most suited methodology to understand the well-being of these users (Huang et al., 2013; Forcada et al., 2021; Fergus Nicol, 2011).

An example of a questionnaire on thermal comfort is presented in ASHRAE Standard 55 (ASHRAE, 2017), while questionnaires to investigate thermal, visual, IAQ and acoustical comfort have been utilized, for instance, by Day et al. (2019), Silva

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et al. (2017), Ricciardi and Buratti (2018) and Ryu et al. (2020). Questionnaires normally include information about the individual (i.e. age, clothes worn, activity level, …) and about the environment (i.e. position in the room, information about the light, windows or shading status, …), while comfort is evaluated on different scales such as preference, sensation or satisfaction.

This approach based on direct questions presumes the existence of a neurotypical user, considering the subjective responses as statistically representative of the general perception, which cannot be assumed when considering subjective alterations of perceptual aspects. Moreover, altered perception of the environments may lead to increased reactions and behavioral problems, psychological symptoms or isolation (Devos et al., 2018; Hoof et al., 2010; Minshawi et al., 2014). Therefore, the same approach might not be directly applicable to investigate the well-being of people with peculiar environmental perception, such as people on the autism spectrum. Thus, developing specific research on environmental comfort is of paramount importance. Indeed, individuals on the spectrum can have high levels of hypo- and hyper-sensitivity to the 5-sense stimuli (Mostafa, 2014; Wali and Sanfilippo, 2019; Belek, 2019; Schofield et al., 2020; Gaines et al., 2016; Jones et al., 2020; Shell, 0000), increasing their stress and anxiety and, especially when featuring high levels of autism, may cause dangerous behaviors, including self-injurious reactions (Minshawi et al., 2014). Investigating environmental perception of neuroatypical people and their awareness to indoor environmental stimuli could help to better understand and manage these issues.

The present literature focuses on the environmental perception of autistic individuals from a medical and neurobiological point of view, giving important information on how to design a less risky environment for them, but it does not report anything about their comfort requirements (Mostafa, 2020; Kaul, 2018; Talay-Ongan and Wood, 2000; Bishop et al., 2013; Law et al., 2015; Danesh et al., 2015; Gomes et al., 2004; Jones et al., 2009; Boer et al., 2013; Lawson et al., 2015; Remington and Fairnie, 2017; Kuiper et al., 2019; Galle et al., 2013; Ashwin et al., 2014; Fadda et al., 2018; Vaughan et al., 2020; Williams et al., 2019). Furthermore, most studies are focused on individuals which can have a normal life. However, autism severities are acknowledged to be three: A-low severity (independent individual), B-medium severity (semi-independent individual) and C-high severity (non-independent individual) (American Psychiatric Association, 2013). In literature, very few results are presented in relation to medium and high severity of autism and most often referring to a very small sample.

Noble et al. (2018) compared anonymous Indoor Environmental Quality (IEQ) surveys by autistic adults and neurotypical users. The two groups were asked to evaluate work and home environments by a 7-points discomfort scale and to use a 7-points avoidance scale to rate generic built environments. Differences were found in the evaluations of many factors, such as electric lighting, glare and noises, highlighting the need of additional studies in order to understand the reason of the larger impact of some factors on people with ASD.

For these reasons, studies on comfort of people on the autistic spectrum are needed, in order to correctly consider them also as users of indoor environments and to properly develop guidelines to design households and extended care units. In the case of high levels of autism, the standard investigation approaches cannot be followed for three specific reasons: (i) the responding person may be affected by a reduced perception of the environment; in some cases this can be harmful, since discomfort (such as the heat or cold, for instance) is not perceived even in unsuitable conditions. Some individuals (ii) have difficulty in interacting and communicating and therefore in reporting their perceptions and preference in questionnaires. The Helsinki Declaration (iii) protects them from direct tests.

Fig. 1. One picture of the "atelier" room of the extended care facility where the local survey was conducted. In this environment, several activities are performed by autistic individuals together with professional caregivers.

In this work we specifically focus on autistic individuals which are not able to have an independent and a normal life (mostly medium and high severities). Also, for this reason, understand the differences in the perceived environment of people in the spectrum depicted on their behalf by parents and caregivers is a focal point. Thus, a control sample was chosen in order to study the answers given by caregivers and parents on the same individuals.

To the authors' knowledge, there are no studies reporting autistic individuals' sensitivity to each of the comfort domains. Investigations focusing on surveys related to individuals with special needs were found in the literature (Koster et al., 2008; Finlay and Lyons, 2001; Matthews et al., 2011; Butterworth et al., 2013; Baron-Cohen and Wheelwright, 2003), but no studies provide a comprehensive representative description of the peculiarities affecting these individuals' sensitivity. Additionally, none of the research on the autism perception of Indoor Comfort described here had a big and representative sample. Moreover, none of these studies looked at the impact of characteristics like gender, age, autism severity, and comorbidities.

For the above reasons, an approach to study the environmental well-being of autistic individuals is required. In this framework, a general method was used with two aims: (i) define which aspects most stress autistic people and if they differ from neurotypical users and (ii) study the possibility of introducing reference thresholds for each of these aspects. Accordingly, a procedure consisting of two steps has been identified: step 1 defines *how* each of the four comfort domains affect autistic people differently than standard users and in particular whether there are increased or reduced sensitivity patterns which should be considered; step 2 detects *how much* the comfort domains affect people on the spectrum, in terms of discomfort or stress, comparing the critical conditions from different subjects in order to identify possible thresholds. Step 1 is investigated in this research. Since we are detecting how each comfort factor affects individuals with ASD and we cannot know the extent to which it does, the surveys' questions must focus on the detection of stress. In this way, it is possible to study indoor environmental issues and to understand which ones affect autistic people differently than standard users. These issues can be investigated in more depth, while traditional thresholds can be considered for the aspects which are not provoking particular sensitivities. Based on the results of

this research, it will be possible to conduct future field studies in order to further investigate these critical aspects and define possible thresholds.

In this way, an approach to investigate indoor environmental issues of neuroatypical people, thus with an altered perception of the environment, was applied, focusing on (i) thermo-hygrometric, (ii) acoustic, (iii) visual and (iv) indoor air quality domains. The proposed approach was applied by means of two different comprehensive surveys (among professional caregivers and parents). The results of the analysis were analyzed in depth by means of quantitative methods, considering the following main aims:

1. Detecting the comfort domains (among thermo-hygrometric, visual, acoustic and IAQ), most affecting autistic individuals.
2. Identifying if there are differences between the evaluations given by professional caregivers (henceforth "caregivers") and parents and also evaluating if the reliability between the two groups differs.
3. Identifying how different parameters like environment, gender, age, severity of autism and co-morbidities could affect the evaluations.

2. Materials and methods

2.1. Development of the questionnaires and survey administration

In order to characterize the sensitivity to environmental factors, anonymous questionnaires were prepared.

