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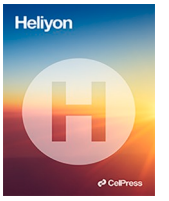

Research article

Awareness of everyday effects of climate change: The climate change perceptual awareness scale (CCPAS)

Enrico Cipriani [a], Angelo Gemignani [a,b], Danilo Menicucci [a,*]

[a] Department of Surgical, Medical and Molecular Pathology and Critical Care Medicine, University of Pisa, Pisa, Italy
[b] Clinical Psychology branch, Azienda Ospedaliero-Universitaria Pisana, Pisa, Italy

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ABSTRACT

Climate change is intrinsically complex and demands a certain degree of abstraction. However, different individuals report a wide range and degree of tangible and sensory experiences of climate change. As perceptual and sensory awareness of climate change has important consequences for the promotion of sustainable behaviors, pro-climate policies, and clinical interventions for climate-related disorders such as climate anxiety, new specific tools are required: herein we detail the development of a psychometric measure of perceptual awareness of climate change, as well as provide evidence for its discriminant, convergent, and predictive validity for sustainable behaviors. The administration of this scale on a representative sample of the UK population (Study 1) yielded a 4-factor structure, with items measuring perception of temperature changes and those measuring perception of humidity changes loading on separate factors, and two additional factors identifying the awareness of own feelings and perception of media attention on climate change. A second administration (Study 2) to an independent sample gathered from the Italian population supports the reliability of this factorial structure. As the rising field of climate neuroscience starts to investigate the determinants of perceptions of climate change, this novel scale will allow assessing the perceptual features affecting awareness of climate change.

1. Introduction

Climate change has frequently been construed as an issue requiring a certain degree of cognitive abstraction [1]: it is complex and interconnected; its physical manifestations are unevenly distributed across the globe, and their intensity ranges from relatively mild annual temperature changes to large-scale extreme weather events. These physical effects are concrete and tangible and influence the lives of millions of humans. However, individuals vary in their likelihood of attributing these effects to the overarching cause of climate change, and they also display differences in their ability to notice and be aware of these effects in the world around them [2–4]. These differences in perceiving are, in part, shaped by the complex interactions between top-down processes, such as the effects of pre-existing beliefs and cognitive biases on awareness [5,6], and bottom-up effects due to the peculiar intrinsic spatiotemporal features of the problem [1]. Individual differences in the functioning of perceptual psychophysiological systems might also contribute to shaping climate change awareness [7].

* Corresponding author. Department of Surgical, Medical and Molecular Pathology and Critical Care Medicine, University of Pisa, Pisa, 56126, Italy.
E-mail address: danilo.menicucci@unipi.it (D. Menicucci).

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The study of perceptual awareness and attention toward the effects of climate change only recently started to gain significant traction. In the past few years, theoretical models detailing the interconnection between physical perception of climate change, beliefs, and pro-environmental attitudes have been proposed and tested, such as Luo and Zhao's model of motivated attention [5]; and the nascent field of climate change neuroscience is starting to investigate climate change awareness with its methods [8–10].

Given the critical threat posed by climate change, there is an urgent demand for innovative lines of research – such as climate change neuroscience – which in turn require the development of new scales. Moreover, tools to measure climate change awareness might also help with clinical research on rapidly emerging psychopathologies due to climate change and its effects, such as Post-Traumatic Stress Disorder (PTSD) due to extreme weather events. While these pathologies share clinical features and neural substrates of other disorders of similar classification, they possess characteristics that are uniquely linked to climate change [11]. Studying the perceptual and sensory characteristics of climate change with the aid of psychometric tools might increase insight into the pathological processes that lay behind these disorders.

In the present paper, we will describe the development of a psychometric scale on climate change perceptual experience and awareness. In **Study 1** we will perform an initial validation through a survey administered to a representative sample of the UK population. In **Study 2**, we will test the dimensionality and factorial structure of our scale in an independent sample gathered from the Italian population.

"Perceptual awareness" is to be fundamentally distinguished from "Attitude" towards climate change. Perceptual awareness entails the subjective detection of a phenomenon or an effect and as a construct, it originates from the theoretical frameworks of psychophysics and psychophysiology [12]. Instead, "Attitude" is a qualitative evaluation of an object [13], and it stems from the theoretical framework of social psychology. While robust and well-designed scales of climate change attitude are already available in the literature, to our knowledge this is the first paper to detail the development of a perceptual awareness scale of climate change.

Perceptual awareness of a phenomenon is usually studied through behavioral tasks in highly controlled laboratory settings, which is unfeasible for a distributed global scale phenomenon such as climate change. The goal of our scale development process is to create a self-reported scale to attempt to measure this construct, and open future avenues in the study of climate change in the field of neuroscience [8].

Perceptual awareness of climate change is a multi-faceted construct, subjected to a multitude of influences [3,4]: First, there is the **perceptual awareness of the physical, sensible effects of climate change**: in everyday life, climate change might unfold in overt or subtle ways, and might adversely affect different targets: humans, other fauna, the flora, or environmental features. Because of this, individuals can experience these effects both *directly* on themselves or *indirectly* through the observation of other subjects, such as vegetation or elements of the landscape like waterways or the snow covering the mountains. A scale on climate change awareness thus needs to incorporate the perception of both direct (i.e. affecting the individual) and indirect effects [14].

It can be argued that most of these climate change-induced effects on the environment may be either too gradual or too complex to be detected with human senses. However, while an individual may not be consciously aware of the climate-related nature of some stimuli, still its brain might be able to process it. Humans are capable of a wide breadth of cognitive and perceptual processes entirely operating subconsciously [15,16]. One example is the elaboration of threatening stimuli, particularly those that are evolutionarily meaningful for adaptation and survival [7,17,18]. We might speculate that cues of environmental alterations, such as those arising from climate change, might constitute a subliminal environmental stimulus.

The second aspect of climate perception is the **awareness of one's own affective states relating to climate change** [19]. Awareness of *climate emotions* [20] is relevant both for clinical purposes – such as in the case of *climate anxiety* [21] – and in the promotion of sustainable behaviors [22]. For example: research shows that even practicing techniques that increase one's own awareness of affective states, such as mindfulness meditation [23], are associated with increased belief in climate change, and increased pro-environmental attitudes [24]. Moreover, individuals who feel connected to nature might enter an empathic relationship with it, interpreting perceived phenomena in nature as negative emotional states [25].

The third aspect concerns the **awareness of changes in media and public discourse:** Besides being an environmental phenomenon, climate change also possesses social connotations and collective expressions: its effects impact to a different degree entire populations across the world. Collective sentiments frequently emerge in the media environment in which an individual lives, such as in the form of news stories [26], which can also reciprocally influence the perception of climate change [27]. Even if an individual may not experience the effects of climate change due to living in a heavily urbanized context far from natural features, or not living in areas that have been subjected to extreme weather events, they might still notice changes in the news cycle and exposure, thus becoming aware of climate change through indirect means [2].

