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Towards an understanding of the cognitive mechanisms involved in threat processing and perception

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Towards an understanding of the cognitive mechanisms involved in threat processing and perception

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Editorial: Towards an understanding of the cognitive mechanisms involved in threat processing and perception

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Editorial on the Research Topic
Towards an understanding of the cognitive mechanisms involved in threat processing and perception

Part I - General introduction and the importance of the Research Topic

Much remains unknown about the cognitive mechanisms and information-processing biases involved in threat detection, and the acquisition and maintenance of threat associations. To complicate matters, these mechanisms and biases are likely to vary for different types of threats (see, e.g., Coelho et al., 2023), such as those posed by animals, weapons, social situations, or groups. There has been a recent push to identify ways to improve the methods used in research in this area, which has also led to reevaluation of theoretical frameworks (March et al., 2022; Landová et al., 2023; Zsido et al., 2024). It is therefore important to continue to elucidate the cognitive mechanisms (e.g., perception, attention, memory, learning) underlying threat processing in order to develop a better understanding of how they affect individual and social outcomes (Gober et al., 2021).

Research on the cognitive mechanisms involved in threat processing and perception can shed light on how our brains respond to threatening stimuli and provide insights into the fundamental processes underlying fear and anxiety (c.f., Clauss et al., 2022). This knowledge is essential for the development of effective interventions for anxiety disorders and phobias. A better understanding of these mechanisms may also help identify individuals who are more susceptible to exaggerated threat responses, allowing for targeted early interventions. Additionally, findings from this research can inform the design of environments and technologies that minimize unnecessary threat cues and promote psychological wellbeing.

Therefore, the goal of our Research Topic was to collect research articles that present empirical data and describe novel theoretical perspectives that address the effects of threats on cognitive processes. We sought to include research on how threat processing uniquely affects perception, attention, memory, attitude and evaluation formation, fear (un)conditioning, decision-making, planning and execution of defensive behaviors, and social processes. Another goal was to elucidate the social/cognitive processes that may play an important role in the etiology and maintenance of specific fears and phobias. Our Research Topic has collected nine papers that explore or elucidate the processes and mechanisms affected by threatening stimuli, with the overall goal of contributing to the field's understanding of the emergence, maintenance, modification, and expression of threat associations.

Part II - Brief summary of the papers included in the topic

The first three studies (Apostolakis et al.; Ben-Baruch et al.; Xiao et al.) deepen our understanding of anxiety, fear perception, and the underlying cognitive processes involved therein. They highlight the importance of considering individual differences, cognitive strategies, and contextual factors in designing interventions and assessment tools for anxiety-related disorders.

Xiao et al. investigated the effects of reward-associative learning and traditional threat-avoidance training on anxiety and attentional bias. Their study focused on high trait anxious individuals and involved reward training or reward control training followed by Attention Bias Modification (ABM) training or control training. The results revealed that reward training reduced general anxiety and attentional bias. Interestingly, traditional ABM training only reduced anxiety when combined with reward training, suggesting a potential synergy between reward-based learning and traditional anxiety reduction techniques.

In Apostolakis et al.'s study, the researchers examined the psychometric properties of the abbreviated Social Phobia and Anxiety Inventory (SPAI-23) in Greek-Cypriot adolescents. They aimed to elucidate the dimensions of social fears in this population. Through exploratory factor analysis, they identified three social phobia factors and one agoraphobia factor, providing more nuanced insights into the assessment of social fears in adolescents. The findings contribute to refining assessment tools and understanding the multidimensional nature of social anxiety.

Ben-Baruch et al. explored the link between implicit and explicit emotion regulation and size estimation among women with arachnophobia. Their study delved into how emotion regulation strategies, such as reappraisal and suppression, influence perceptual biases in individuals afraid of spiders. While implicit emotion regulation did not directly impact size and valence ratings, the researchers found that greater use of reappraisal was associated with reduced negative feelings, whereas suppression was linked to increased size estimation of spider stimuli. These results shed light on the role of emotion regulation in modulating perceptual biases and offer potential avenues for the development of targeted treatments for specific phobias.

The subsequent four papers (Abado et al.; Kang and Osinsky; Peléšková et al.; Stolero et al.) collectively provide valuable insights into various aspects of human perception, attention, and emotional responses to threats, contributing to our understanding of human psychology in different contexts of danger.

Stolero et al. investigated differences and similarities in the perception of various risks (including extreme weather events, pandemics, and social disruption) between first responders and the public in several European countries. First responders tend to perceive higher risks for weather and natural events, while the public is more concerned about critical infrastructure dependencies and pandemics. The extent of these differences varies between countries, with Norway showing significant differences for all risks except extreme weather, while Sweden shows less variation. Understanding these differences is crucial to developing effective protective measures.

Kang and Osinsky studied attentional biases toward threatening faces in the context of social anxiety and explored methods to manipulate these biases. Using reward-based contingencies and neurophysiological measures, the researchers aimed to improve the efficacy and reliability of attentional bias modification (ABM) training. They found a general bias toward angry faces but observed variability in lateralization effects.

Abado et al. investigated the influence of a priori expectancies on the allocation of attention to phylogenetic (spiders) vs. ontogenetic (guns) threatening stimuli. Using a visual search array paradigm, the researchers manipulated expectancies and examined attentional biases toward these stimuli. Results indicate that while attentional bias was observed for spiders, it did not extend to ontogenetic threats such as guns. The results also replicated previous findings on attentional bias to spiders and revealed correlations between fear levels and attentional processes. The study highlights the role of expectancies and individual differences in shaping attention to different types of threat.

Similarly, Peléšková et al. investigated the evolutionary concepts of fear, disgust and anger responses to ancient and modern types of threat. The results suggest that modern threats elicit the strongest fear responses, while ancestral threats elicit the highest levels of disgust. Interestingly, modern threats such as toxic substances mainly evoke fear and anger rather than disgust. Pandemic threats evoke both fear and disgust responses. The study suggests that ancient threats are not necessarily more powerful stimuli than modern threats, but they are highly specific, with snakes and heights being particularly prominent fear factors.

Turning to snakes in the last two papers, Štolhoferová et al. investigated the fear response to snakes in individuals from Somaliland and the Czech Republic. They conducted experiments using a picture-sorting approach with 48 snake species, including venomous viperids and elapids. The results showed significant agreement between the Somali and Czech respondents, with vipers eliciting the highest levels of fear in both populations. Interestingly, fear scores for vipers were consistently higher than for deadly venomous elapids, and snake body width emerged as a significant predictor of fear. This suggests that evolutionary, cultural and cognitive factors contribute to the fear response to snakes.

Frynta et al. studied the effect of snake threat displays on spontaneous human attention. They conducted an eye-tracking experiment on populations in Somaliland and the Czech Republic to determine whether human attention is drawn to snakes in threatening postures. The results showed that participants in both regions showed increased attention to snakes in threatening postures compared to relaxed postures. The study also found a significant effect of snake morphotype, with cobras eliciting the most attention, followed by vipers, while other morphotypes showed less significant effects. Despite cultural and environmental differences, the overall pattern of responses to snakes was similar in both populations, supporting the evolutionary origin of the phenomenon.

Conclusion

Collectively, this set of articles represents an important step forward in our understanding of the cognitive processes underlying threat processing and perception. Much work is left to be done because this topic touches such a broad swath of cognition, from the everyday processing of threats that are encountered, to the clinical and social impacts of disorders including anxiety and phobias. Our hope is that this Research Topic will answer some unresolved questions, will stimulate new questions and theoretical outlooks, and will raise awareness of the need for more research in these areas.

Author contributions

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Reducing anxiety and attentional bias with reward association learning and attentional bias modification

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The current study examined the effects of a reward associative learning procedure and the traditional threat-avoidance ABM paradigm on anxiety and attentional bias. In reward training, participants were given high rewards for correct responses to neutral target and low rewards for correct responses to negative target. In reward control training, participants received no cues of rewards after their responses. High trait anxious individuals (*N*=76) first completed a session of reward training or reward control training, followed by four sessions of ABM training or ABM control training. Generalized anxiety disorder symptom (GAD-7) and attentional bias in a dot-probe task were assessed during pre-and post-training. Results indicated that the effect of ABM training on reducing anxiety was only obtained in the reward training condition. Participants who received reward training showed significantly less attentional bias compared with those receiving reward control training. There was no significant training effect of ABM on atttentiona bias. Results suggested that reward training reduced general anxiety and attentional bias. Traditional ABM training reduced anxiety only when combined with reward training. Attentional bias in anxiety are modifiable through reward training.