People with a high severity of autism, especially individuals who cannot live a normal life, could not be able to properly answer the questions concerning their own well-being. Indeed, they often have difficulties in interacting with other individuals and they rarely answer direct questions, such as "How are you feeling?". Neglecting this aspect may, for instance, provoke a crisis. Therefore, it was necessary to ask the questions focusing on individuals' sensitivity to specific environmental stimuli. In this view, it was necessary to include a "third-party approach", developing the questionnaires focusing on diverse respondents: (i) caregivers working in care units and (ii) parents of autistic individuals. Caregivers' answers were given in care units, while parents' answers are referred to the observations taken in everyday household environments.

After initial instructions and explanations, questionnaires' respondents were asked to indicate whether they were caregivers or parents. In each questionnaire filling, the respondent was required to report the main information about the autistic individual he/she was referring to: data such as gender (male, female or other), age, severity of autism and comorbidities (Obsessive–Compulsive Disorder — OCD, depressive disorder, anxiety disorder or other psychiatric or neurocognitive disorders) needed to be reported. The indication of the severity of autism and presence of co-morbidities was asked according to *The Diagnostic and statistical manual of mental disorders* of the American Psychiatric American Psychiatric Association (2013). Accordingly, the autism severity was identified in three main level

- Level A — low severity, requiring support
- Level B — medium severity, requiring substantial support
- Level C — high severity, requiring very substantial support.

In addition, questions regarding the date of questionnaire completion and the environment where the described individual was (family house, apartment, assisted facility, etc.) were included in the introduction of the questionnaire.

Table 1
Sensitivity levels used in questionnaires.

Sensitivity level	Explanation
Absent (0)	If the indicated factor does not produce abnormal stress levels
Minor (1)	If the factor produces an increase in stress levels of limited and/or non-systematic intensity and/or frequency
Average (2)	If the factor produces a systematic increase in the stress level of average intensity and/or frequency
Extreme (3)	If the factor systematically produces an increase in the level of stress of high intensity and/or frequency
Sporadic (S)	When cases of increased sensitivity are present in a sporadic and non-systematic way (few observations, low repeatability or predictability), even if of high intensity. Use the same scale as above (1, 2, 3) and tick in addition the box S ('sporadically') next to each application
Hypo-sensitive (H)	If the individual submits the cases indicated in hyposensitive form (i.e. that there is no reaction despite the presence of an obvious stimulus), only tick the box "H" near the scale of levels of stress

The main part of the questionnaire was then devoted to the registration of the individual's special sensitivity to the thermo-hygrometric, acoustical, visual and indoor air environments, through multiple choice scales. These scales refer to the levels of hyper-sensitivity to the different aspects based on the level of stress produced, as reported in Table 1. Since preliminary studies (Minshawi et al., 2014; Mostafa, 2014; Wali and Sanfilippo, 2019; Belek, 2019; Schofield et al., 2020; Gaines et al., 2016; Jones et al., 2020; Shell, 0000; Mostafa, 2020; Kaul, 2018; Talay-Ongan and Wood, 2000; Bishop et al., 2013; Law et al., 2015; Danesh et al., 2015; Gomes et al., 2004; Jones et al., 2009; Boer et al., 2013; Lawson et al., 2015; Remington and Fairnie, 2017; Kuiper et al., 2019; Galle et al., 2013; Ashwin et al., 2014; Fadda et al., 2018; Vaughan et al., 2020; Williams et al., 2019) have shown the occurrence of hypo-sensitivity cases the questionnaire included the possibility to indicate whether the individual was hypo-sensitive to a specific environmental domain. Additionally, it was also possible to indicate whether the stressful condition, if present, occurred in a non-systematic way ("sporadically") instead of regularly.

The questionnaire was administered by means of two survey campaigns. The first one, referred to as *online survey*, was addressed to several Austrian and Italian associations of support and assistance for autistic people and their families. The second one, referred to as *local survey*, considered an extended healthcare unit located in Northern Italy. In both cases, questionnaires were exactly the same and were filled in by caregivers and parents. The center involved in the *local survey* is in a recently refurbished building, inaugurated in 2019 and developed as a result of a Ph.D. thesis, studying the design of structures specifically for autistic people (Porro, 2018). The outcome is a three-floor (2700 m^2 each) semi-residential and non-residential multipurpose structure, where residential, therapy and recreational rooms are all designed in order to ensure the well-being of people on the spectrum. For instance, the following features were developed to ensure users' well-being: cozy environments and colors, proper lighting and daylight exploitation, attention to the acoustics (e.g. sound-absorbing panels), proper ventilation and thermo-hygrometric regulation.

Locked files were used to administer the questionnaires in the *local survey*: automatic filling was implemented in order to only allow the possible combinations (i.e. "minorly", "averagely", "sporadically minorly", "sporadically averagely", etc.). The same procedure was used for the *online survey* questionnaires, creating

Table 2
The scale used in the Mann–Whitney tests and its correspondence with the questionnaires' answers.

Level	Reaction
0	Absent reaction
1	Minor and sporadic minor reactions
2	Average and sporadic average reactions
3	Extreme and sporadic extreme reactions

Table 3
Number of questionnaires completed by parents and caregivers by patients during the online and the local survey. The overall sample corresponds to the sum of data from online survey sample and local survey sample. Data from the control sample are shown in brackets as part of the local survey.

	Parents	Caregivers	Total
Online survey	32	39	71
Local survey	26 (19)	41 (19)	67 (38)
Overall	58	80	138

contiguity and allowing comparisons between the two surveys. This was done taking into account the different sensitivity that an autistic person could present with respect to other people and the impact of co-morbidities (Morgan, 2019; Cassidy, 2018; Geilman, 2016; Bogsdashina, 2014).

Considering the different languages of participants, surveys were prepared in Italian, English and German, in order to collect responses within an international framework. Furthermore, for an inclusive participation of the stakeholders, the questionnaire was reviewed and built with the help of psychologists and experts in communication with people with ASD, parents and caregivers. In addition, as widely used (Dixon, 2007; Leighton, 2010; Clawson et al., 2012; Herrera et al., 2012; Hervás et al., 2020; National Autistic Society, 2020), pictograms were inserted in specific sections of the questionnaires in order to help respondents to better understand the survey topics. The whole questionnaire is reported as Supplementary File. In this research, only questions A1, B1, C1 and D1 regarding the environmental comfort domains as a whole were considered. The minimum age of the subjects considered for this research was 7 years old, since younger individuals may not present a complete autism diagnosis and, thus, the severity of autism cannot be assessed with certainty (Matson, 2016).

2.2. Data processing

Four different sample groups were identified and used: 1. *Online survey sample*, 2. *Local survey sample*, 3. *Control sample* and 4. *Overall sample*. The *control sample* was characterized inside the *local survey*, isolating all the individuals whose perception was evaluated by both parents and caregivers. For this reason, this sample is a subset of the *local survey sample*, containing only those people whose sensitivity was evaluated two times: one by each of the respondents' type. Finally, the *overall sample* comprises the questionnaires from both the surveys.