Most of the previously developed scales concentrate on attitudes, or factual, knowledge-based facets of climate change awareness, rather than its more subjective, perceptual aspects: Halady and Rao developed a questionnaire that did not address individual perception, but rather knowledge (as in awareness of facts) of climate change [28]. Valkengoed and colleagues developed a climate change perception scale that did not address the sensory aspects of climate change, but rather subjective interpretations, assessments, attributions, and beliefs towards the reality, the causes, the consequences, and the perceived temporal or spatial distance of climate change [29]. This instrument was developed with reference to the "Construal level theory" (CLT) of psychological distance [30]. Another questionnaire was again concerned with factual awareness of causes, effects, and mitigation actions towards climate change [31]. The "experience" subscale of Clayton and Karazsia's Climate Change Anxiety Scale is the instrument that sits the closest to our domain of investigation, however, it measures first-hand experiences with climate change effects, rather than sensory perceptions [32]. Considering these precedents, we aim to fill this gap by adding an instrument specifically addressing perceptual and sensory aspects.

Accordingly, we have built a scale investigating the aspects influencing climate change awareness, first evaluated by a panel of

experts to ensure construct validity, then submitted to a UK representative sample to determine the factor structure of the scale, and finally administered to an independent sample to replicate it.

2. Scale design

To properly design and validate our instrument, we followed the best practices, recommendations, and steps outlined in the paper by Boateng and colleagues [33]. By design, we expected our scale to possess specific properties.

1) We hypothesize a 3-latent factors structure corresponding to the three aspects of climate change awareness we described above (awareness of physical effects, awareness of affective states, and awareness of media changes).
2) We hypothesize that conservative individuals notice fewer climate change effects than other individuals. To test the discriminant validity of our measure, we predicted that there would be substantial differences in climate change awareness among different sides of the political spectrum, reflecting the current polarized attitudes towards this issue [34].
3) To check for convergent validity, we hypothesize that our measure displays moderate correlations with measures of climate anxiety, belief in climate change, pro-environmental behaviors, and general environmentalist attitudes. In addition, we will test whether items on awareness of affective states related to climate change correlate with individual habitual tendencies to observe and be aware of one's affective states.
4) We hypothesize that there is an association between climate anxiety and noticing climate change effects. Experiencing anxiety increases the perceptual salience toward threatening climate-related stimuli [35]. To verify predictive validity, we expect that experiencing greater symptoms of climate change anxiety predicts increased awareness of the effects of climate change.
5) We hypothesize that there is an association between noticing the effects of climate change and engagement in pro-environmental behaviors. As predicted by Luo and Zhao's model [5], increased attention and awareness towards climate change stimuli increases the intention to perform pro-climate behaviors. We hypothesize that a higher score in our instrument predicts a higher frequency of pro-environmental behaviors.

We designed our measure to include items pertaining to **perceptual awareness of the physical, sensible effects of climate change** (e.g. *"I have noticed an increase in the number of heat waves."*), **awareness of one's own affective states relating to climate change** (e.g. *I felt a sense of anger because of the changes that are happening in the environment.*), and **awareness of changes in media and public discourse:** (e.g. "*I have noticed an increase in the amount of news reports about floods.*"). For each item, participants must answer by reporting the frequency they experience the described phenomenon. For this, a 5-point Likert scale of frequency was used (1 = "Never"; 2 = "Rarely"; 3 = "Occasionally"; 4 = "Frequently"; 5 = "Very Frequently").

To avoid vagueness and increase objectivity, the questions refer to a specific time frame: the participants are asked explicitly to rate their perception relative to the past five years before the scale presentation.

To keep our instrument simple and parsimonious, we opted not to use reverse-coded items, since the benefits of their utilization have been called into question [36].

2.1. Item generation

The draft scale items were formulated by reviewing the current literature on the topic, combined with information gathered from mixed sources. First, from August to October 2022, we submitted a series of forum posts on online discussion platforms such as *reddit.com*, asking the public questions pertaining to the perceivable effects of climate change (e.g. *"What is a tangible but not obvious sign of climate change?"*). Later, from November 2022 to March 2023, we recorded a series of 9 informal interviews with geoscientists, members of the general population claiming to be particularly perceptive of climate change, and activists approached at public demonstrations.

This process resulted in a pool of 48 draft items, which were then submitted for evaluation by a panel of experts. These items were originally written in English by one of the authors (EC). The items were then independently reviewed by a native English speaker to ensure that the items were using proper grammar and that they employed a simple, unambiguous, and comprehensible language form.

2.2. Expert evaluation

To ensure the content validity of the draft items, we followed the procedure to compute a Content Validity index (CVI), as detailed by Lynn and colleagues [37]. We contacted 9 experts in geosciences and sustainability. The experts were required to evaluate the relevancy of each draft item to measure how much an individual claims to have noticed signs of climate change. The relevancy was measured on a 4-point scale ranging from "Not relevant", to "Very relevant".

The initial 4-point score was averaged between the experts, thus obtaining a mean measure of relevance for each item. Subsequently, to compute the CVI, we re-coded the ratings as a dichotomic "Relevant/not Relevant" scale (scores 1 and 2 as "Not relevant", and 3 and 4 as "Relevant"), and we computed the percentage of experts which rated each item as "Relevant"; thus, gaining a measure of expert agreement. According to guidelines, for the next phases, we only retained the items that passed a CVI cutoff of 0.78 [37]. We also added another, more stringent cutoff, retaining only the items that had a mean score of 3 or higher.

This procedure resulted in a 19-item scale which was then subjected to the next validation phases. The complete list of draft items, together with their mean ratings and CVIs are displayed in Table S3.

3. Study 1: initial validation

3.1. Methods

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. To perform a proper evaluation of the factor structure of our instrument and its associations with other existing scales, we aimed to submit our instrument to a recommended sample size of at least 300 individuals [33,38].

Participants were recruited online through the Prolific® crowdsourcing platform [39]. To increase the validity of our instrument, we requested a representative sample of the United Kingdom population, aged 18 years and over. The survey was administered through the Microsoft Forms online platform, and each participant was compensated an average of 1.4 £ for their time.

At the start of the survey, participants were briefed on the study protocol and were asked to provide their informed consent to the participation and for the data handling. If the subjects did not consent, the form would be immediately and automatically interrupted. At the end of the survey, the participants were debriefed about the purposes of the study.

The online survey was launched on Friday June 30, 2023, at 12:47 h GMT, and ran until 17:30 GMT of the same day.