KEYWORDS

anxiety, attentional bias, attention bias modification, reward, reward association learning

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Introduction

Anxiety disorders are common mental-health problems that affect ~30% of the population within their lifetime (Hirschfeld, 2001; Bandelow and Michaelis, 2015). As anxiety disorders could be burdensome for sufferers and health services, there is need for developing treatment options that are effective, low-cost, and easily delivered. Attentional bias modification (ABM) is designed to train anxious individuals orient attention away from threat, but has variable effects on anxiety and threat-related attentional bias (Williams et al., 1997; MacLeod et al., 2002; Bar-Haim, 2010; MacLeod and Clarke, 2015; Mogg and Bradley, 2016). The mixed outcomes of ABM training encourage the development of alternative novel training methods and theoretical understanding of the cognitive process underlying anxiety and attentional bias. The current study aimed to directly evaluate and compare the efficacy of two attention-based treatments for anxiety in altering attentional bias for negative information for negative information, namely reward association learning and ABM.

Anxious individuals are characterized by a bias to selectively attend to threat cues in their environment (e.g., MacLeod et al., 1986; Beck and Clark, 1997; Mathews et al., 1997). Compared with non-anxious individuals, they are more prone to stimuli perceived as threatening (Bar-Haim et al., 2007). And such tendency are often characterized with the nature of automatic capture, and even prior to the processing of consciousness (Williams et al., 1996; Mathews et al., 1997; Mogg and Bradley, 1998). Attentional bias in anxious individuals could be due to a deficit in diverting attention from threat-related stimuli (e.g., Pacheco-Unguetti et al., 2011). For example, anxious participants show slower performance than the control group in visual search experiments in which they have to find neutral targets among threatening distractions (Gerdes et al., 2008). Anxious individuals also perform more slowly than the control group in dot-probe tasks in which the target follows the neutral stimulus rather than the threatening stimulus (e.g., Koster et al., 2006), and in spatial cuing trials in which a target appears on the opposite side of a computer screen from a preceding threatening stimulus (e.g., Cisler and Olatunji, 2010).

ABM threat-avoidance training is the most widely used method designed to direct anxious individuals' attention away from threat cues (MacLeod et al., 1986). In a typical visual-probe task, a threat and a non-threat cue simultaneously present in different locations of a computer screen, immediately followed by a probe (e.g., a dot) which replaces one of the cues. In ABM training, probes always appears in a different location just occupied by the threat cues. Hence, after hundreds of training participants implicitly learn to orient attention away from the location of threat. As anxiety-related AB operates automatically and unconsciously, ABM threat-avoidance training reduce this automatic attention-orienting to threat through implicit training procedures (i.e., training without awareness of what is being taught; Mogg and Bradley, 2018). Another less frequently used method is ABM-positive-search training, which explicitly requires participants to search for positive/non-threat target cues that are embedded among arrays of negative/threat cues (e.g., Dandeneau et al., 2007; Waters et al., 2013; De Voogd et al., 2014; Waters et al., 2016).

Early studies using ABM-threat-avoidance training as treatment for clinically anxious individuals were promising (e.g., Amir et al., 2009a). However, other replication studies and recent meta-analyses revealed that the clinical efficacy of ABM was questionable (for a review see Bar-Haim, 2010; Browning et al., 2010; Mogoaşe et al., 2014; Mogg et al., 2017). Whereas some studies continue to show that ABM reduces attentional bias and anxiety, others have found small effect sizes for changes in symptomology or non-significant effect in ABM and control conditions (Cristea et al., 2015; Heeren et al., 2015; Kuckertz and Amir, 2015; MacLeod and Clarke, 2015; Mogg et al., 2017; Fodor et al., 2020). The reasons of inconsistent results could be due to various study design, for example, different types of attention-training paradigms, different numbers of trials, and various stimuli types. Given the differences in methodology between these ABM studies, it is important to identify what features are necessary and sufficient for ABM to be efficacious.

Recent studies using reward association paradigm demonstrate some positive training effects in attentional bias. The reward association training task paradigm, proposed by Libera and Chelazzi (2006), is a visual search paradigm. In the training stage, participants receive different reward feedback, high reward or low reward after they respond correctly to the different type of stimuli. In the test phase, the participants are clearly told that the reward had been revoked, and even so the previous reward learning still has an impact on the participants' behaviors. Failing and Theeuwes (2014) provided further evidence for performance costs and benefits of involuntary attentional orienting toward previously reward associated stimuli in a spatial cueing task. In short, previously rewarded stimuli indeed captured attention in spite of concurrently presented stimuli that were equally often selected but not rewarded during the training session. This shows that reward-based selection history affects attention selection for considerably longer than the immediately following trial. Since reward delivery can directly alter the processing of specific stimuli by increasing their attentional priority, an intriguing question is whether these effects can be used to modify dysfunctional attention. The current study test this hypothesis by examining reward association training effect on anxiety and attentional bias.

Recent evidence suggests that reward modulates bottom-up and top-down attentional selection (see Chelazzi et al., 2013, for review). Reward-based contingency learned in a bottom-up search task is transferred to a subsequent top-down search task (Lee and Shomstein, 2014). Reward-based attention priority was originally reflective of bottom-up salience, and then top-down influences such as context and goal are also incorporated (Mazer and Gallant, 2003; Thompson and Bichot, 2005; Gottlieb, 2007). For example, participants responded slower when the interference stimuli was previously rewarded, which implies that previously rewarded distractors can effectively capture attention (e.g., Koenig et al., 2017). O'Brien and Raymond (2012) found that the recognition rate of faces with high reward was higher relative to faces trained with low reward, indicating that reward training could influence participants' priority of attention. To test this hypothesis, the current study used visual-search task for reward association training, which presented negative and neutral words arrays. Participants are required to search for the odd item among other similar distractors. A higher or lower reward is presented if the odd item is a neutral word or a negative word, respectively. Based on the phenomenon of value-driven attentional capture, it is hypothesized that differential reward learning during training could cause implicit change in automatic attentional bias during the test session.

Taken together, in the present study we investigated the influences of reward association training and ABM on anxiety and attentional bias. ABM studies typically do not compare different methods of ABM in the same study (e.g., Baert et al., 2010). The current study draw comparisons between the two attention-based training paradigms in order to understand the key component of training that may successfully reduce anxiety and attentional bias. For this study, participants were randomly assigned to one of four training conditions: reward + ABM, reward control + ABM, reward + ABM control, reward control + ABM control. All participants completed a dot-probe task at pre-training and post-training in order to evaluate change in attention. Anxiety level was measured by GAD-7 during the pre-and post-training. The following hypotheses were tested:

> *Hypothesis 1*: compared with reward control training, reward-base training enhancing the attention and vigilance to non-threatening stimuli will reduce anxiety and attentional bias.
> *Hypothesis 2*: compared with ABM control training, ABM training will reduce attentional interference from threatening stimuli leading to a reduction in anxiety and attentional bias.
> *Hypothesis 3*: compared with the participants receiving only reward training or ABM training, the anxiety level and attentional bias of the participants receiving combined reward and ABM training will decrease significantly more than those receiving separate training.

Materials and methods

Experimental design

This study used three factor mixed experimental design: reward association (reward vs. reward control) × ABM (ABM vs. ABM control) × time (pre-training vs. post-training), with reward association and ABM being the between-subject variables, and time being the within-subject variable. Analyses focused on the effects of training type and time on the dependent variables of anxiety score as measured by GAD scale and attentional bias as measured by probe-dot tasks.

Participants and procedure

1,032 university students from southern China filled out the Chinese version of GAD-7 questionnaire online (Sun et al., 2021) and 76 participants (36 females) were screened out with anxiety score over 10. The selected participants were invited to paricipate in the experiments and randomly assigned to one of the four groups: reward + ABM group, reward control + ABM, reward + ABM control, reward control + ABM control, fully counterbalanced. The experiment was explained to the participants before the pretest session began, and each participant completed an informed consent form. The four groups were not significantly different in terms of general anxiety symptoms, $F(3,71) = 0.97$, ns. Power was calculated using the GPOWER software (Faul et al., 2007). Presuming a moderate effect size (0.25) according to Cohen (1988), the power to detect a significant interaction effect among four groups and a time series of two repeated measurements at the 0.05 level of significance is 0.96. The parameter of correlation among repeated measures was 0.5 and the non-sphericity correction was 1.

Participants were asked to perform the tasks in a quiet, distraction-free environment in their own homes. The experiment was conducted through the Psycloud system, and subjects only needed to use their own computer to open the link provided by the experimenter and completed the tasks remotely. Upon entering the experiment, instructions were displayed on the screen to guide the subject through the experimental task. The study was divided into five phases: Screening of the subjects, pretest, reward (or reward control) training, ABM (or ABM control) training, and posttest (Figure 1). At the begining of the experiments, participants filled out the GAD-7 online. During the pretest, attentional function was tested using a dot-probe task. Following the pretest assessment, participants were randomly divided into two groups; one received a modified reward visual search task, and the other completed same task without reward feedback. Then each group were divided again into two group; one received a modified dot-probe ABM training task, and the other completed the sham ABM control task. Participants completed an ABM (or ABM control) training session every other day for 7 days. In total, they received 4 ABM (or ABM control) training sessions. After the training sessions, participants performed the regular dot-probe task during a posttest session to measure AB and completed the GAD-7 scale. At the end of the posttest session, participants received a comprehensive debriefing and compensation of $4–7.