In order to check the reliability of the questionnaire and thus the suitability of its structure for the different respondents, a Cronbach's alpha test was performed grouping the types of respondents as follows: 1. parents' results; 2. Caregivers' results; 3. merging together caregivers' and parents' results. The test was repeated for all the four samples, with 0.70 considered as a threshold for reliability (George and Mallery, 2003).

An ANOVA analysis (Hinkin and Tracey, 1999) was performed to check the distribution of the *local survey* and *online survey* samples, to control whereas an homogeneity among the distribution of age and the autism severity in the two surveys existed. Where a distinction was needed, a Tukey HSD test was performed in order to understand in which age ranges or severity levels the difference existed. The four comfort domains were analyzed according to the percentage of respondents giving a specific answer. A preliminary analysis was made on all the four samples (*control*, *local*, *online* and *overall*) by means of descriptive statistics, identifying the common and different trends in the percentages of answerers indicating a specific sensitivity. When analyzing the *online survey*, the *local survey* and the *control samples*, parents' and caregivers' answers were considered separately. The Mann–Whitney test was used to evaluate if the differences found were statistically significant (Zaniboni et al., 2020; Xue et al., 2014; Pierrette et al., 2014; Berquist et al., 2019; Liu et al., 2019).

Descriptive statistics and Mann–Whitney tests were additionally used with the *overall sample* to identify association of sensitivities to the four main comfort domains using:

1. Gender (females or males);
2. Presence of co-morbidities;
3. Severity of autism;
4. Age.

The following age groups were selected: 1. "7–9" 2. "10–17"; 3. "18–29"; 4. "30–39"; 5. "40–49"; 6. "$\geq$ 50". These age groups were chosen in order to differentiate among age decades, as well as between childhood and adolescence and adolescence and adulthood.

In all cases, the Mann–Whitney test was selected due to the independence and the unknown distribution of the samples. Moreover, as the analyses were explorative, a 10% level was used in addition to the conventional 5% level of significance (Zaniboni et al., 2020; StatisticsSolutions, 2020; Lane et al., 2017). Table 2 reports all the scale of the answers considered for the tests. Answers dealing with sporadic sensitiveness were considered together with the corresponding "non-sporadic" levels (e.g., "sporadically average" together with "average"). Since they refer to an altered and non-scalable missed perception of environmental stimuli, hypo-sensitive answers were not considered for this part of the analysis.

2.3. Research ethics and proxy respondents

The procedure was implemented in order to comply with the Declaration of Helsink (World Medical Association, 1991). The first page of the questionnaire clearly included the aim and scope of the research and the informed consent for the study. Start, fill in and conclude any of the survey was not mandatory, so all the participants were volunteers. The presented research is part of wider study, approved by Ethics Committee of the Free University of Bozen-Bolzano. Furthermore, to include all the severities of autism in the survey it was admitted the possibility of proxy respondents. The use of proxy respondents is a common practice especially in health and disability surveys, as this makes it possible to collect information about persons who may be unable to directly participate in the survey (Loeb et al., 2018; Neumann et al., 2000; Iezzoni et al., 2000). For this specific case, the invitation to fill in was specifically addressed to parents and caregivers who are regularly involved with the observed individuals.

3. Results and discussions

3.1. Population

A total of 71 and 67 questionnaires were collected during the *online* and the *local survey*, respectively (Table 3). Particularly in the latter, caregivers were the highest number of respondents

Table 4
Gender and age of autistic subjects in the online and in the local survey, in number of answers. The overall sample corresponds to the sum of data from online survey sample and local survey sample. Data from the control sample are shown in brackets as part of the local survey.

Age	Online survey			Local survey			Overall		
	Females	Males	Other	Females	Males	Other	Females	Males	Other
7–10	0	0	0	1 (0)	15 (5)	2 (0)	1	15	2
10–17	3	14	1	12 (5)	12 (1)	0 (0)	15	26	1
18–29	7	15	0	4 (1)	21 (7)	0 (0)	11	36	0
30–39	12	6	0	0 (0)	0 (0)	0 (0)	12	6	0
40–49	1	5	0	0 (0)	0 (0)	0 (0)	1	5	0
50+	3	4	0	0 (0)	0 (0)	0 (0)	3	4	0

Table 5
Severity of autism and co-morbidities detected by caregivers and parents in the online and in the local survey, in number of answers. The overall sample corresponds to the sum of data from online survey sample and local survey sample. Data from the control sample are shown in brackets as part of the local survey.

		Online survey		Local survey		Overall	
		Parents	Caregivers	Parents	Caregivers	Parents	Caregivers
Severity of autism	A	8	10	12 (8)	17 (6)	20	27
	B	14	7	8 (7)	17 (9)	22	24
	C	10	22	6 (4)	7 (4)	16	29
Co-morbidities	OCD	12	6	0 (0)	2 (1)	12	8
	ID	18	23	11 (9)	10 (6)	29	33
	AD	7	8	3 (3)	1 (0)	10	9
	Other	12	17	1 (1)	2 (0)	13	19

OCD = obsessive–compulsive disorder; ID = intellectual disability; AD = anxiety disorder.

(32 parents 39 caregivers in the *online survey*, 26 parents and 41 caregivers in the *local survey*).

The gender and the age of the respondents of the two surveys are reported in Table 4. Both in the *online* and in the *local* survey, the majority of subjects are males (62% and 72% respectively). Moreover, subjects are younger in the *local survey*, with all the subjects under 30. Table 5 shows the number of questionnaires collected for each grade of severity of autism and the number of co-morbidities indicated for each survey. The majority of the answers regard individuals with Levels B and C. Intellectual disability was the co-morbidity detected most often, both in *online* and *local* surveys. More co-morbidities were detected in the *online survey*, consistently with the stronger forms of autism of the subjects involved. Data from the *control group* (referred for the same group of individuals) highlight that both parents and caregivers mostly agreed in the evaluation of the severity of autism and of the co-morbidities. Slight differences are present and are due to the different background of the two proxy respondents (e.g., home everyday experience vs. a more scientific background, psychological aspects of parents when evaluating their own children, etc.).

In order to discover whether the distribution of answers provided was homogeneous with the severity of autism and the age distribution, an ANOVA test, combined with a Tukey HSD test where a statistical significance was found, was performed. The tests were done distinguishing between *online* and *local* surveys to investigate if an inhomogeneity may exist. Results highlighted that several statistical differences were found among the groups. Indeed Table 6 shows a significant difference between *online survey* and *local survey* samples. Thus, confirming what is also showed in Table 4, the majority of younger individuals observed were involved in the *local* survey, while the older ones were included in the *online* survey. Looking at autism severity (Table 7), it is possible to highlight that significant differences between individuals with higher severity of autism and lower and medium severities are present. Furthermore, the results confirmed what previously observed in Table 5.