3.1.1. Data quality checks

The survey included one "Captcha" (i.e., an image containing a code, designed to be readable only by humans and thus excluding bots and other automatic responders), and 5 attention check items interspersed throughout the form. The attention checks were presented as scale items prompting the individual to click a specific answer (e.g. "Please, select 'Never' for this question").

We excluded from analysis all the subjects that did not enter the captcha correctly or failed more than 1 attention check.

Ethical statement

The survey study protocol and its contents were approved by the bioethical committee of the University of Pisa on May 26, 2023 (n.15/2023, p. 74188/2023).

3.1.2. Pre-registration

Our validation hypotheses and our study protocol were pre-registered on the OSF platform and are available for consultation at the following address: https://doi.org/10.17605/OSF.IO/4KDSC.

3.1.3. Materials

After gathering consent, the survey proceeded with a series of demographic questions asking the participants their age, gender identification, and ethnicity. The survey was composed of four scales, along with the Climate Change Perceptual Awareness Scale to be validated and several single-item questions.

3.1.3.1. Climate change perceptual awareness (CCPAS). We presented the participants with a 19-item form of our scale, extracted from the expert evaluation stage. As mentioned above, participants were asked to indicate, on a 5-point Likert scale, how frequently they noticed or felt the following effects of climate change (1 = "Never", 5 = "Very frequently"). Along with our instrument, the form was composed of the following psychometric scales and single-item measures.

3.1.3.2. Climate Change Anxiety Scale (CCAS). This scale, developed by Clayton and Karaszia [32], is currently the psychometric golden standard for the measurement of the construct of climate anxiety [21]. In its standard 13-item form, it is composed of two subscales measuring cognitive and functional impairment imputable to climate change anxiety, while the extended 22-item scale also adds two additional ones: direct climate change experience, and behavioral engagement towards climate change. Each item response is composed of a 5-point Likert scale ranging from "Never" to "Almost always".

The scale was introduced to test the convergent and predictive validity of our scale. We opted to employ the extended scale in our survey so that we could explore the relationship between our instrument and the climate change experience subscale of the CCAS.

3.1.3.3. Pro-environmental Behaviour scale (PEBS). The PEBS is a 19-item scale designed to measure individual sustainable and environmentally friendly behaviors [40]. It is composed of four subscales: conservation behavior, environmental citizenship, food, and transportation. The PEBS items employ mixed response types: 8 items are on a 5-point Likert scale (ranging from "Never" to "Always", 3 are on a 3-point scale ("Never/Occasionally/Always"), 6 are dichotomous "Yes/No" questions, one asks to indicate the temperature they usually wash their clothes in (Hot/Warm/Cold), and one asks the participant to estimate how many miles per gallon does their vehicle (if they use one habitually) consumes.

We included this scale to test the predictive validity of our instrument: in literature, perception of climate change has been found to predict pro-climate and pro-environmental behaviors and intentions [41]. Moreover, according to Luo & Zhao's "motivated attention" model of climate perception and action [5], noticing the effects of climate change is part of a feedback loop in which increases in attention paid to climate change predicts increases in climate change action, which in turn improves the awareness of climate change effects.

3.1.3.4. Multidimensional assessment of interoceptive awareness, version 2 (MAIA-2). This measurement scale is composed of 37 5-point

Likert scale items. It is designed to examine seven different dimensions of awareness of interoceptive stimuli [42]: these scales are labeled “Noticing” (awareness of body sensations), “Not distracting” (the tendency to not ignore bodily sensations), “Not-worrying” (tendency not to worry when a physical sensation arises), “Attention regulation” (the capacity to modulate attention to bodily sensations), “Emotional awareness” (awareness of one’s one affective states), “Self-regulation” (capacity to modulate distress towards bodily sensations), “Body listening” (active attention to body sensation as support for cognition), and “Trusting” (“experiencing the body and its sensations as trustworthy). This measure was added to our survey for future research purposes which go beyond the present validation paper, thus its results will be reported elsewhere.

3.1.3.5. Climate change belief, belief Certainty, belief in anthropogenic origin of climate change, political orientation (single items). We measured belief in the reality of climate change/global warming using a single question (Do you think global warming is happening?), with “Yes”, “No”, and “I don’t know” as possible answers. This question was followed by another examining how much the individual was sure of their answer (“If you answered "Yes" or "No" at the previous question, how sure are you of your position?“), with answers on a 4-point scale ranging from “Not at all sure” to “Extremely sure”.

We also introduced a question asking the participants to indicate how much they believe that climate change was human-caused (“Assuming global warming IS happening, how much of it do you believe is caused by human activities, natural changes in the environment, or a combination of both?“), with answers on a 7-point bipolar scale ranging from “I believe that global warming is caused mostly by natural changes in the environment”, to “I believe that global warming is caused mostly by human activities”.

Lastly, we measured political identification by asking participants to indicate their approximate political alignment on an 11-point bipolar scale ranging from “extremely left-wing” to “extremely right-wing”.

3.1.4. Data analysis

The representativeness of the sample was determined by testing for differences with the UK census data [43], using Fisher’s exact test with 10000 iterations of p-value estimation.

Factor structure was examined by performing an Exploratory Factor Analysis (EFA) using the “MinRes” (minimum residual) estimator, and “oblimin” factor rotation. The number of factors to retain was determined priorly using parallel analysis [44]. We opted to drop the scale items which obtained significant cross-loadings between the factors (loadings $\geq$0.32 over two factors or more), or which failed to reach at least a communality value of 0.40 [45]. The EFA was repeated for the reduced scale until a satisfying factor structure was reached.

We computed reliability estimates (Cronbach’s α) for all the scales and subscales, as well as a comprehensive correlation matrix using Spearman’s ρ. Confirmatory Factor Analysis (CFA) using WLSMV estimator and Satorra-Bentler correction was used to test dimensional invariance between males and females [46].

We assessed convergent validity by computing and evaluating the matrix of correlations between scale scores, and by performing a regression with our scale as a dependent variable, and the “Experience” subscale of CCAS as independent.

We also assessed predictive validity by performing linear regression models using CCPAS scores as independent variables, with PEBS scores as dependent. We also tested predictive validity in the opposite direction by computing another regression model, this time with CCAS “Cognitive Impairment” and “Functional Impairment” scales as independent variables, and CCPAS scores as dependent. We chose to test these linear relationships to replicate the models previously established by Sussman and colleagues [35] and Luo and Zhao [5].

Finally, we assessed discriminatory validity by considering differences in CCPAS scores between “left-wing” and “right-wing” individuals (“Left-wing” $\leq$ 1 SDs from the mean on the political identification scale; “Right-wing” $\geq$ 1 SDs from the mean), these differences were tested using Mann-Whitney U. These populations were chosen to be compared because of the relationship, well-established in literature, between political identification and perception of climate change [34,47].