Materials and tasks

We selected 180 words (90 negative, 90 neutral) from Chinese Affective Words System (Wang et al., 2008). All of the words were then evaluated by 18 Chinese students in terms of the valence and arousal degree. Based on the rating results, 68 neutral and 60 negative words were selected to be the experimental materials (Table 1). The word set was divided into two equal halves with different sets used for the test and training sessions to prevent practice effect.

Dot-probe task

The dot-probe task (MacLeod et al., 1986) was performed during the pre-training and post-training sessions. At the beginning of each trial, a fixation cross appeared at the center of the screen for 500 ms. Afterward, two words (800 × 600 dpi, 3 cm apart) were presented simultaneously to the right and left of the fixation cross for 1,500 ms. This relatively long presentation time was set to enable participants to process the meaning and emotional valence enough because attentional bias to negative verbal stimuli was found when stimuli were deeply processed enough (Wisco, 2009). Following these word cues, a target appeared either to the left or right of fixation at one of the two word locations. The target remained on the screen until a response

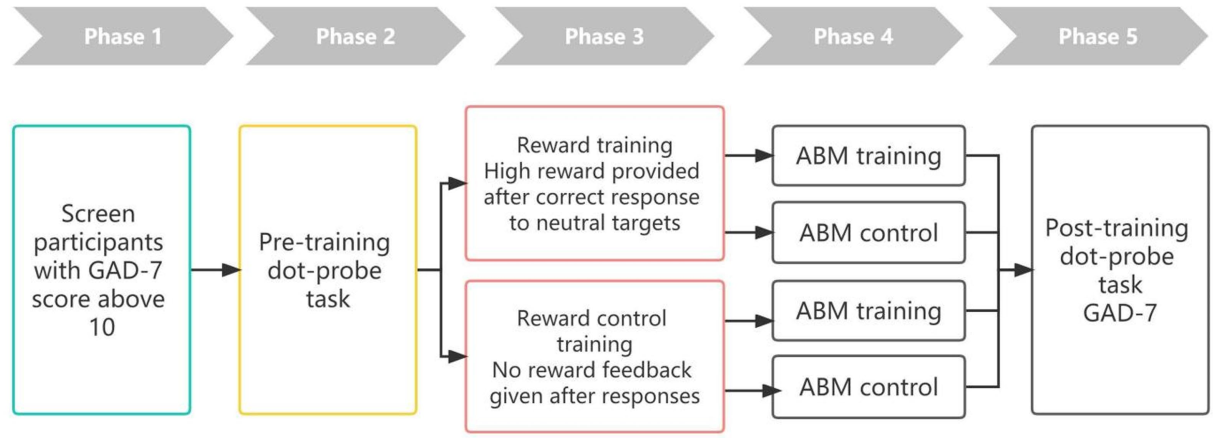

FIGURE 1
Flow of the experiment procedure.

TABLE 1 Mean and SD of valence and arousal ratings for all the words.

Dimension	**Neutral words (*n* = 68)**		**Negative words (*n* = 60)**		***t***	***p***
	Mean	**SD**	**Mean**	**SD**		
Valence	5.43	0.38	2.32	0.19	57.54	<0.001
Arousal	3.59	0.30	6.80	0.32	−58.18	<0.001

was made. Participants were asked to press the key correspondingly to the target type as quickly and accurately as possible (press F for ● and press J for ●●). Following the participant's response, there was a 200–500 ms inter-trial interval (see Figure 2).

There were 10 practice trials to make sure participants understand the requirement of the task. Participants were told that fixation cross was first presented at the beginning of a trial, then the words would appear at the left and right side of the cross, and finally the target probe would appear on either left or right side of the fixation after the words disappeared. Participants were not given any information about the relationship between emotional valence of words and the place where targets appeared in this task.

During the dot-probe task, there were three types of trials: neutral, congruent negative, and incongruent negative trials. During neutral trials, the valence of the two words presented were both neutral. During the negative congruent trials and negative incongruent trials, there was one negative word paired one neutral word. Targets appeared at the same location of the negative words for the negative congruent trials while the target appeared at the opposite location of negative words for the negative incongruent trials. One test session consisted of 136 trials in total. These trials were presented in random order and separated into two blocks of 68 trials, 8 of them were neutral, 30 of them were congruent negative and 30 of them were incongruent negative. The left–right position of the words were counterbalanced across trials. Participants were allowed to take a break as they wanted between the two blocks to prevent fatigue.

Reward association training task

This task is broadly based on the additional singleton paradigm of Theeuwes (1991). In this paradigm participants were presented word array displayed in 2 × 2 matrix. Their task was to search the target among the homogeneous non-targets. The target sometimes was a neutral word with all other same words negative, or vice versa, and this changed from trial to trial. To determine the impact of reward on attentional bias, we added reward feedback at the end of every trial (see Figure 3) for the reward training group. Reward could be either of high (10 points) or low magnitude (1 point) and participants were paid based on the number of points they accumulated throughout the experiment. The rate of reward was set to be 80% high reward and 20% low reward feedback for correct responses to neutral target word, while 80% low reward and 20% high reward feedback for correct responses to negative target word. For the reward control group, there was no feedback provided after each trial.

The experiment consisted of 300 trials where half of them contained neutral target and the other half contained negative target. The total experiment took ~20 min. There were 15 practice trials before the training to ensure participants understood the instruction of the task. Each trial began with the presentation of a fixation point for 500 ms, followed by the presentation of a visual search array. Participants were instructed to search for the target word that was of different valence as the others and press the "F" key when the target was neutral and the "J" key when the target was negative. Correct responses to the search target were immediately followed by an indication of reward feedback, either "+10," denoting the receipt of 10 points, or "+1," denoting the receipt of 1 point. Incorrect responses were followed by "−5," denoting the loss of 5 points. The average accuracy was 0.97. Feedback regarding the reward point was displayed for 1,000 ms.

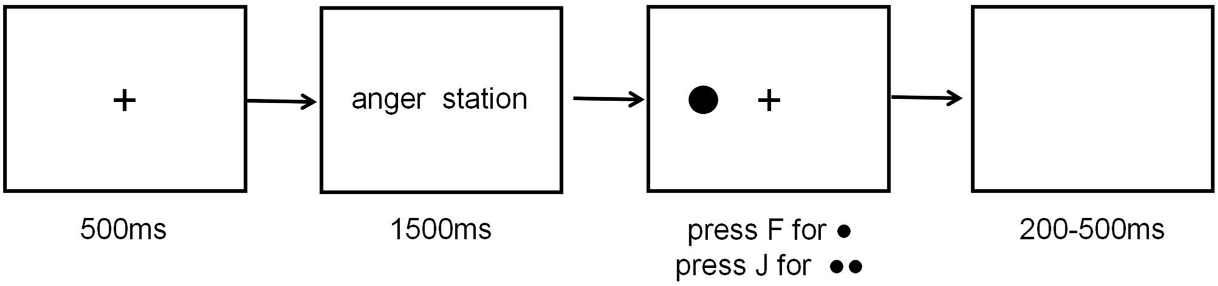

FIGURE 2
An example of the paradigm used to measure and modify attentional bias.