3.2. Questionnaires reliability

Table 8 shows that all the Cronbach's alpha tests always scored higher than 0.85, meaning a high questionnaire reliability for all the respondents involved and in the several surveys conducted. Thus, in all cases, the questionnaire design ensured to give results with a good repeatability with the same conditions in all cases. Cronbach's test showed high values for the adoption of this questionnaire for parents, caregivers and a combination of these two proxy respondents (i) in the *online survey*, *local survey* and *overall* samples (> 0.90), and (ii) in the *control* sample (> 0.85).

3.3. Trends, influence of respondents and environments

The sensitivities to the four environmental domains are reported in Figs. 2–4. The figures report the answerers percentage within each sample indicating a particular sensitivity level as regards the four comfort domains (questions A1, B1, C1 and D1 — Supplementary File). The results of the statistical tests used to investigate the association of answers with the type of respondent and the type of survey are reported in Tables 9 and 10.

The analysis of the *control sample* (Fig. 2) further distinguishes between the observations of parents and caregivers. In the analysis, the chart on the left represents subjects in households, while the one on the right shows subjects in the care units. The second column of Table 9 reports the results of the test to evaluate the statistical differences between the answers of parents and caregivers in *the control sample*. These findings can be highlighted:

1. In everyday life (answers provided by parents in households), there is a slight shift to higher sensitivities. The only other remarkable difference between the two environments is a major rate of "hypo-sensitivity" to the thermo-hygrometric environment in the care units.
2. The percentages of "average" and "extreme" sensitivity to the acoustic environment are quite high in both cases (35% "average" and 20% "extreme" by parents, 30% "average" and 20% "extreme" by caregivers). In the extended-care unit the number of subjects who rated "absent" sensitivity

Table 6
ANOVA and Tukey HSD test between the two types of surveys (online and local) and the age groups of the observed individuals with ASD.

ANOVA					
(1) online (2) local					
	Sum of squares	df	Mean square	F	Sig.
Between groups	12.77	5	2.554	15.536	< **0,01****
Within groups	21.701	132	0.164		
Total	34.471	137			
Multiple comparisons: Tukey HSD					
Dependent variable: (1) online (2) local					
(I) Age range (7–9 (1); 10–17 (2);18–29 (3); 30–39 (4); 40–49 (5); 50+(6))	(J) Age range (7–9 (1); 10–17 (2);18–29 (3); 30–39 (4); 40–49 (5); 50+(6))	Mean difference (I-J)		Std. error	Sig.
Age range: 7–9	10–17	0.391		0.113	**0.009****
	18–29	0.512		0.114	**< 0.001****
	30–39	1.000		0.135	**< 0.001****
	40–49	1.000		0.191	**< 0.001****
	50+	1.000		0.181	**< 0.001****
Age range:10–17	7–9	−0.391		0.113	**0.009****
	18–29	0.120		0.086	0.728
	30–39	0.609		0.113	**< 0.001****
	40–49	0.609		0.176	**0.009****
	50+	0.609		0.164	**0.004****
Age range: 18–29	7–9	−0.512		0.114	**< 0.001****
	10–17	−0.120		0.086	0.728
	30–39	0.488		0.114	**< 0.001****
	40–49	0.488		0.177	**0.070***
	50+	0.488		0.165	**0.042****
Age range: 30–39	7–9	−1.000		0.135	**< 0.001****
	10–17	−0.609		0.113	**< 0.001****
	18–29	−0.488		0.114	**< 0.001****
	40–49	0.000		0.191	1.000
	50+	0.000		0.181	1.000
Age range: 40–49	7–9	−1.000		0.191	**< 0.001****
	10–17	−0.609		0.176	**0.009****
	18–29	−0.488		0.177	**0.070***
	30–39	0.000		0.191	1.000
	50+	0.000		0.226	1.000
Age range: 50+	7–9	−1.000		0.181	**< 0.001****
	10–17	−0.609		0.164	**0.004****
	18–29	−0.488		0.165	**0.042****
	30–39	0.000		0.181	1.000
	40–49	0.000		0.226	1.000

Table 7
ANOVA and Tukey HSD test between the two types of surveys (online and local) and the autism severity of the observed individuals.

ANOVA					
(1) online (2) local					
	Sum of squares	df	Mean square	F	Sig.
Between groups	2.777	2	1.388	5.913	**0.003****
Within groups	31.694	135	0.235		
Total	34.471	137			
Multiple comparisons: Tukey HSD test					
Dependent variable: (1) online (2) local					
(I) severity of autism	(J) severity of autism	Mean difference (I-J)		Std. error	Sig.
Level A	Level B	0.092		0.101	0.634
	Level C	.336*		0.101	**0.003****
Level B	Level A	−0.092		0.101	0.634
	Level C	.244*		0.102	**0.047****
Level C	Level A	−.336*		0.101	**0.003****
	Level B	−.244*		0.102	**0.047****

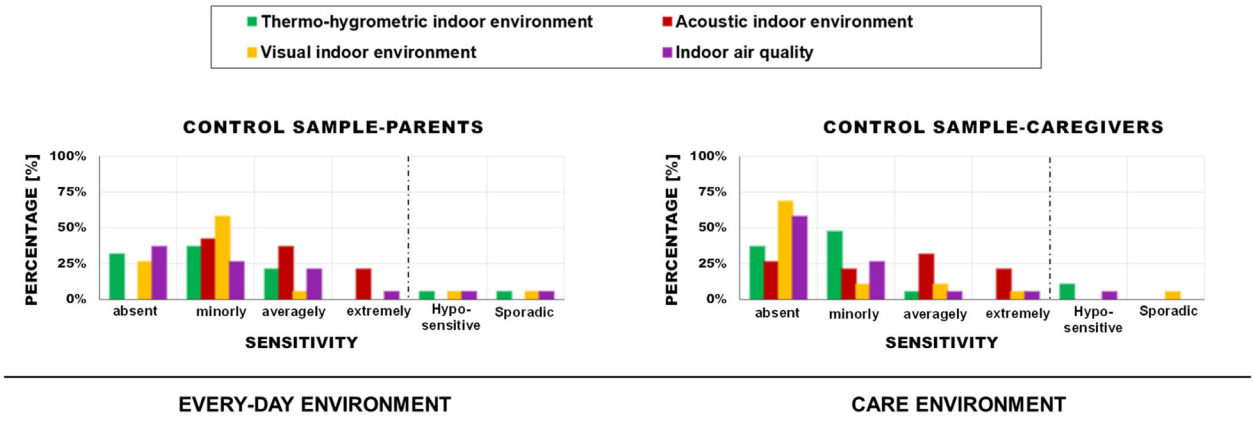

Fig. 2. Sensitivity of the respondents to the four environmental factors — control sample, with caregivers' and parents' answers differentiated.

to this field is higher (25% by caregivers vs. 0% by parents). Even though some sound absorbing panels are present in order to reduce reverberation in the rooms, they still do not prevent acoustics from being the most stressful comfort domain for individuals on the spectrum.