All data handling and statistical analyses were performed in R (ver. 4.2.0) running in RStudio. EFA, parallel analysis, and reliability estimates were computed using the “psych” (ver. 2.3.6) package [48]. While CFA for dimensional invariance was performed using the “lavaan” (ver 0.6–15) package [49].

3.2. Results

3.2.1. Survey results

In total, 349 individuals participated in the survey. Of these, 17 were excluded (n = 1 did not consent to the study; n = 14 entered the wrong captcha; n = 2 failed more than one attention check), thus retaining a final sample size of n = 332 participants (attrition rate: 4 %). This sample is larger than our predetermined target of 300 participants, and it is considered an appropriate size to perform an Exploratory Factor Analysis [33,38].

Fisher’s Exact test with p-value estimation (100000 iterations), shows that our sample characteristics are representative of the UK population for sex ($p = 0.955$) and age ($p = 0.774$), but not for 5-category ethnicity ($p = 0.002$**). This might be due to the low number of individuals in our sample belonging to some categories. However, if we collapse ethnicity into two broad groups (“White” and “Other Ethnicity”), the sample appears to retain a level of representativeness ($p = 0.593$).

The median time spent by participants on the survey was 11 min. The demographic characteristics of the sample, along with a comparison with the UK census [43], are displayed in Table 1.

3.2.2. Factor analysis results

Performing Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity on our final survey sample suggested that it was adequate to perform a factor analysis ($MSA_{KMO} = 0.93$; Bartlett = 103.77, $p \leq 0.001$). Parallel analysis with 1000 iterations and scree plot inspection, suggested that the appropriate number of latent factors to retain was 4 (Fig. 1).

Table 2 displays the EFA results of the 19-item scale. We opted to drop four items due to underloading or cross-loading, thus retaining a 15-item scale. Three of the items had two-factor loadings of 0.32 or more [45], while one item failed to reach a communality value of at least 0.40. After discarding these items, we performed the parallel analysis and EFA again on the reduced scale, reaching a satisfying factor structure. Fig. 2 displays a graph of the four factors, with their respective item loadings.

Based on the item loads, we decided to label the factors "Awareness of feelings" (e.g. *"I felt a sense of anger because of the changes that are happening in the environment."*; 40 % of variance explained), "Awareness of media changes" (e.g. *"I have noticed an increase in reports about forest fires."*; 20 % of variance explained), "Awareness of temperature changes" (e.g. *"I have noticed an increase in the number of heat waves."*; 18 % of variance explained), and "Awareness of water scarcity/drought" (e.g. *"I have noticed an increase in the number of dry plants"*; 21 % of variance explained).

3.2.3. Internal reliability

Internal reliability estimates for the scales derived from EFA ranged from "good" (α $CCPAS_{Temperatures} = 0.81$) to "excellent" ($\alpha$ $CCPAS_{Feelings} = 0.94$) [50,51]. α values for the scores related to the other scales used in the survey are displayed on the diagonal of the correlation matrix in Table 3.

3.2.4. Dimensional invariance

Performing a Shapiro-Wilk test for normality assumptions on our total scale score shows that the data violate the assumptions of normality ($W = 0.983$, p-value ≤ 0.001***), thus we decided to test dimensional invariance between Males and Females by performing a Confirmatory Factor Analysis with WLSMV estimator and Satorra-Bentler correction [46]. The results show that the model possesses a good fit in both groups (Omnibus: scaled $\chi 2$ (168) = 457.822; Correction factor = 0.191; $p \leq 0.001$***; Robust CFI = 0.993; Robust TLI = 0.991; Robust RMSEA = 0.046; 90 % CI [0.038, 0.053]; SRMR = 0.050).

3.2.5. Validity assessment

Table 3 displays the correlation matrix between the scales and subscales used in our survey.

3.2.5.1. Convergent validity. Our instrument shows significant low-to-moderate correlations (ρ range: 0.20–0.40) with all CCAS scores and total PEBS scores [52], as well as with the single questions about belief in climate change, and belief in the anthropogenic origin of climate change, suggesting good convergent validity with these measures.

Testing for convergent validity by computing a multiple regression model of the climate change experience of the CCAS scale, using the CCPAS subscales as predictors, shows that the personal experience with climate change is significantly predicted by the "Awareness of feelings" and "Temperature" Subscales ($b_{Feelings} = 0.185$; $p_{Feelings} < 0.001$***; $b_{Water} = 0.105$; $p_{Water} = 0.150$; $b_{Temperatures} = 0.161$; $p_{Temperatures} = 0.046$*; $b_{Media} = 0.238$; $p_{Media} = 0.758$; $R^2 = 0.313$).

3.2.5.2. Predictive validity. Testing predictive validity by performing a linear multiple regression model, awareness of feelings appears to be the best predictor of PEBS score ($b_{Feelings} = 0.596$; $p_{Feelings} < 0.001$***; $b_{Water} = 0.289$; $p_{Water} = 0.268$; $b_{Temperatures} = -0.383$; $p_{Temperatures} = 0.186$; $b_{Media} = -0.293$; $p_{Media} = 0.292$; $R^2 = 0.162$).

Performing a multiple regression model using the two climate anxiety subscales of CCAS as predictors ("Cognitive impairment" and "Functional impairment") and the CCPAS subscales as the dependent variables, shows that the Cognitive impairment aspect of climate anxiety is a significant predictor of all CCPAS subscales ($CCPAS_{Feelings}$: $b_{CogImp} = 0.719$; $p_{CogImp} < 0.001$***; $b_{FunImp} = -0.037$; p_{FunImp}

Table 1
Summary of demographic statistics of our sample and comparison with 2021 UK census data.

Variable		Study Sample	UK Census
Numerosity (n)		332	47205385
Percentage (%) of females		51.27 %	51.04 %
Age (mean, SD)		45.92 (15.4)	
	18–27	16.88 %	15.36 %
	28–37	16.88 %	17.30 %
	38–47	17.83 %	15.94 %
	48–57	16.24 %	17.33 %
	58–150	32.17 %	34.06 %
Ethnicity			
	Asian	6.37 %	9.25 %
	Black	2.87 %	4.04 %
	Mixed	2.87 %	0.78 %
	Other	2.87 %	2.11 %
	White	85.03 %	83.81 %

UK: United Kingdom; SD: Standard deviation.