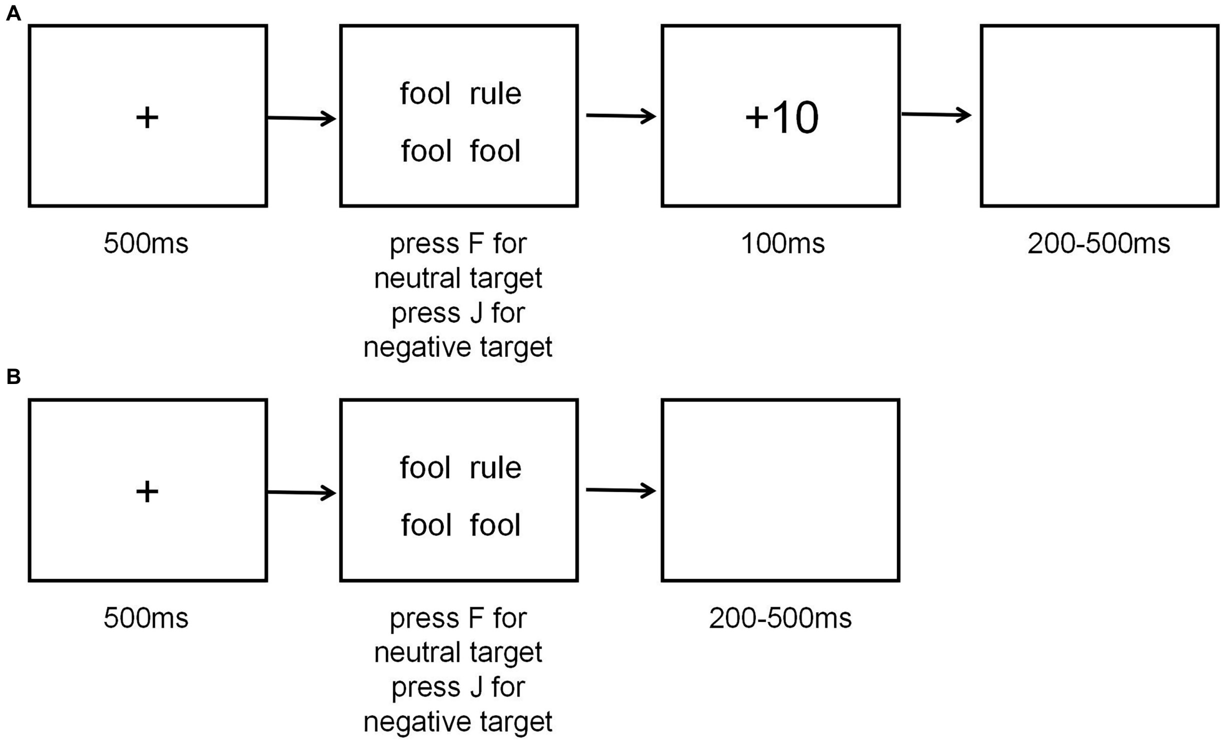

FIGURE 3
Examples of the reward and reward control training. **(A)** Reward training. **(B)** Reward control training.

Attentional bias modification task

Participants completed four training sessions every other day. Each session contained five blocks of 60 trials. Therefore, participants completed a total of 1,200 trials across four training sessions. Participants were assigned to either the ABM group or the ABM control group. This task was the same as the dot-probe task measuring AB, except for the ratios of different type of trials. For the ABM group, 10% of the trials were congruent negative and 90% were incongruent negative trials. For the ABM control group, half of the trials were congruent negative and the other half were incongruent negative trials. The materials were the same words used in reward training but appeared in different word pairs across training sessions.

Generalized anxiety disorder (GAD-7)

To measure the level of anxiety, we used the Chinese version of Generalized Anxiety Disorder Scale (Sun et al., 2021). The Generalized Anxiety Disorder (GAD-7) questionnaire is a seven-item, self-report anxiety questionnaire designed to assess the patient's health status during the previous 2 weeks. The items enquire about the degree to which the patient has been bothered by feeling nervous, anxious or on edge, not being able to stop or control worrying, worrying too much about different things, having trouble relaxing, being so restless that it is hard to sit still, becoming easily annoyed or irritable and feeling afraid as if something might happen. The GAD-7 has been demonstrated to be a reliable and valid measure in assessing mental health in the Chinese population. GAD-7 measured state anxiety on four-point Likert scale from "1-Occasionally" to "4-Frequently." Individuals who score <4 on the GAD-7 have been found to experience minimal levels of worry, and individuals who score >10 on the GAD-7 have been found to experience high levels of worry (Borkovec et al., 1998).

Results

The data of one participant was excluded for further analysis because of incomplete training. Only correct responses that occurred between 200 and 1,200 ms post-target onset and RTs that fell within 3 SD of the mean were included for analysis. An index of negative attentional bias was computed by subtracting average RT for congruent negative trials (probe at negative word location) from incongruent negative trials (probe at neutral word location). A higher bias index indicated that the participant oriented more to the location of negative words compared with neutral words. A mixed design 2 × 2 × 2 analysis of variance (ANOVA) was conducted to assess the effects of time (pre-training vs. post-training), reward association (reward vs. reward control) and ABM (ABM vs. ABM control) on anxiety and AB. The between-group factors were reward association and ABM, and the repeated measure factor was time.

Training effects on anxiety

A significant main effect of time was obtained, $F(1,71) = 52.75$, $p < 0.001$, $\eta^2 = 0.426$, reflecting the fact that post-training anxiety score ($M = 10.23$, SD = 3.38) was lower than pre-training anxiety score ($M = 12.91$, SD = 2.53). There was neither a main effect of reward association, $F(1,71) = 2.65$, $p = 0.11$, $\eta^2 = 0.036$, nor a main effect of ABM, $F(1,71) = 2.17$, $p = 0.15$, $\eta^2 = 0.030$. The time × reward association interaction was significant, $F(1,71) = 15.30$, $p < 0.001$, $\eta^2 = 0.177$. So did the time × ABM interaction, $F(1,71) = 16.90$, $p < 0.001$, $\eta^2 = 0.192$. The reward association × ABM interaction was not significant, $F(1,71) = 2.32$, $p = 0.132$, $\eta^2 = 0.032$. Most importantly, this analysis revealed the presence of a significant three-way reward association × ABM × time interaction, $F(1,71) = 7.60$, $p = 0.01$, $\eta^2 = 0.088$. Calculation of component effects demonstrated that this higher order interaction was due to the presence of a simple time × ABM interaction restricted in reward condition, $F(1,36) = 22.81$, $p < 0.001$, $\eta^2 = 0.388$. As shown in Figure 4, anxiety score decreased significantly more from pre-training to post-training in ABM training than in ABM control training. The time × ABM interaction was not significant in reward control condition, $F(1,35) = 1.10$, $p = 0.30$, $\eta^2 = 0.031$, indicating ABM training effect was not significant in reward control condition. The mean scores and SD were shown in Table 2.

Training effects on attentional bias

A significant main effect of time was obtained, $F(1,71) = 16.02$, $p < 0.001$, $\eta^2 = 0.184$, reflecting the fact that AB in post-training tended to decrease from those measured in the baseline (0.15 vs. 7.53). A significant main effect of reward association also emerged, $F(1,71) = 9.17$, $p < 0.01$, $\eta^2 = 0.114$, the result of a tendency for AB index to be lower in the reward condition than those in the reward control condition. The main effect of ABM was not significant, $F(1,71) = 0.02$, $p = 0.88$, $\eta^2 = 0.001$. These effects were further qualified by a significant time × reward association interaction, $F(1,71) = 12.12$, $p < 0.01$, $\eta^2 = 0.146$, indicating a significant decrease in AB from pre-training to post-training only occurred in the reward condition but not in reward control condition (see Figure 5), regardless of ABM training type. Neither the time × ABM interaction nor the reward association × ABM interaction was significant, $F(1,71) = 0.12$, $p = 0.73$, $\eta^2 = 0.002$ and $F(1,71) = 0.08$, $p = 0.78$, $\eta^2 = 0.001$, respectively. The three-way interaction of reward association × ABM × time was not significant, $F(1,71) = 0.01$, $p = 0.91$, $\eta^2 = 0.001$.

Discussion

The current study developed a novel reward association training and examined its effect in modifying anxiety and AB. Our results demonstrated that participants who completed reward training showed improvement in anxiety as measured by the GAD-7 score compared with those who had reward control attention training, even when the training was completed remotely by the participants themselves. In addition, the current study highlighted the effectiveness of reward association training in decreasing threat-related AB, indexed by negative attentional bias in dot-probe task. Anxious individuals receiving ABM-threat-avoidance training showed significantly decrease in anxiety from pre-to post-training relative to ABM control training only when they received reward training. The advantages of ABM-threat-avoidance training over ABM control training were not shown in AB change.