3. In terms of the visual indoor environment and indoor air quality, the results show a major sensitivity to visual environment in the everyday life environment (households), in the range of "minor" sensitivity (60% by parents vs. 10% by caregivers). These differences are due to the design of the extended care unit, specifically designed to be utilized by people with ASD, such as the presence of mechanical ventilation, proper illumination, lamps and light colors, or proper daylight exploitation (e.g., rooms with large windows areas and a proper view to the outside). This is in contrast with normal conditions in domestic environments.
4. The statistical analysis reported in the second column of Table 9 shows that, with the exception of visual environment, the differences between answers in the everyday life and care environments are not significant. Differences between the two groups are meaningful (points 1–3) and are most likely due to the different environments where the surveys were completed. Nevertheless, these differences are mainly in lower and similar levels of sensitivity. Since there are few major differences, the two groups do not seem to show different levels of reliability.

From the analysis of the *overall sample* (Fig. 3), it is possible to understand how, among all the fields, the acoustic indoor environment seems to be most impactful, showing the highest percentages of "averagely" (around 35% of the respondents) and "extremely" (around 25%) sensitivity. All other domains show a similar trend: the only exceptions are the thermo-hygrometric domain, which shows a slightly higher percentage of subjects being "minorly" sensitive (30% vs. 20%–25% of the other fields).

Fig. 4 reports the sensitivity of subjects in the *online* and *local survey* samples, with caregivers' and parents' answers further differentiated. As can be seen, four graphs are reported. On the left, the answers given by parents in everyday home environments, and, on the right, the answers given by caregivers in extended care units are reported. Similarly, the two graphs below represent the answers given in the *local survey* and the two above the answers given in the *online survey,* where, as previously explained, higher ages, levels of autism and number of co-morbidities were detected. The third and fourth columns of Table 9 report the results of the statistical tests evaluating the difference in parents' and caregivers' answers respectively for the *online* and *local survey*. Similarly, statistical differences between answers detected during the two surveys are reported in Table 10, differentiating between parents' and caregivers' answers.

Based on the trends reported in Fig. 4 and on the statistical analyses in tables, these findings can be highlighted:

1. The sensitivity trends in thermo-hygrometric, visual and IAQ environments decrease as the perception scale increases, with low response rates for "averagely and extremely".
2. On the other hand, the acoustic environment shows a different trend in the answers from both caregivers and parents, constituting a strong nuisance to users in both the control environment of care facilities and in everyday life.
3. The trends in the sensitivity of the respondents to the four environmental comfort domains are generally similar in the four graphs, showing a concordance in the perception, even though the conditions (respondents, environments etc.) were different.
4. Partially higher acoustic sensitivities were detected in the *online survey* (shift of the peak towards "averagely", with 35%–40% of the respondents in the *online survey* vs. 25% in the *local survey*), where higher ages and severity of autism were present. As confirmed by the statistical analysis in Table 10, this is particularly significant with caregivers' answers, which show that even in a controlled environment, acoustics seems to be a significant stressful stimulus.
5. Higher sensitivities were detected in the *online survey* also in the case of the visual environment, particularly in caregivers' answers (50% with "absent" reaction in the *online survey* vs. 75% in the *local*): this could be linked to general and physiological lowering of sight capabilities and appearance of visual defects with increasing age (older individuals were present in the *online survey*, see Section 3.1) and it is confirmed by the statistical analysis in Table 10.
6. Slightly higher sensitivities were rated by parents as regards thermo-hygrometric, visual and IAQ fields (lower percentages of "absent" indicated by parents, with a shift towards higher sensitivities): these answers were mainly given in households environments which may not be specifically designed for individuals with ASD.
7. The differences between parents and caregivers, highlighted in point 6, as well as the differences in acoustic sensitivities detected by the two types of respondents, were statistically significant only in the case of the *local survey* (see Table 9, third and fourth columns): in this case only one extended care unit, which was specifically designed for people on the spectrum, was considered.

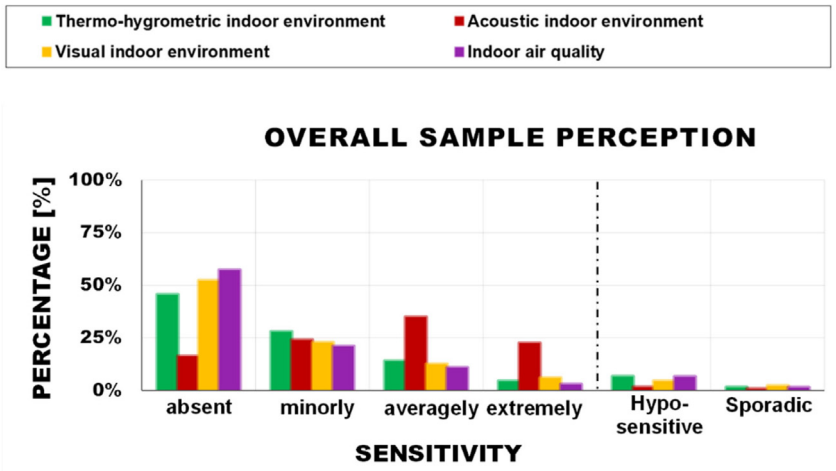

Fig. 3. Sensitivity of the respondents to the four environmental comfort domains — overall sample.