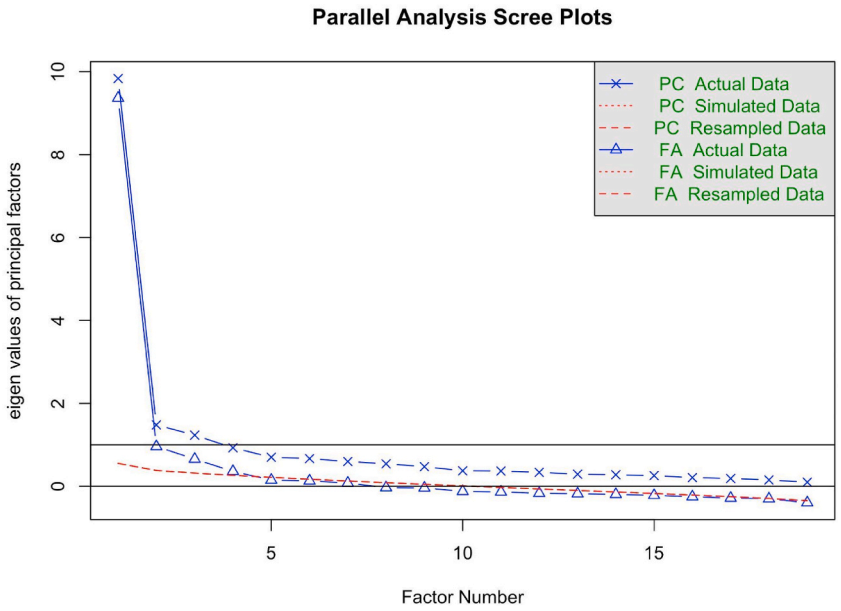

Fig. 1. Parallel analysis scree plot (1000 iterations).
FA: factor analysis.

Table 2
Exploratory Factor Analysis (EFA) results with factor loadings for each item. EFA 2 was performed on the reduced 15-item scale. Item loadings ≥0.40 are highlighted in bold.

No.	Text	mean	SD	EFA 1 (Factor loadings)				EFA 2 (Factor loadings)			
				Fac. 1	*Fac. 2*	*Fac. 3*	*Fac. 4*	*Fac. 1*	*Fac. 2*	*Fac. 3*	*Fac. 4*
1	*"I have noticed a more frequent drying up of streams and other bodies of water."*	2.96	1.04	0.06	0.27	**0.50**	0.00	0.03	0.23	**0.45**	0.05
2	*"I have noticed an increase in reports about forest fires."*	3.83	0.88	0.17	**0.44**	−0.01	0.26	0.19	**0.42**	−0.10	0.32
3	*"I have noticed a reduction of glaciers on mountains."*[a]	2.72	1.20	0.16	0.31	0.39	−0.11	–	–	–	–
4	*"I have noticed a decrease in the number of snowfalls."*[a]	3.10	1.21	−0.02	0.02	0.36	0.35	–	–	–	–
5	*"I have noticed an increase in the number of dry plants."*	3.25	1.18	0.05	0.04	**0.59**	0.27	−0.03	0.02	**0.73**	0.15
6	*"I felt like nature was suffering more and more."*	3.68	1.14	**0.48**	0.00	0.19	0.30	**0.44**	−0.01	0.23	0.29
7	*"I have noticed an increase in the number of heat waves."*	3.92	1.02	0.25	0.10	−0.07	**0.59**	0.23	0.09	−0.04	**0.60**
8	*"I have noticed changes in temperatures in the Winter."*	3.53	1.04	−0.02	0.09	0.06	**0.72**	−0.03	0.03	0.11	**0.73**
9	*"I have noticed an increase in the amount of news reports about droughts."*	3.68	1.06	0.02	**0.71**	0.14	0.05	−0.01	**0.81**	0.07	0.02
10	*"I have noticed changes in temperature in the Autumn."*	3.23	1.04	−0.01	0.24	0.26	**0.46**	−0.03	0.20	0.31	**0.40**
11	*"I felt like the trees and the plants were suffering more and more."*[a]	3.35	1.13	**0.44**	−0.02	0.36	0.25	–	–	–	–
12	*"I felt like animals were suffering more and more."*	3.24	1.14	**0.55**	−0.03	0.23	0.18	**0.50**	−0.04	0.27	0.17
13	*"I felt a sense of anger because of the changes that are happening in the environment."*	3.15	1.21	**0.93**	0.01	0.05	−0.05	**0.91**	0.00	0.05	−0.03
14	*"I felt a sense of frustration due to the changes that are happening in the environment."*	3.39	1.24	**0.95**	−0.02	−0.08	0.05	**0.94**	−0.03	−0.06	0.05
15	*"I have noticed an increase in the amount of news about climate change."*[b]	4.05	0.92	0.06	**0.62**	−0.21	0.08	–	–	–	–
16	*"I have experienced a feeling of failure due to the changes that are happening in the environment."*	2.77	1.19	**0.72**	0.10	0.16	−0.09	**0.71**	0.10	0.13	−0.06
17	*"I felt a sense of annoyance due to the changes that are happening in the environment."*	3.31	1.17	**0.86**	0.07	−0.08	0.02	**0.85**	0.06	−0.02	0.00
18	*"I have noticed an increase in the amount of news reports about floods."*	3.73	1.01	−0.02	**0.86**	0.01	−0.01	0.01	**0.82**	−0.01	−0.02
19	*"I have noticed an increase in leaf yellowing on plants."*	2.68	1.15	0.24	0.10	**0.57**	0.06	0.15	0.07	**0.75**	−0.06

EFA: Exploratory Factor Analysis. Fac: Factor; SD: standard deviation.
[a] Item dropped due to cross loadings.
[b] Item dropped due to low communality (0.39).

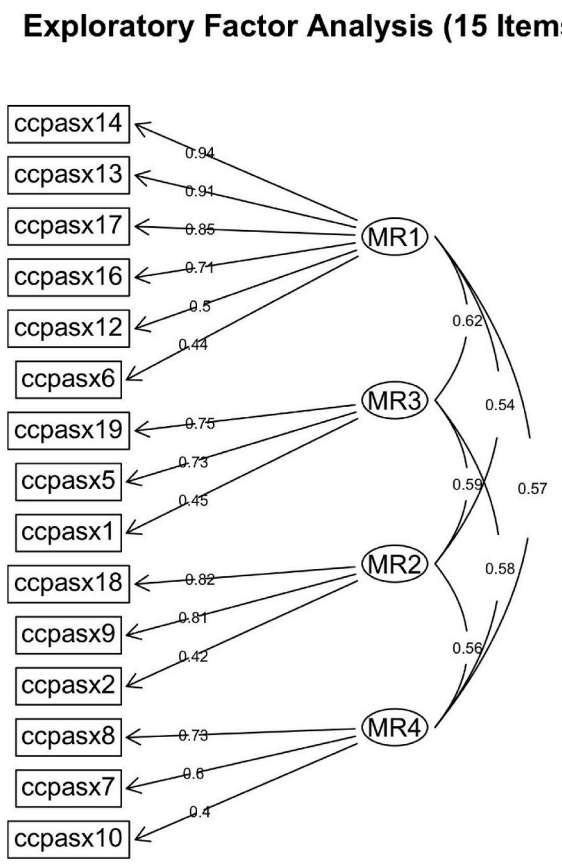

Fig. 2. EFA Loadings and between-factor correlations for the final 15-item scale. Each ellipsis labeled with "MR" (Minimum Residuals) represents a factor, and each rectangle represents an item. Each arrow represents factor-item loadings. MR1: "Awareness of feelings"; MR2: "Awareness of media changes"; MR3: "Awareness of water scarcity/drought"; MR4: "Awareness of temperature changes".