In terms of the effect of ABM training, several studies reported greater anxiety reduction during ABM-threat-avoidance than control attention training in laboratory-based setting (Amir et al., 2009a,b; Hazen et al., 2009; Bar-Haim et al., 2011; Eldar et al., 2012; Kuckertz et al., 2017). Our study added to the evidence of ABM training effect on anxiety observed when preceded by reward training. Previous reviews (Cristea et al., 2015; MacLeod and Clarke, 2015) suggested that a superior anxiolytic effect of ABM-threat-avoidance training were more likely to be found in laboratory-rather than home-based studies. The current study used the visual-probe task for ABM training with parings of

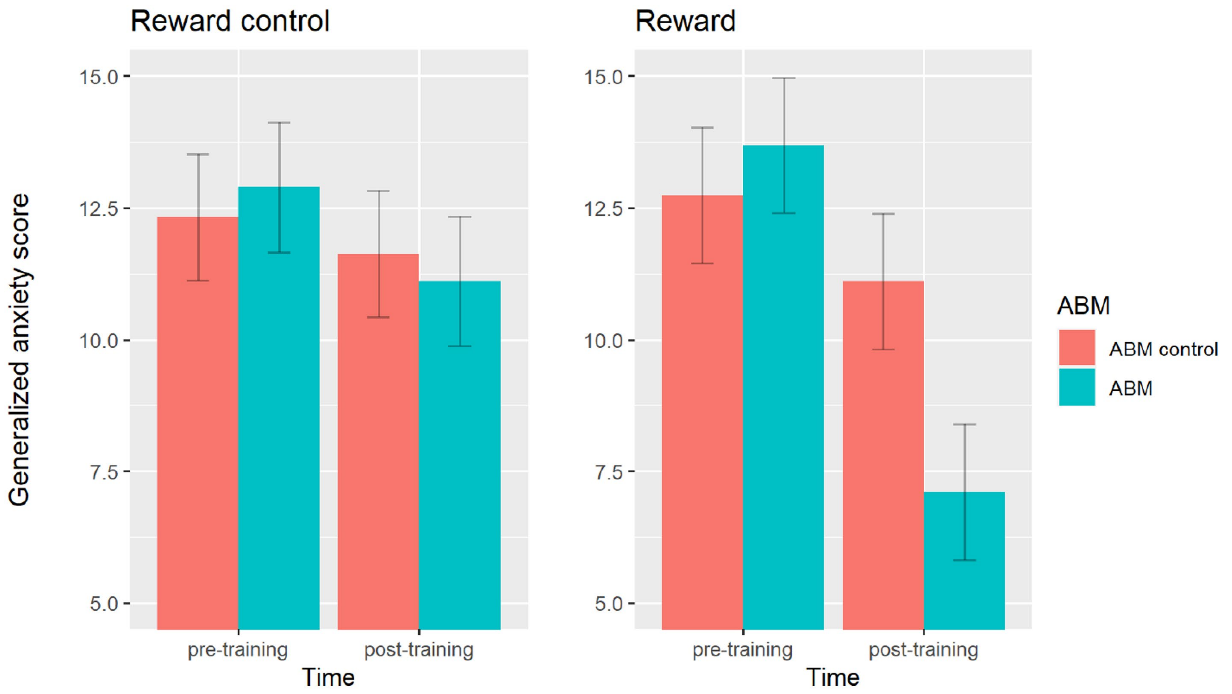

FIGURE 4
Generalized anxiety score for each group before and after training. The Time×Reward×ABM three-way interaction was significant, characterized by a significant Time×ABM interaction in the reward condition but not in the reward control condition. Upper and lower ranges are represented in the figure by the error bars attached to each column.

TABLE 2 Mean and SD of GAD-7 and attentional bias index by group during pre-training and post-training.

		Reward control				Reward			
		ABM control ($n = 19$)		ABM ($n = 18$)		ABM control ($n = 19$)		ABM ($n = 19$)	
		M	SD	*M*	SD	*M*	SD	*M*	SD
GAD-7	Pre-training	12.32	2.24	12.89	2.76	12.74	2.51	13.68	2.60
	Post-training	11.63	2.52	11.11	2.92	11.10	3.01	7.11	2.97
Attentional bias index	Pre-training	6.68	6.28	8.50	11.44	7.42	10.56	7.57	12.58
	Post-training	6.57	9.42	6.21	10.09	−6.05	13.76	−6.79	11.51

threat-neutral words as stimulus type in home-based settings. Our results shed light on the promising approaches to improve anxiety in home-based settings.

Although anxiety reduced during training, our results found no change in AB toward negative information between pre-and post-training for ABM-threat-avoidance training and for ABM control training. This results implied a reconsideration about the assumptions that anxiety reduction after ABM training was due to AB modification during ABM training. That is, ABM training may influence other mechanisms that underlie change in anxiety, such as improvement in attention control (e.g., Chen et al., 2015), which was not measured in the dot-probe task. If so, anxiety reduction may be a consequence of improved attention control, rather than modifying the direction of AB in orienting away from threat (Eysenck and Derakshan, 2011; Mogg et al., 2017). The role of attention control was suggested by findings that anxiety reduction was observed in different attention-training methods, such as ABM-threat-avoidance, inverse-ABM, and control attention training (McNally et al., 2013; Heeren et al., 2015). These training methods share the common features of extended practice on attention tasks during exposure to task-irrelevant threat cues, which may promote attention control and ability to ignore threat cues. Furthermore, anxious individuals did not show preexisting AB in orienting toward threat in most ABM studies (Mogg et al., 2017). These combined evidence pose a challenge toward the fundamental assumption of ABM-threat-avoidance training.

In light of the role of attention control, the current study showed reward association training reduced anxiety and AB toward threat. Recent evidence suggests that reward is a powerful determinant of bottom-up and top-down attentional deployment

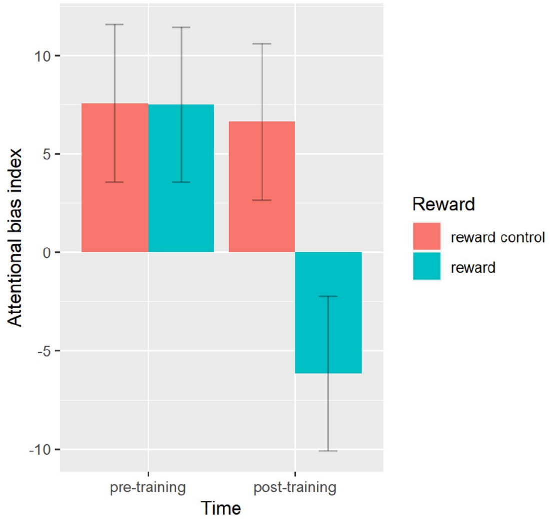

FIGURE 5
Mean attentional bias index by reward group and time. There was a significant interaction between reward training group and time. Upper and lower ranges are represented in the figure by the error bars attached to each column.

(Kiss et al., 2009; Lee and Shomstein, 2014). In the reward training, we trained reward contingency for neutral targets in a pop-out search task using a biased reward schedule. Rewards presented after responses to neutral targets were of higher probability and higher amount than rewards for responses to negative targets. Such differential reward scheme encourages automatic attention selection for neutral targets versus negative targets. It aims to change AB through habituation to the repeated practice of reinforced positive target search. Participants receiving training with high reward to neutral stimuli alleviated the symptoms of generalized anxiety to a certain extent. It was speculated that the reward contingencies facilitated individuals' attention selection toward the reward associated stimuli, changed the attention priority of anxious individuals to threat stimuli, and enhanced the attention orienting to non-threat stimuli. There was no interaction between ABM and reward association training indicating that the modifying effect of reward was likely to be independent of the effect of the ABM probe task training. The positive training effects suggested reward association training should be considered as an effective cognitive treatment for patients with anxiety disorders.

The results of this study show that using reward to modify dysfunctional attention in high trait anxious individuals are encouraging. A related method is ABM-positive-search training which explicitly requires participants to search for search for a positive/non-threat targets embedded among negative/threat distractor pictures (e.g., search for happy face in an angry crowd; Waters et al., 2013). In the comparison condition, participants search for a non-threat target among non-threat distractors (e.g., search for a bird among flowers). The difference of reward association training was the use of implicit learning to modify the automatic attention selection processes. Participants were not given explicit instructions as to the reward contingency, and had to learn it implicitly through bottom-up search trials with ambiguous probabilistic reward schedules. In the reward control training as the comparison condition, no rewards were presented after any of the participants responses. Anxiety reduction was greater for reward training than reward control training. As mentioned above, improvements in anxiety might be a consequence of enhanced top-down attention control. Therefore, the reward-based contingency learned in a bottom-up search task is transferred to top-down attention control, resulting in anxiety reduction and modified threat-related AB.

In the absence of consensus as to why traditional ABM threat avoidance training has inconsistent effects (e.g., Cisler et al., 2009), several alternative methods have been developed with preliminary data suggesting efficacy. The results of this study suggested that the combination of reward association training and attentional bias training most effectively ameliorate the anxiety level of generalized anxiety individuals and help them regulate their emotional state than using training method separately. That is to say, after the training of reward association and ABM, the score of generalized anxiety individuals in GAD-7 scale decreased significantly more than that of using either training method alone. Anxious participant receiving the two training methods first established the association of neutral stimulus and high reward in the reward training stage. This enabled anxious individuals to respond to neutral stimulus more quickly during attentional bias training. In addition, the improved version of probe-dot detection further turn the attention of anxious individuals engaged to neutral stimulus. Providing feedback in ABM training were found to promote learning; for example, feedback on correct/incorrect responses, response time measures of attentional bias, or require correct responses before training advances. In gaze-contingent music-reward therapy (Kuckertz et al., 2017), pleasant music plays when participants look at neutral versus the simultaneously presented negative faces. Without explicitly being informed of this response–reward contingency, or of specific training goals, participants may deduce them from feedback during training. Thus, anxious individuals revealed the effect of dual training in reducing anxiety level. ABM training methods should target multiple combined procedures to reduce anxiety in preliminary home-based treatment background, which warrant further evaluation in larger-scale clinical trials.