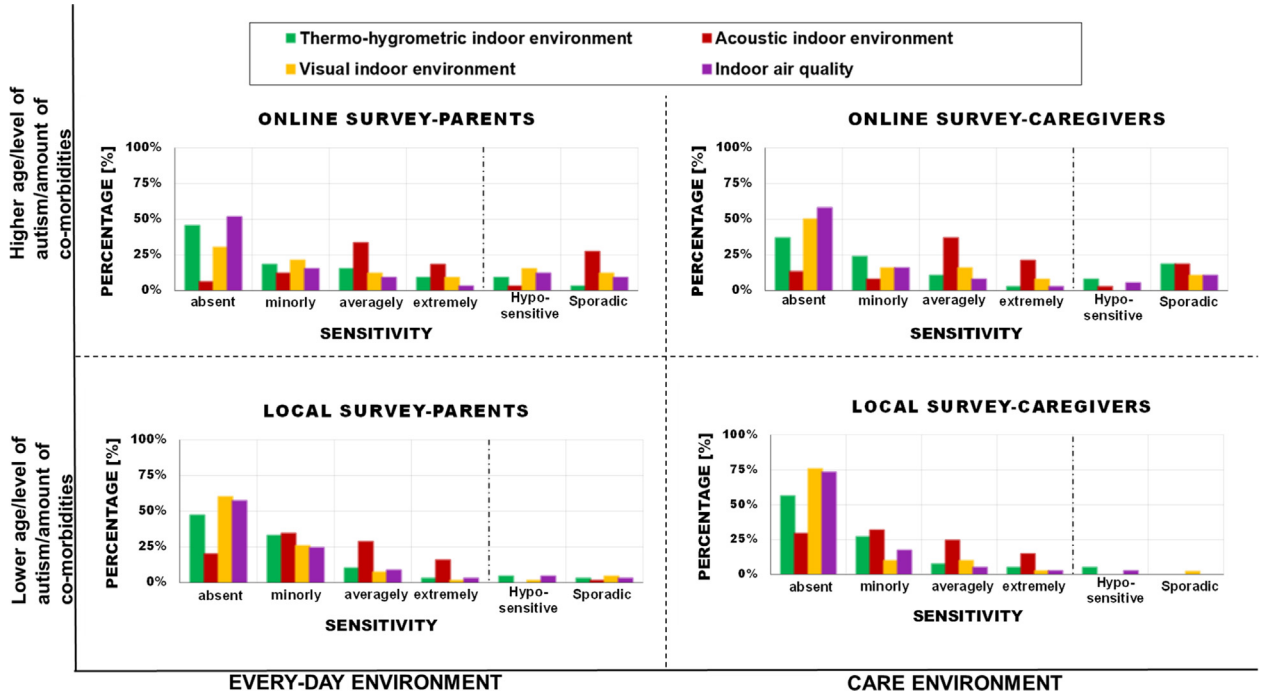

Fig. 4. Sensitivity of the respondents to the four environmental comfort domains — online and local survey, with caregivers' and parents' answers differentiated.

Table 8
Results of the Cronbach's alpha test on *online survey*, *local survey* on the *control* sample and on the *overall* sample.

	Parents	Caregivers	Aggregation of parents and caregivers
Online	0.90	0.95	0.93
Local	0.98	0.97	0.97
Control sample	0.85	0.88	0.88
Overall	0.97	0.99	0.97

Moreover, younger subjects were considered, with lower severity of autism and co-morbidities: in these conditions, the stress might be reduced more easily in a controlled environment. Conversely, with higher severity of autism, the benefits of having a well-designed environment could be less significant. This aspect is also highlighted by the statistically significant differences found in the answers of caregivers during the *online* and the *local survey* (Table 10).

3.4. Influence of gender, co-morbidities, severity of autism and age

No strong differences were found between males and females (Fig. 5), with the exception of a slightly higher sensitivity of the latter to the visual (10% "extremely" vs. 5% by males) and acoustic (25% "extremely" vs. 15% by males) environment. Moreover, a slightly higher "hypo-sensitivity" rate was found in female subjects as regards the thermo-hygrometric environment (20% – 25%

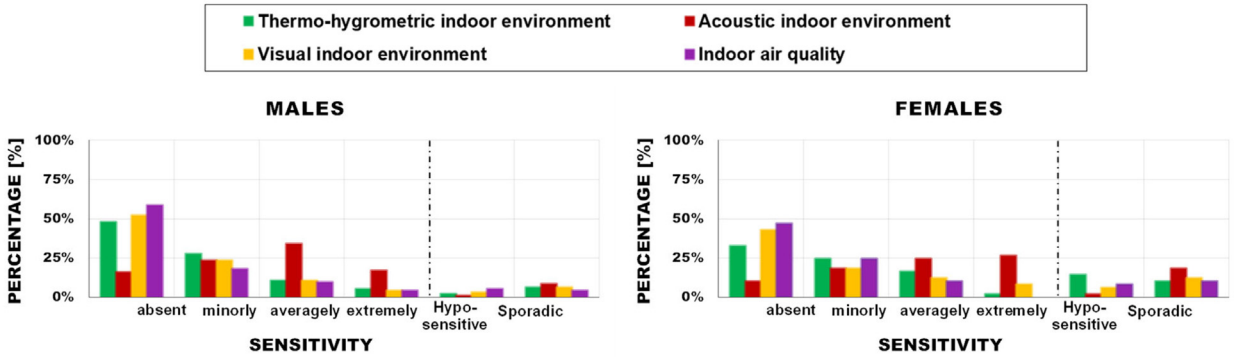

Fig. 5. Sensitivity of the respondents to the four environmental comfort domains — influence of gender of the subjects.

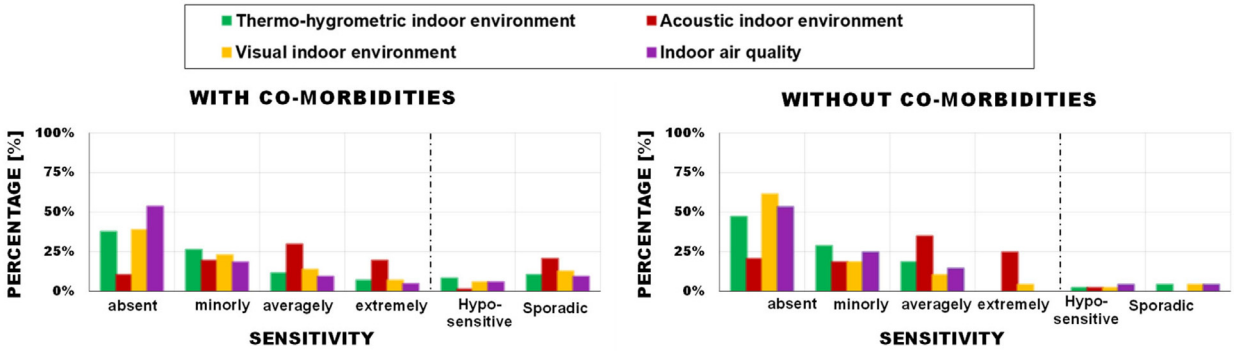

Fig. 6. Sensitivity of the respondents to the four environmental comfort domains — influence of the presence of co-morbidities.

Table 9
Results of the Mann–Whitney test to highlights the differences present in parents' and caregivers' answers.

	P-value		
	Control sample ($N_P = 19$; $N_C = 19$)	Online survey ($N_P = 32$; $N_C = 39$)	Local Survey ($N_P = 26$; $N_C = 41$)
Thermo-hygrometric	0.405	0.472	**0.062***
Acoustic	0.435	0.623	**0.055***
Visual	**0.098***	0.798	**0.015****
IAQ	0.203	0.982	**0.005****

* = 10% significance level; ** = 5% significance level. N_P = number of answers by parents; N_C = number of answers by caregivers.

vs. 5% by males). No significant differences were evidenced by statistical analyses (second column of Table 11).

Moreover, no high variations are related to the presence of co-morbidities (Fig. 6), with the exception of a slightly lower sensitivity to visual, thermo-hygrometric and acoustic environments of subjects without co-morbidities: the percentages with "absent" reaction increased of 25%, 10% and 10% with respect to what indicated about individuals with co-morbidities. Moreover, as expected, there are slightly higher percentages of "hypo-sensitivity" (5% – 10% more) and "sporadic" (10% – 25% more) sensitivities among individuals with co-morbidities. The dependence of visual sensitivity on co-morbidities was found to be statistically significant (third column of Table 11).