$= 0.847$; $R^2 = 0.246$; $CCPAS_{Water}$: $b_{CogImp} = 0.213$; $p_{CogImp} < 0.001$***; $b_{FunImp} = 0.131$; $p_{FunImp} = 0.168$; $R^2 = 0.180$; $CCPAS_{Temperatures}$: $b_{CogImp} = 0.167$; $p_{CogImp} = 0.002$**; $b_{FunImp} = 0.091$ $p_{FunImp} = 0.309$; $R^2 = 0.124$; $CCPAS_{Media}$: $b_{CogImp} = 0.121$; $p_{CogImp} = 0.024$*; $b_{FunImp} = 0.099$; $p_{FunImp} = 0.257$; $R^2 = 0.087$).

3.2.5.3. Discriminant validity. Performing the Mann-Whitney *U* test for differences in total CCPAS scores between "Left-wing" ($n = 67$) and "Right-wing" ($n = 35$) individuals shows that our instrument score is significantly different in the two populations, with Left-wing individuals displaying significantly higher scores for the "Feelings" subscale ($m_{RightWing} = 15.89$; $m_{LeftWing} = 22$; $U = 591.5$; $p \leq 0.001$***), and for the "Temperature" subscale ($m_{RightWing} = 9.57$; $m_{LeftWing} = 11.31$; $U = 794$; $p \leq 0.007$**). This suggests that our scale can discriminate between the two groups.

4. Study 2: Replication in an independent sample

4.1. Methods

As for the previous study, we report how we determined our sample size, all data exclusions, all manipulations, and all measures employed in this cross-sectional study. To verify whether the factor structure of our scale remains consistent in different samples and socio-cultural contexts, we performed a second cross-sectional survey study recruiting a target sample of 300 individuals from the Italian population.

As for Study 1, participants were recruited online through the Prolific® crowdsourcing platform [39]. At the time of the survey launch, Prolific® did not allow for requesting the selection of a representative sample of the Italian population. However, we requested a quota sample of 50 % men and 50 % women to reduce bias. The survey was administered through the Google Forms online platform.

Similarly to Study 1, participants were briefed at the start of the survey, and were asked to provide their informed consent to the participation of the study, and for the data handling. The form would be immediately and automatically interrupted in case the participants withheld their consent. At the end of the survey, the participants were debriefed about the purposes of the study.

The online survey was launched on Monday April 08, 2024, at 14:42 h GMT, and ran until 17:31 GMT of the same day. Participants

Table 3
Matrix of correlation values (Spearman's Rho) between scale measures used in the survey, with means and standard deviations.

no.	Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	*CCPAS Feelings*	19.55	6.16	**0.94**																
2	*CCPAS Draughts/water scarcity*	8.89	2.90	0.67[c]	**0.82**															
3	*CCPAS Temperature changes*	11.25	2.52	0.65[c]	0.63[c]	**0.81**														
4	*CCPAS Media changes*	10.68	2.64	0.60[c]	0.58[c]	0.61[c]	**0.81**													
5	*Belief in CC*	0.84	0.48	0.41[c]	0.34[c]	0.30[c]	0.28[c]	–												
6	*Belief certainty*	3.36	0.80	0.41[c]	0.21[c]	0.35[c]	0.25[c]	0.39[c]	–											
7	*Belief in human causation*	5.55	1.81	0.42[c]	0.22[c]	0.29[c]	0.18[c]	0.49[c]	0.57[c]	–										
8	*Political identification*	4.22	1.98	−0.22[c]	−0.08	−0.12[a]	−0.07	−0.2[c]	−0.28[c]	−0.25[c]	–									
9	*CCAS Cognitive impairment*	11.49	4.41	0.59[c]	0.49[c]	0.40[c]	0.37[c]	0.3[c]	0.17[b]	0.23[c]	−0.15[b]	**0.91**								
10	*CCAS Functional impairment*	6.80	2.70	0.46[c]	0.42[c]	0.35[c]	0.35[c]	0.26[c]	0.18[c]	0.26[c]	−0.11[a]	0.66[c]	**0.85**							
11	*CCAS CC Experience*	6.28	3.06	0.56[c]	0.44[c]	0.46[c]	0.42[c]	0.34[c]	0.36[c]	0.37[c]	−0.14[a]	0.45[c]	0.49[c]	**0.89**						
12	*CCAS Behavioural engagement*	22.34	3.99	0.53[c]	0.41[c]	0.36[c]	0.42[c]	0.28[c]	0.26[c]	0.3[c]	−0.09	0.38[c]	0.42[c]	0.48[c]	**0.76**					
13	*PEBS Total score*	44.45	5.68	0.42[c]	0.33[c]	0.26[c]	0.31[c]	0.18[b]	0.22[c]	0.25[c]	−0.18[a]	0.36[c]	0.37[c]	0.38[c]	0.44[c]	**0.72**				
14	*PEBS Conservation*	25.62	3.88	0.23[c]	0.23[c]	0.15[b]	0.18[b]	0.07	0.12[a]	0.1	0.01	0.20[c]	0.19[c]	0.23[c]	0.44[c]	0.55[c]	**0.70**			
15	*PEBS Env. Citizenship*	7.90	1.90	0.35[c]	0.32[c]	0.18[b]	0.34[c]	0.17[b]	0.19[c]	0.22[c]	−0.09	0.32[c]	0.36[c]	0.34[c]	0.41[c]	0.73[c]	0.26[c]	**0.61**		
16	*PEBS Food*	5.05	2.03	0.28[c]	0.19[c]	0.19[c]	0.15[b]	0.1	0.11[a]	0.16[b]	−0.22[c]	0.27[c]	0.25[c]	0.22[c]	0.20[c]	0.72[c]	0.17[b]	0.29[c]	**0.83**	
17	*PEBS Transportation*	5.88	1.39	0.14[b]	0.06	0.09	0.07	0.12[a]	0.21[c]	0.20[c]	−0.16[b]	0.10	0.08	0.13[a]	0.05	0.42[c]	0.12[a]	0.15[b]	0.14[a]	**0.38**

Cronbach Alpha indices of reliability are displayed in bold in the diagonal.
[a] p-value ≤0.05.
[b] p-value ≤0.01.
[c] p-value ≤0.001.

were compensated for their time with a 1.50£ payment on average.