A limitation to this study is that the experimental tasks were conducted online and remotely. Participants' performance was not observed and monitored and the experimental environment was not standard across participant. Albeit these variances that have not been perfectly controlled, the current study still obtained significant findings regarding the effect of training. Nonetheless, the standardized procedure and the current results need to be independently replicated in future studies. Another limitation of the current study was small sample size that might challenge the confidence level of the study. But the sample were first screened and selected *via* GAD-7, it shall give more meaningful results in attentional bias in high trait anxious individuals than in general population. According to the power analysis, the effect size calculated from the current sample size was above 0.25, which was small but acceptable (Durlak, 2009). Future research should continue to verify the effect of training by increasing the sample size and different types of population. Last but not the least, multiple evaluation methods should be adopted to obtain more accurate data, for example eye tracking or EEG experiment. Recent methodological advances have allowed increasing ecological validity by measuring the real-time attentional bias. In future research, we can also explore the long-term impact on subjects through longitudinal study.

In conclusion, the results of training effects on anxiety and AB yielded different conclusions regarding the effectiveness of reward association and ABM training. While anxiety reduction between pre-and post-training was found in both reward association and ABM training, AB improved only along with reward association training but no in ABM training. In addition, the results of this study show that ABM training with the dot-probe paradigm did not affect participants' AB or generalized anxiety symptoms in the reward control training condition. These results add to the growing evidence suggesting that benefits of ABM through dot-probe training are unreliable, which may questioned the presumed mechanism underlying ABM training. When comparing the effect of the reward training and dot-probe training paradigms, it seems that reward is more consistent in modifying AB and anxiety. This may have strong implications for the future treatment of anxiety symptoms, and further underscores the strong effects that rewards have on attention.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics statement

The studies involving human participants were reviewed and approved by University Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

WX: conceptualization, writing–original draft, and writing–review and editing. XZ: conceptualization, methodology, software, formal analysis, writing–review and editing, and project administration. YL: conceptualization, methodology, writing–review and editing. JP: conceptualization, methodology, formal analysis, writing – review and editing, funding acquisition, and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Measuring social phobia symptoms in a community sample of adolescents: An examination of the psychometric properties of the SPAI-23

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A number of studies to date examine dimensions of social phobia and anxiety in adolescents. A variety of tools has been developed, along with their abbreviated versions, that are used to assess Social Anxiety (SA) but little research has been devoted to the types of fears they each assess. Due to differences in the content of the multitude of instruments, different aspects of SA are addressed and this leads to confusion when the relationship between SA and other constructs is being investigated. The aim of the present study was to examine the psychometric properties of the abbreviated Social Phobia and Anxiety Inventory SPAI-23 in Greek-Cypriot community adolescents and describe dimensions of social fears at that age. Seven hundred twenty-one adolescent students from Cyprus, (Mean Age: 15.5, Range: 13–19, SD: 1.12, 64% female) participated in the study. Participants completed, among others, an abbreviated version of the Social Phobia and Anxiety Inventory (SPAI-23). Exploratory Factor Analysis on the SPAI-23 revealed a quite similar structure to the original questionnaire (SPAI). Three Social Phobia factors, describing distinct socially fearful situations, were identified (Performance, Interaction, and Presence in a social context) and one Agoraphobia factor after the evaluation of alternative solutions. Findings were verified by means of Confirmatory Factor Analysis, testing alternative models. Overall, findings were in line with recent evidence on youth samples, and contribute to significant insights towards more sophisticated and personalized assessments.

KEYWORDS

social phobia, social anxiety, SPAI, assessment, confirmatory factor analysis, exploratory factor analysis, adolescence

Introduction

Social Anxiety Disorder (SAD), characterized by discomfort during actual or anticipated social situations, is highly prevalent in childhood and adolescence, and significantly increases the risk for socioemotional maladjustment later in life (Degnan et al., 2010; Fox and Pine, 2012). SAD typically develops during late childhood - early adolescence (Beesdo et al., 2007; Kessler et al., 2007; Burstein et al., 2011; Leigh and Clark, 2018) and, if left untreated, persists in adulthood and negatively impacts quality of life (Van Ameringen et al., 2003; Ryan and Warner, 2012). Even subclinical levels of social anxiety (SA), that do not meet criteria for SAD diagnosis, can be quite distressing and cause difficulties in multiple life domains of adolescents, including academic (Ranta et al., 2009), forming friendships and peer and romantic relationships. Socially anxious youth tend to form relationships of lower quality (La Greca and Harrison, 2005; Hebert et al., 2013) and are at increased risk of peer victimization (Ranta et al., 2009; Acquah et al., 2016).

Social anxiety, whether clinical or subclinical, can be manifested in a wide range of situations. Socially anxious individuals may feel anxiety in only a few social situations or most/all social situations (Hofmann et al., 2004; Vriends et al., 2007), something that may reflect a continuum of severity (Bögels et al., 2010). Whether this diversity in the contexts where symptoms are manifested and the types of symptoms one predominantly displays represent SA subtypes or diverse phenomenologies of the same disorder, has been debated in the literature, but the consensus, as shown in DSM-5 is that these are not real subtypes due to similar etiologies and response to treatment and the fact that the majority of individuals with SA are anxious in multiple situations (Heimberg et al., 1993). Nevertheless, knowing one's unique profile of specific social fears is important in designing personalized treatments for people with SAD, and helping those with subclinical SA develop strategies to cope with everyday challenges.

In the case of performance fears, where the individual presents with anxiety in performance situations only, e.g., speaking in front of an audience, knowing that anxiety is circumscribed to such settings is critical for diagnosis and case formulation. Fear of performance constitutes a unique diagnostic specifier in DSM-5 for SAD, and individuals with this form of the disorder may have unique characteristics. According to Hofmann et al. (2004) and Hook and Valentiner (2002) people with performance anxiety are qualitatively distinct in that they are more similar to people with specific phobias in terms of heredity, psychophysiological response to feared situations, onset and predisposing risk factors.

In fact, beyond the well-established Performance Only specifier, included in DSM-5, multiple studies suggest the presence of distinct domains of anxiety-provoking social situations, based typically on factor analyses of responses to social anxiety psychometric tools, which typically yield three to five factors. These include "fear of interaction," e.g., dating, "fear of observation" e.g. being watched when eating in front of others (Cox et al., 2008; Bögels et al., 2010) and additional factors pertaining to the predominance of physical and somatic symptoms vs. avoidance (Cederlund and Öst, 2013; Panayiotou et al., 2017). Research has not yet reached consensus regarding the number or content of SA subdimensions and existing research has focused primarily on adult populations (Dalrymple and D'Avanzato, 2013).

Factor analytic studies of SA psychometric tools typically yield between one and five dimensions, reflecting different situations where symptoms appear, as well as types of symptoms experienced. Knappe et al. (2011) assessed 3,201 youth between 14 and 24 years old using a computer-assisted version of the Munich-Composite International Diagnostic Interview (DIA-X/M-CIDI), conducted an Exploratory Factor Analysis (EFA) and identified one general factor. Mörtberg and Jansson Fröjmark (2019) run a study using the Social Phobia Inventory (SPIN) in a young adult sample, and reported two factors; fear and avoidance of social interaction and fear and avoidance of criticism. A two-factor model was also reported by Ouyang et al. (2020), who examined the factor structure of the Social Interaction Anxiety Scale (SIAS) and Social Phobia Scale (SPS) in a young adult sample, similar to Zsido et al. (2021) who tested the same scales in adults and adolescents. Panayiotou et al. (2017) administered the Social Phobia and Anxiety Inventory (SPAI) (Turner et al., 1989) to a sample of young adults to evaluate its psychometric properties and then compared it, using CFA, with several models of previous studies and a preliminary EFA. The results revealed four correlated Social Phobia factors, an agoraphobia factor and four situation factors defining the context in which symptoms are expressed. In this study, of particular importance is that the items of the best fitting model were allowed to load on two factors, a subdimension of social fears factor (e.g., Social Interaction, Focus of Attention) and a situation factor (e.g., Strangers, Authority Figures). This suggests that a bifactor structure may be better at explaining social fear subdimensions in SPAI. Lastly, Schry et al. (2012) used the SPAI-23 with an adult sample and identified two different models both of which fit the data well: A two-factor model, where the factors were social anxiety and agoraphobia, and a three-factor model, consisting of factors representing social anxiety, public speaking anxiety, and agoraphobia. However, it is not known how this questionnaire performs in an adolescent population and whether the same factors would appear.