From the analysis in Fig. 7, it is possible to notice how the sensitivity to acoustic environment increases along with the severity of autism (25% with "absent" and 15% with "extreme" sensitivity with low severity subjects vs. 10% with "absent" and 25% with "extreme" at higher autism levels). This result is confirmed by the statistical analysis in Table 11 (fourth column): a strong connection between stress from the acoustic issue and the severity of autism was found. On the other hand, a slightly higher sensitivity to thermo-hygrometric environment seems to be present among individuals with a low severity (level - A) (20% with "averagely" vs. 5%–10% at higher autism levels): this might be due to the fact that most of these subjects were from the *local survey*, where higher sensitivity was found in households. Moreover, answers

Table 10
Results of the Mann–Whitney test to highlight the differences present in answers from *online* and *local survey*.

	P-value	
	Parents ($N_O = 32$; $N_L = 26$)	Caregivers ($N_O = 39$; $N_L = 41$)
Thermo-hygrometric	0.436	**0.076***
Acoustic	0.623	**0.005****
Visual	0.501	**0.009****
IAQ	0.156	0.145

* = 10% significance level; ** = 5% significance level. N_O = number of answers from online survey; N_L = number of answers from local survey.

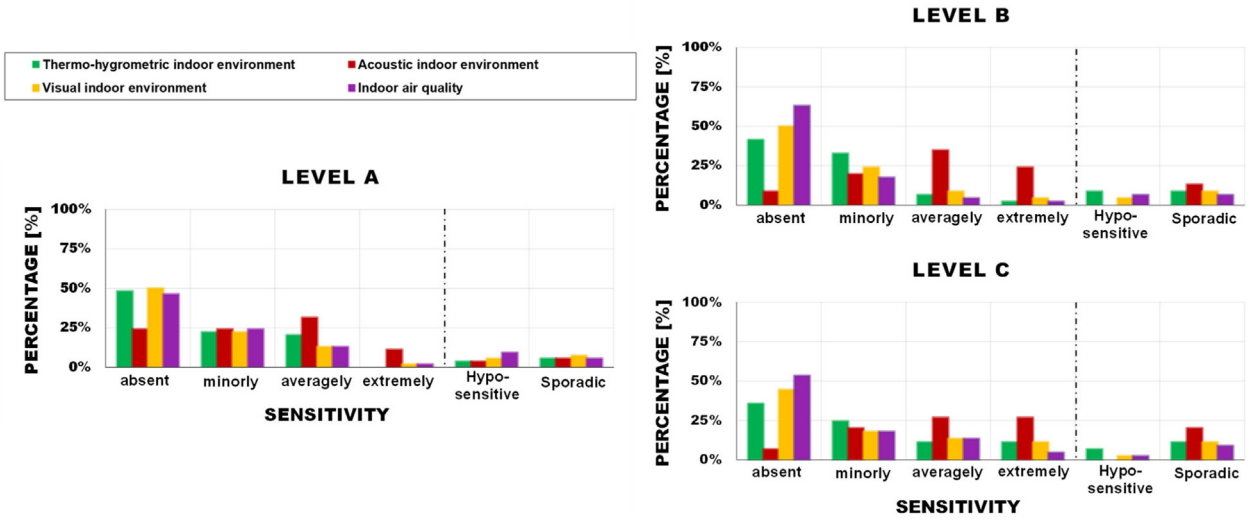

Fig. 7. Sensitivity of the respondents to the four environmental comfort domains — influence of the level of autism.

reporting sporadic sensitivity seem to increase slightly with the autism severity (10% – 15% with Level A — low severity, 15% – 25% with Level C — high severity).

From the age analysis (Fig. 8 and Table 12), the following findings can be highlighted:

1. Sensitivity to thermo-hygrometric environment increases with age: all the trends depicted in the graph are similar, with the exception of the ones regarding subjects older than 40 and older than 50, which show a peak of respondents declaring average sensitivity (40% among over 40 and 20% among over 50). This aspect is also highlighted by the Mann–Whitney test in Table 12, where a significant change of the sensitivity to the thermo-hygrometric environment was found after 30.
2. As regards the acoustic indoor environment, the dependence on age is less evident, since the "absent" and "minorly" rates seem to decrease slightly with age, shifting to higher sensitivities (the shift of the peak is less evident here). Moreover, a slight increase of "sporadic" answers seems to occur with increasing age. This might be due to the appearance of some cognitive disturbances in older subjects, altering and lowering their acoustic perception.
3. The absence of a substantial nuisance coming from the visual environment for almost all age groups, except the oldest, who perceive it more clearly as a source of stress (20% with extreme sensitivity are among over 50 subjects).
4. The presence of a low sensitivity to IAQ is observed, with a low average nuisance from all the age groups, with only a slight shift towards higher sensitivities at higher ages (the percentage with absent reaction decreases from 70% for under 10 to 40% for over 50).

4. Limitations of the present study

The aim of the study is to apply a methodology to study environmental stress factors in people unable to express their opinions directly in traditional comfort questionnaires or surveys. These traditional questionnaires and surveys aim at defining the environmental factors which mainly cause discomfort and not just the "neutrality" conditions. In this light, a limitation of the study is that surveys were conducted with people exposed to different environments with little if no information on individuals' characteristics. Another limitation was due to the difficulties in collecting questionnaire results in autistic people. In fact, the questionnaires were answered by proxy respondents (parents or professional caregivers) and this might have affected the results since biases and misunderstanding of behaviors and feelings are likely to be present depending on the respondent: this aspect introduces further ranges of uncertainties in the evaluations. A range of individuals – children to adults – with different autism severities and co-morbidities, were considered. For these reasons, statistical analyses were used to identify common trends between answers from different caregivers, or referring to individuals with different ages, levels of autism or co-morbidities. A further limitation is represented by the fact that a total sample of 138 individuals was used. The individuals involved lived or had their activities in specific contexts and without references (benchmarks) from the standard population. For this reason, the conclusions are intended to suggest an approach that may be useful to unravel analogies and differences between different health-contexts observed during different time-periods. However, even if the sample is not huge, this represents a first step in this research field. Further studies involving a higher number of autistic individuals are necessary in order to investigate in more depth the results of the present study, further differentiating the outcomes among all the possible wide range of subgroups constituting people on the autism spectrum.