4.1.1. Data quality checks

As for Study 1, five attention check items were inserted in the form. The attention checks were presented as scale items prompting the individual to click a specific answer (e.g. "Please, select 'Never' for this question").

4.1.2. Pre-registration

Unlike Study 1, this cross-sectional survey was not pre-registered.

4.1.3. Materials

In addition to the CCPAS scale to be validated three other scales were administered in this survey.

4.1.3.1. Climate change perceptual awareness scale (CCPAS). Participants were presented with the full 19-item version of our scale which was previously back-translated by the authors in the Italian language. The Italian version of the CCPAS scale is displayed in the Supplementary Materials (Table S2).

4.1.3.2. New Environmental Paradigm – revised (NEP-R). The NEP-R scale is a 15-item 5-point Likert scale designed to measure individual pro-environmental orientation [53], with responses ranging from 1 = "Strongly disagree", to 5 = "Strongly agree". It is a revised version of the original scale published by Dunlap and Liere [54]. The odd-numbered items reflect attitudes belonging to the New Environmental Paradigm, such as sustainability, stewardship, and conservation; while the reverse-coded even items represent statements congruent with an attitude of human domination over nature, and exploitation of resources. In this survey study, we employed the validated Italian version [55].

We opted to include this measure in our study to further test the convergent validity of our scale and specifically to test whether our scale does not overlap with the general orientation towards environmentalism.

4.1.3.3. Five facets of mindfulness questionnaire (FFMQ-15). This scale is composed of 15 items on a five-point Likert scale measuring five-dimensional facets relative to individual differences in mindfulness: *Observing, Describing, acting with awareness, Non-judging, and Non-reacting;* each measured by three items of the scale [56,57]. In our survey, we employed a validated Italian version of the questionnaire [58]. Item responses range from 1 = "*Never or very rarely true*", to 5 = "*Very often or always true*".

We included this questionnaire to test whether the "Feelings" subscale of CCPAS is associated with individual differences in the habitual capacity to observe and bring awareness to affective states.

4.1.3.4. Big five inventory - 10 item version (BFI-10). The BFI-10 is a brief personality questionnaire comprising 10 items on a 5-point Likert scale [59]. It is a brief version of the original 42-item scale by John and colleagues [60]. This questionnaire measures the 5 dimensions of the "five-factor model of personality": *Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism* [61]. In this survey, we administered the validated Italian version of this questionnaire [62].

This measure was added to our survey for future research purposes which go beyond the present validation paper, thus its results will be reported elsewhere.

4.1.4. Data-analysis

As for the previous study, we computed Cronbach's α for all the scales and subscales, as well as a comprehensive correlation matrix using Spearman's ρ. Confirmatory Factor Analysis (CFA) using WLSMV estimator and Satorra-Bentler correction was used to test the dimensional invariance of the scale [46].

Convergent validity was determined by evaluating the matrix of correlations between scale scores. All data handling and statistical analyses were performed in R (ver. 4.2.0) running in RStudio. EFA, parallel analysis, and reliability estimates were computed using the "psych" (ver. 2.3.6) package [48]. While CFA for dimensional invariance was performed using the "lavaan" (ver 0.6–15) package [49].

4.2. Results

4.2.1. Survey results

In total, 303 individuals participated in the survey. Of these, only 1 was excluded due to failing two attention checks, thus retaining a final sample size of n = 302 participants (attrition rate: 0.003 %). The sample was composed of 152 men (50.33 %), 142 women (47.02 %), and 8 individuals identifying as non-binary (2.65 %). The mean age of the sample was 32.82 years (SD = 10.56). The median time spent by participants on the survey was 09:48 min.

4.2.2. Internal reliability

Internal reliability estimates for the subscales remained in the range from "good" (α $CCPAS_{Media\ changes}$ = 0.78) to "excellent" (α $CCPAS_{Feelings}$ = 0.92) [50,51]. α values of the other scales used in the survey are displayed on the diagonal cells of the correlation matrix in Table 4.

4.2.3. Dimensional invariance

The Shapiro-Wilk test for normality on the CCPAS total scale score shows that the data violate the assumptions of normality ($W = 0.963$, p-value ≤ 0.001***). Thus, as for Study 1, we decided to test the dimensional invariance of our scale by performing a Confirmatory Factor Analysis with WLSMV estimator and Satorra-Bentler correction [46]. The results show that the model possesses a good fit for the Italian sample (Omnibus: scaled $\chi 2$ (105) = 1533,229; Correction factor = 4.151; $p \leq 0.001$***; Robust CFI = 0.990 Robust TLI = 0.987; Robust RMSEA = 0.049; 90 % CI [0.042, 0.057]; SRMR = 0.052).

4.2.4. Validity assessment

4.2.4.1. Convergent validity. All CCPAS scales displayed moderate correlation coefficients with the NEP scale, ranging from $\rho = 0.55$ for the correlation between NEP and $CCPAS_{Feelings}$, to $\rho = 0.33$ for the correlation with $CCPAS_{Draught/water\ scarcity}$ (all $p \leq 0.001$***). The $CCPAS_{Feelings}$ subscale shows a moderate correlation with the *"Observing"* ($\rho = 0.24$; $p \leq 0.01$**) facet of the FFMQ, and a weaker negative one with the *"Non-judging"* facet ($\rho = -0.16$; $p \leq 0.05$*).

5. General discussion

In this paper, we detailed the development and validation of a psychometric scale measuring perceptual awareness of the everyday effects of climate change. The scale shows good reliability and stability across different samples and populations, as evidenced by the two cross-sectional surveys performed.

Contrary to our initial hypothesis of a three-factor structure, the proposed CCPAS scale appears to include four distinct factors, since the perceived physical effects of climate change resulted in being split in two: one pertaining to effects of changing temperatures, and the other pertaining to droughts/water scarcity. This unexpected result does not undermine our original premises; instead, it might suggest that different people perceive signs of changes in temperature or humidity over time with different intensities, or that the perceptions of these kinds of stimuli are underpinned by two segregated sensory modalities. Most non-human animals are capable of detecting changes and cues that might suggest an incoming period of decreased resources for survival. When these changes are detected, these animals enact behaviors to increase their fitness, such as migration or hibernation [63,64]. It might be possible that humans also possess similar evolutionarily determined residual sensory abilities [7]. To provide an example: the molecule geosmin, which is produced by actinobacteria and cyanobacteria in the soil after being exposed to water, is responsible for petrichor (i.e. the characteristic smell of dirt after a rainfall). When inhaled, this compound can elicit positive affective states and physiological relaxation responses [65,66]. It can be speculated that this constitutes a kind of evolutionarily determined sensory cue related to drought cessation.