Research with youth, adolescents and children has also yielded different numbers of factors on a variety of screening tools that adequately detect social anxiety (García-López et al., 2015) and there is some consistency in the dimensions describing anxiety in specific situations, interactions or other symptoms. Cederlund and Öst (2013) administered the Social Phobia and Anxiety Inventory for Children (SPAI-C) to 59 youth between 8 and 14 years old fulfilling the criteria for SAD (based on DSM-IV), and identified three latent factors using EFA: (1) social interactions, (2) public performance situations, (3) physical and cognitive symptoms related to social anxiety. Five social anxiety factors were identified by Aune et al. (2008), who administered SPAI-C in a sample of 2,148 students (11 to 14 years old) and conducted initially an EFA and 1 year later confirmatory factor analysis (CFA). These five factors were labelled as: (1) Assertiveness, (2) Public Performance, (3) Physical/Cognitive Symptoms, (4) Social Encounter and (5) Avoidance. In addition to EFA approaches, Piqueras et al. (2008), tested 971 adolescents, from which 795 fulfilled the criteria for SAD, between the ages 14 and 18 using the Anxiety Disorder Interview Schedule for DSM-IV, Lifetime Version (ADIS-IV-L), conducted Principal Component Analysis (PCA) which identified two factors: interaction and performance. They also conducted a cluster analysis of the participants which grouped them into four subgroups; the 1st group with specific social phobia, the 2nd with mild generalized social phobia, the 3rd with moderate generalized social phobia and the last group with severe generalized social phobia. Thus, the two subtypes of SAD that were suggested were "specific social phobia" and "generalized social phobia."

As the studies above demonstrate, social anxiety and its subdimensions has been extensively investigated with several psychometric instruments, among which the well-established Social Phobia and Anxiety Inventory (SPAI) (Turner et al., 1989), which has been proven to be a very reliable tool in the assessment of SA in general and clinical populations (Beidel et al., 1989; Herbert et al., 1991; Peters, 2000; Bunnell et al., 2013). It consists of a Social Phobia (SP) subscale that contains 32 items and an Agoraphobia (AG) subscale that contains 13 items and assesses anxiety in a wide range of situations and settings. It has been translated and utilized in several countries, e.g., the Netherlands (Bögels and Reith, 1999), Spain (García-López et al., 2001), Cyprus (Panayiotou et al., 2017) and others, in which its psychometric characteristics in clinical and community samples have been demonstrated.

Several abbreviated versions have been created to reduce administration time and all have turned out to be highly reliable, with psychometric properties comparable to those of the original version. SPAI-18 (de Vente et al., 2014) contains 18 items all stemming from the Social Phobia subscale and assesses all five aspects of social anxiety included in the original SPAI (social situations, center of attention, avoidance, cognitive symptoms and somatic reactions). Reliability for community individuals was $\alpha = 0.93$ and patients $\alpha = 0.91$, and it correlated highly with the social phobia subscale of SPAI, $r = 0.98$. SPAI-B (García-López et al., 2008) contains 16 items assessing cognitive behavioral and somatic symptoms of the social phobia subscale. SPAI-B correlated highly with SPAI ($r = 0.76$) and was highly reliable in a community sample of adolescents ($\alpha = 0.92$). SPAI-C (Beidel et al., 1995) was specifically designed to be administered in children and it contains 26 items along with sub-items from the social phobia subscale of SPAI. It assesses physical, cognitive and behavioral characteristics of SA and reliability was high ($\alpha = 0.95$).

In this study, SPAI-23 (Roberson-Nay et al., 2007) was used, which has 23 items, 16 measuring Social Phobia and 7 measuring Agoraphobia. It was developed using item response theory (IRT), instead of the commonly used classical test theory (CTT), which allowed the authors to assess responses to each item of the scale and the performance of the scale overall and, thus, select the items from the SP and AG subscales that best measure these constructs. A major advantage compared to other abbreviated versions is that it contains both SP and AG items and item selection was based on methodological rigor. Additionally, both SP and AG subscales correlate highly with those of SPAI ($r = 0.97$ and $r = 0.90$ respectively). Demonstrating that this tool is psychometrically solid and yields similar sub-factors obtained from other instruments, when used with adolescents, can increase the usability of this well-constructed instrument for young populations. Furthermore, assessing its factor structure will contribute new evidence with regards to the dominant social fears and social anxiety symptoms experienced by adolescent populations.

Social anxiety has also been found to correlate with a number of vulnerability factors and temperament characteristics in both adults and youths (e.g., Mick and Telch, 1998; Panayiotou et al., 2014), which may have meaningful associations with specific social anxiety dimensions. Associations between observed SA dimensions and these well-established correlates of SA can add credibility to the observed factor structure of the SPAI and its abbreviations and suggest hypotheses regarding the mechanisms that may drive each symptom category. More specifically, temperamental traits, specifically Behavioral Inhibition, predicts SA directly and interaction fears are particularly related to it (Degnan et al., 2010; Knappe et al., 2011; Panayiotou et al., 2014). Anxiety Sensitivity, another temperamental predictor of SA, maintains symptoms of clinical levels of SA *via* a tendency to avoid undesirable experiences (Experiential Avoidance), which mediates its predictive role (Orsillo et al., 1994; Panayiotou et al., 2014; Papachristou et al., 2018). Additional vulnerability factors, including Psychological Inflexibility are positively associated with SA or agoraphobia in samples of adults, children, and adolescents (Muris, 2002; McLaughlin et al., 2007; Levin et al., 2014; Tillfors et al., 2015; Simon and Verboon, 2016; Papachristou et al., 2018). Experiential avoidance and psychological inflexibility are considered malleable factors that can be addressed through psychological interventions, and therefore are particularly useful to identify as predictors of SA, as addressing these may lower the risk conferred by temperamental characteristics. Lastly, using psychophysiological indices, Panayiotou et al. (2017) suggested that fear of public speaking may be more akin to a specific phobia, while the more generalized SAD subtype may reflect generalized distress rather than fear. This leads to the prediction that these different fear categories suggest alternative maintenance mechanisms that can operate as putative vulnerability factors for developing SAD later in life.

The present study aims to extend research on social anxiety dimensions and social fear clusters, in a non-clinical community sample of adolescents, by examining for that purpose the factor structure of a commonly used instrument, the SPAI-23, and evaluating the relationship between vulnerability factors and temperamental characteristics and SPAI-23 factors. It was expected that the extracted factors of the abbreviated version of the Social Phobia and Anxiety Inventory (SPAI-23) would reflect the structure of the full version (SPAI) and confirm it by means of confirmatory factor analysis (CFA) as well as bifactor CFA. Given that SPAI-23 does not include specific situations for each symptom, specified bifactor models would not distinguish between social anxiety dimensions and situations, rather a general Social Phobia factor because the primary aim of an abbreviated questionnaire, apart from reducing administration time, is to maintain its capacity to assess overall symptomatology and additional factors would include domains of Social Anxiety. Specifying bifactor models would allow us to define a general factor representing the main construct of interest (SP) and specific factors explaining variance other than that accounted for by the general factor (Reise et al., 2010). Taken that SPAI is a widely used questionnaire, the factor structure should resemble the most commonly reported SA dimensions, and, therefore, it was expected that results would confirm the validity and reliability of the Greek translation and its capacity to detect the most common SA dimensions, proving that it is a valuable tool for quick administration. Lastly, it was expected that behavioral inhibition, anxiety sensitivity and psychological inflexibility would positively correlate with SA dimensions but given the unclear previous results, the relationships will be explored.

Materials and methods

Participants

Seven-hundred twenty one (433 female) Greek-Cypriot high-school students from five districts of the Republic of Cyprus participated in the study. Participants' age was between 13 and 19 (mean age = 15.5, SD = 1.12). A stratified random sampling approach was used to select a representative sample of secondary schools (based on geographic area). Schools were selected from the rosters of the Ministry of Education. Then specific grades were selected from each school randomly. All students from the selected grades were invited to participate in the study. Only students whose parents gave written consent, participated in the study. The study received approval from the Cyprus National Bioethics Committee and from the Ministry of Education of the Republic of Cyprus. Data on the demographic characteristics of the sample show a similar distribution of subjects in rural (44.7%) and urban areas (54.3), most lived with both their parents at the time of testing (84.7%), fewer lived with one parent (14.6%) and 0.4% reported "other." The educational level of mother and father had a different pattern, 29% of mothers had completed secondary education, 19.3% technical education and 17.8% higher education whereas 41% of fathers completed secondary education, 4.6% completed technical education and 20% higher education. Additionally, most subjects had between one and three more siblings (85.7% cumulative).

Measures

Demographics

A number of items assessed demographic characteristics such as area of residence (rural or urban), household members and educational level of parents.