5. Conclusions

A methodology to study global indoor environmental comfort related to people with ASD was applied in this research. Questionnaires were designed so that they could be completed by parents and caregivers. One *online survey*, involving different international stakeholders from different assistance associations and one *local survey*, involving a specific extended care unit were developed. The study led to the following main conclusions:

1. A relevant number of questionnaires was collected and the Cronbach's alpha test showed a high reliability for all the cases considered. When dealing with the same subjects, parents and caregivers did not show particularly statistically significant differences, confirming the reliability of the survey with both groups of respondents.
2. In all the cases considered, acoustic was the most stressful comfort domain, constituting a strong nuisance both in the extended care units and in households, in all the surveys considered. The other environmental issues, namely

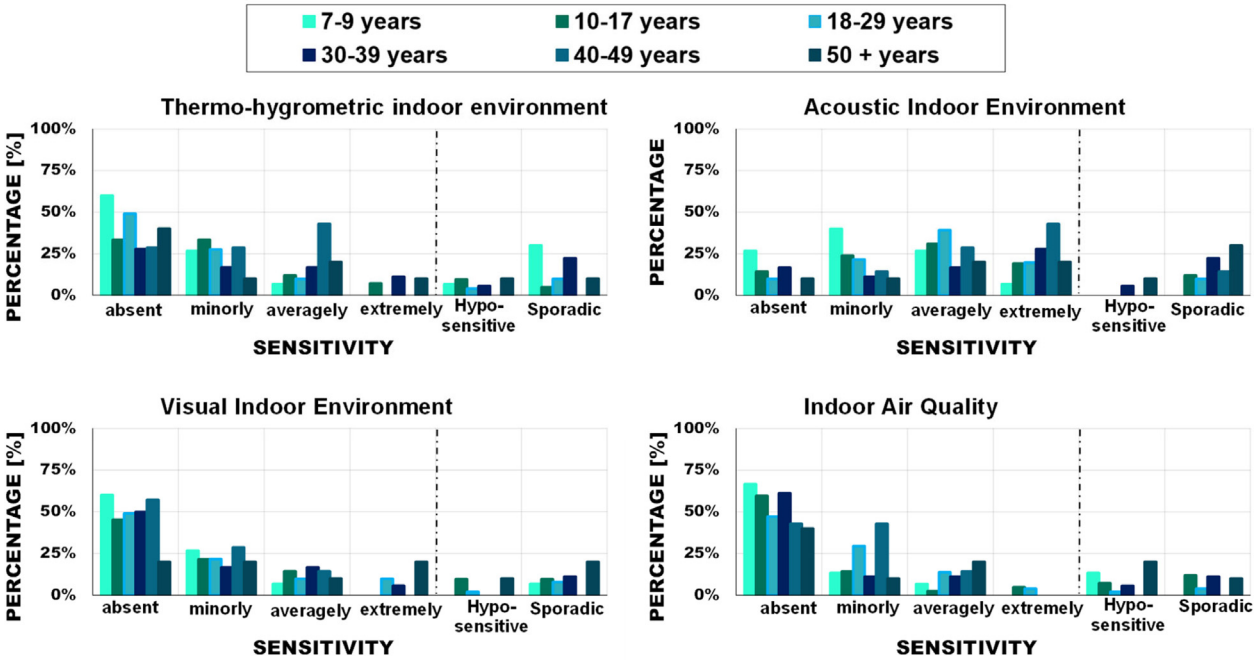

Fig. 8. Sensitivity of the respondents to the four environmental comfort domains — influence of age of the subjects.

Table 11
Results of the Mann–Whitney test to highlight dependence of answers on gender, presence of co-morbidities and severity of autism.

	P-value		
	Gender ($N_F = 42$; $N_M = 94$)	Co-morbidities ($N_{NC} = 53$; $N_C = 85$)	Level of autism ($N_A = 48$; $N_{B+C} = 90$)
Thermo-hygrometric	0.419	0.105	0.303
Acoustic	0.167	0.192	**0.001****
Visual	0.389	**0.005****	0.467
IAQ	0.740	0.567	0.631

* = 10% significance level; ** = 5% significance level. N_F = number of females; N_M = number of males; N_{NC} = number of answers regarding subjects without co-morbidities; N_C = number of answers regarding subjects with co-morbidities; N_A = number of answers regarding autistic individuals of severity A; N_{B+C} = number of answers regarding autistic individuals pf severity B or C.

Table 12
Results of the Mann–Whitney test to highlight dependence of answers on age. Only tests regarding robust samples (with enough individuals in the two groups) are reported.

	P-value		
	≥ 18 ($N_U = 59$; $N_O = 79$)	≥ 30 ($N_U = 107$; $N_O = 31$)	≥ 40 ($N_U = 124$; $N_O = 14$)
Thermo-hygrometric	0.683	**0.012****	0.168
Acoustic	0.102	0.270	0.461
Visual	0.191	0.179	0.215
IAQ	0.119	0.957	0.417

* = 10 % significance level; ** = 5 % significance level. N_U = number of answers regarding subjects under the considered threshold; N_O = number of answers regarding subjects over the considered threshold.

thermo-hygrometric, visual and IAQ were in general much less disturbing, with similar trends in all cases, with percentages of respondents decreasing as the sensitivity scale increases.

3. The sensitivity to acoustics seemed to depend on the severity of autism, being higher when the autism severity was higher.
4. Thermo-hygrometric, visual and IAQ sensitivities depended slightly on the environment where the answer was given, being slightly higher in households. This is related to these environments being less controlled and not specifically designed for autistic people. Thermo-hygrometric, visual and IAQ sensitivities increased slightly with age. A strong change of thermo-hygrometric perception was found after 30 years old. On the other hand, acoustic domain was less dependent on age, being of significant disturbance both in individuals under 18 and adults.
5. The differences in perception detected in living and care environments were more evident with lower ages, severity of autism and diagnosed co-morbidities, as well as when well-designed care units were present.

6. The number of hypo-sensitive or sporadic sensitive individuals was quite low in all cases, but increased slightly with age, severity of autism and number of co-morbidities.

An approach to study environmental stress was applied with neuroatypical individuals. The same approach might be used with other types of individuals with special needs who cannot be involved in direct surveys. The four comfort domains were found to have similar trends in the different cases (answers by parents and professional caregivers) considered, but some dependences on individual conditions (e.g., age or severity of autism) were found. Comfort domains where high sensitivities and stresses were found, potentially affect autistic individuals differently than neurotypical users. For this reason, further studies are necessary in order to identify the specific environmental stimuli which affect more the perception and sensitivity in this type of users, and therefore need particular attention in project-phase (see Part 2 of the present work Caniato et al., 2022). After that, studies will be necessary as regards these stimuli, in order to implement the definition of comfort ranges for developing standards in the design of environments for autistic users. For further detail on future perspectives, please refer to the second part of this research (Caniato et al., 2022).

CRediT authorship contribution statement

Marco Caniato: Conceptualization, Data curation, Data Interpretation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Luca Zaniboni:** Data Interpretation, Writing – original draft, Writing – review & editing. **Arianna Marzi:** Formal analysis, Data Interpretation; Writing – original draft, Writing – review & editing. **Andrea Gasparella:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.egyr.2022.01.009.

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