Our hypotheses relating to the discriminant validity and predictive validity of our instrument are substantially confirmed by our statistical analyses: participants self-identifying as left-wing possess significantly different scores in our scale than right-wing ones. This is in line with previous findings in the literature on the relationship between political polarization and climate change perception. Interestingly, when observing sub-scale level correlations, political self-identification is correlated with awareness of feelings and media awareness, but not with awareness of temperature changes or awareness of water scarcity. This finding might suggest that, while social and affective aspects of climate perception are particularly influenced by political leanings, sensory experiences are not. This phenomenon might constitute a worthwhile subject of future investigations.

The CCPAS total score is significantly predicted by the cognitive impairment and the climate change experience subscales of CCAS. One possible explanation for this selective effect of cognitive impairment might be that, as in other anxiety disorders, anxiety towards climate change increases attention and monitoring of climate change-related stimuli, subtracting important cognitive resources from the individual and interfering with normal functioning [35].

Our instrument predicts pro-environmental behaviors, as measured by the PEBS scale. This substantially confirms its predictive validity, as it is in line with Luo and Zhao's Motivated Attention model of climate perception and action [5]. This is further evidenced by the fact that only the "Awareness of feelings" subscale of our scale significantly predicts the PEBS total score; thus, this predictive effect might be driven specifically by motivational and affective aspects of climate awareness which might prime pro-environmental behavior.

One unexpected finding that we gathered on this topic is that all subscales of our instrument and PEBS subscales are correlated, except for the "transportation" subscale. This might be because, while participants might possess the intention to change their transportation behaviors, these remain the most difficult kind of pro-environmental behavior to implement in the general population, as evidenced by recent literature reviews [67].

Our scale shows good convergent validity with the "New Environmental Paradigm" scale, an established measure of general environmentalism. The moderate correlation coefficients suggest that the two measurement instruments do not overlap with each other, and thus CCPAS scores are not the mere product of a general environmentalist attitude, but of a self-reported perception. This positive correlation between NEP and CCPAS might be ascribable to top-down attentional effects and feedback loops related to motivated cognition, such as the one demonstrated by Luo and Zhao [5].

The moderate correlations with self-reported measures of mindfulness and emotional awareness support the idea that the $CCPAS_{Feeling}$ subscale measures actual awareness of climate-related emotional state, and it is coherent with previous research on mindfulness and sustainable behaviors [23,68,69].

Our study possesses some limitations: while we believe we successfully gathered evidence to confirm the reliability and validity of

Table 4
Matrix of correlation values (Spearman's Rho) between scale measures used in the survey. with means and standard deviations.

no.	Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10
1	*NEP (Total score)*	56.86	8.47	**0.84**									
2	*CCPAS Feelings*	20.72	6.61	0.55[c]	**0.92**								
3	*CCPAS Media changes*	11.5	2.75	0.41[c]	0.59[c]	**0.78**							
4	*CCPAS Temperature changes*	12.55	2.59	0.54[c]	0.64[c]	0.57[c]	**0.86**						
5	*CCPAS Draughts/water scarcity*	9.41	3.1	0.33[c]	0.6[c]	0.52[c]	0.51[c]	**0.76**					
6	*FFMQ Observing*	9.98	2.7	0.06	0.24[c]	0.11[a]	0.13[a]	0.17[b]	**0.69**				
7	*FFMQ Describing*	9.28	1.57	−0.03	0.05	0.04	0.01	0.06	0.28[c]	**0.87**			
8	*FFMQ Acting mindfully*	10.09	2.92	0.1	−0.04	0.01	−0.03	0	−0.01	0.11	**0.79**		
9	*FFMQ Non-judging*	9.88	3.2	0.04	−0.16[b]	−0.11	−0.08	−0.11[a]	−0.16[b]	0.04	0.47[c]	**0.8**	
10	*FFMQ Non-reacting*	8.91	2.53	−0.02	−0.01	−0.06	−0.03	−0.05	0.01	0.33[c]	0.09	0.16[b]	**0.75**

Cronbach Alpha indices of reliability are displayed in bold in the diagonal.
[a] p-value ≤0.05.
[b] p-value ≤0.01.
[c] p-value ≤0.001.

our scale, our studies are still limited by being cross-sectional surveys. Only experimental research in controlled settings or longitudinal studies can establish whether the CCPAS is capable of detecting changes in individual climate change perception over time. Additionally, although balanced for gender, we could not gather a representative sample for Study 2, thus limiting the generalizability of our findings for the Italian population. Overall, we believe that these limitations do not critically impact the quality of our studies and of the CCPAS measuring scale.

6. Conclusions and policy implications

In this paper, we detailed the development of the Climate Change Perceptual Awareness scale (CCPAS). We believe our measurement scale to be innovative for its focus on awareness of everyday effects, rather than attitudes or semantic knowledge of the phenomenon of climate change, and its potential to open new lines of research in a neuroscientific framework. Our scale shows good evidence of reliability and validity: its dimensional structure remains invariant when administered to independent samples gathered from two different countries, it is not redundant with existing climate change scales, and successfully replicates relationships previously established in the literature. Overall, we believe our scale to be suitable to be used for future research in the field of the neuroscience of climate change in English, and Italian-speaking populations.

Using the data collected from our studies, we can draw some policy implications: while the "Awareness of feelings" subscale of CCPAS is significantly correlated with political orientation, the other subscales either have a negligible correlation (in the case of "Temperatures") or have no correlation at all. Policymakers and communicators might leverage the awareness of these effects of climate change to bypass political polarization and promote pro-environmental behaviors by drawing attention to these everyday effects of climate change [5].

Additionally, the "Awareness of feelings" subscale is a significant predictor of pro-environmental behavior, as measured by the PEBS scale. We can speculate that interventions aimed at increasing awareness of one's feelings related to climate change, such as mindfulness-based interventions might also increase awareness of climate change and pro-environmental behaviors. Further research could explore the possible associations between affective awareness, perceptual awareness, and positive climate action.

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Data availability statement

Full survey anonymized dataset, CVI calculation dataset, demographics, and R codes are available upon request.

CRediT authorship contribution statement

Enrico Cipriani: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Angelo Gemignani:** Supervision, Project administration, Conceptualization. **Danilo Menicucci:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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 data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38461.

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