SPAI-23

SPAI-23 (Roberson-Nay et al., 2007) measures symptoms of Social Anxiety. It contains 23 items and includes two subscales; agoraphobia (7 items) and Social Phobia (16 items). The items are rated on a 5-point Likert scale and range from 0 to 4 (never to always). It is an abbreviated version of the SPAI questionnaire (Turner et al., 1989) which contains 45 items and assesses cognitive and somatic symptoms and behaviors in a wide range of situations that have the potential to elicit SA. Roberson-Nay et al. (2007), who created the abbreviated version based on data collected from young adults, reported strong factor loadings for all items, high correlations between the subscales of SPAI-23 and the original SPAI, it is comparable with other social anxiety measures similar to the original SPAI and, also, it adheres to a normal distribution better that the original version. The reduced number of items did not result in significant reduction of reliability, which was .95 for the Social Phobia subscale and.85 for the Agoraphobia subscale, and validity of the test scores (Roberson-Nay et al., 2007). Similarly, Schry et al. (2012) report strong psychometric properties; results from four studies with different populations, showed reliability >0.90 in the Social Phobia subscale and > 0.80 for the agoraphobia subscale. An exploratory factor analysis resulted in a two-factor model, where the factors were social anxiety and agoraphobia, and a three-factor model, in which the factors were social anxiety, public speaking and agoraphobia, and both models fit the data well (Schry et al., 2012). However, it is not known how this questionnaire performs with an adolescent population as this is one of the first studies evaluating SPAI-23 psychometric properties in youth.

BIS/BAS

The Behavioral Inhibition System/Behavioral Activation System scale (Carver and White, 1994) assesses two basic motivational systems underlying appetitive and aversive behavior. It contains 20 items on a four-point Likert-type questions, ranging from "totally disagree" to "totally agree." It consists of four subscales, one BIS subscale (7 items) and three BAS subscales (13 items), i.e., the Punishment Sensitivity subscale (BIS), the Drive subscale (BAS), the Fun Seeking subscale (BAS) and the Reward responsiveness subscale (BAS). Its reliability has been deemed acceptable (see Table 1 for reliability in the current sample), e.g., Carver and White (1994) found the reliability of the subscales in an adult population to be between.73 and 0.76 for the BIS, Reward Responsiveness and Drive subscales, and 0.66 for the Fun Seeking subscale. A recent study with adolescents as the sample (Vandeweghe et al., 2016) report similar αs, 0.74 for the BIS subscale and.70 for all BAS subscales. The scale has been validated in the Greek Language in an adolescent sample by Kokkinos and Voulgaridou (2017) and demonstrated good psychometric properties with $\alpha = 0.75$ for the BIS subscale and $\alpha = 0.79$ for the BAS subscale.

AFQ-Y8

The Avoidance and Fusion Questionnaire-Youth 8-item scale (AFQ-Y8) (Greco et al., 2008) is measuring psychological

TABLE 1 Descriptives and Cronbach's alphas for each scale with the current sample.

	SPAI-23	AFQ-8	CASI	BIS/BAS
Mean	0.90	1.12	0.67	1.32/1.82
Median	0.82	1	0.67	1.28/1.84
SD	0.53	0.81	0.38	0.55/0.65
Skewness	0.70	0.91	0.40	−0.19/−0.65
Kurtosis	0.34	0.56	−0.17	−0.27/0.09
Cronbach's α	0.92	0.84	0.88	0.67/0.90

inflexibility (PI) in children and adolescents. It contains 8 items and responses are given on five-point Likert-type questions, ranging from 0 "not at all true" to 4 "totally true." It is an abbreviated version of the 17-item AFQ-Y (Greco et al., 2008) which assess PI engendered by cognitive fusion (*CF*) and experiential avoidance. A study investigating the psychometric properties of the Greek translation of the AFQ-Y8 reported excellent Cronbach's alpha level, 0.87, (see Table 1 for reliability in the current sample; Christodoulou et al., 2018) similarly to the original version (Greco et al., 2008).

CASI

The Childhood Anxiety Sensitivity Index (CASI) (Silverman et al., 1991) measures anxiety sensitivity in children. It contains 18 items and responses are given in three-point Likert-type questions with responses ranging from 0 "not at all" to 2 "a lot." Psychometric evaluation of the scale shows adequate and acceptable internal consistency in samples of children and adolescents of Dutch and Catalan origin (van Widenfelt et al., 2002; Fullana et al., 2003) as well as in the current sample (Table 1). Adaptation in the Greek language has been performed for the current study by means of front and back translation (see Papachristou et al. (2018), for a detailed description).

Procedure

After gaining school permission, the research team initially visited each school to provide students with invitations and informed consent forms to take home. The students who provided a written consent from both their self and parents, were eligible to participate in the study. Then, Participants completed a self-report paper-and-pencil questionnaire package, in a classroom format, during school-hours. The questionnaire completion took approximately 45 min. During the data collection a research assistant and a school teacher were present in order to answer questions when necessary and ensure confidentiality and independent responding.

Statistical analyses

All data were entered in SPSS (IBM Corp. Released, 2017. IBM SPSS Statistics for Windows, version 25.0. Armonk, NY: IBM Corp.) and were initially screened for missing values. No cases were deleted as missing values per item did not exceed 1.1%. Next, data were assessed for multivariate outliers based on Mahalanobis distance (Tabachnick and Fidell, 2013) and 41 cases were excluded, resulting in a sample of 680 subjects. Internal reliability indices for measures used in the current study were calculated (Table 1).

To our knowledge, no other study has investigated the factor structure of the SPAI-23 in adolescents and, therefore, exploratory factor analysis was selected as the first step of our analyses and then a confirmatory factor analysis was carried out to test current findings and previous studies. The analytic procedure was based on previous findings, i.e., factor structure of SPAI-23 in adults, and the conceptual framework around Social Anxiety, i.e., suggested SA subtypes in the literature. More specifically, an exploratory factor analysis, using principal axis factoring (PAF) and oblique rotation, because the factors were expected to be correlated, were applied and models with two to four factors were explored for best fit on the data. For the sake of comparability with the two previous latent factor evaluations of the SPAI-23 in adults, the same analytic adjustments were made, that is, it was required that items should load >0.30 on their primary factor, items were required to have <0.30 cross-loadings on secondary factors and, lastly, in order for a factor to be accepted it should have included more than two items with a loading >0.30 (Roberson-Nay et al., 2007; Schry et al., 2012).

Results

Exploratory factor analyses

A series of exploratory factor analyses were carried out to examine different models and identify the best fitting model to the data. At first, restricted EFAs to two factors and three factors, based on previous studies (Roberson-Nay et al., 2007; Schry et al., 2012) and analysis strategies were performed, and then an unrestricted EFA. In all EFAs, principal axis factoring (PAF) and an oblique rotation (Oblimin) were used. Maximum likelihood estimator was also attempted as in Schry et al. (2012) but results were not meaningful and were rejected.

The two-factor constrained EFA (Table 2) was carried out because SPAI-23 contains an SP subscale and an AG subscale, which were expected to be shown. The two factors that were extracted both had an Eigenvalue over 1, the factor loadings were 0.3 or more and explained 41.6% of the variance. Factor one contained all items of the SP scale and factor two all items of the AG subscale, as expected. Three items (8, 13, and 16) had cross-loadings of 0.30 to 0.35. No item failed to load on a factor. A three-factor constrained EFA (Table 3) was carried out to replicate Schry et al. (2012). The extracted factors had eigenvalues above 1 explaining 38.5% of the variance, all items loaded on at least one factor and factor loadings were 0.3 or more, two items (items 20 and 19) loaded in two factors. Factor 1 termed "Social Anxiety" (SA) contained 15 items, factor 2, "Agoraphobia" contained all items of the agoraphobia subscale and the third factor contained items related to public performance and, thus, labelled "Performance" (Perf) factor. The unrestricted EFA resulted in four factors (Table 4) with an Eigenvalue over 1 and

TABLE 2 Results of a two factor solution from a forced EFA using PAF and oblique rotation.

SPAI-23 item	Factors and factor loadings	
	Social Phobia	Agoraphobia
2	0.77	
3	0.76	
1	0.74	
5	0.71	
6	0.65	
7	0.65	
4	0.64	
14	0.53	
9	0.52	
15	0.51	
13	0.44	0.34
10	0.44	
12	0.41	
16	0.41	0.35
11	0.32	
19		0.66
22		0.65
20		0.60
18		0.54
21		0.50
23		0.49
17		0.49
8	0.30	0.39

Factor loadings > 0.30 are listed.

TABLE 3 Results of a three factor solution from a forced EFA using PAF and oblique rotation.

SPAI-23 items	Factors and factor loadings		
	Social anxiety	Agoraphobia	Performance
13	0.82		
7	0.70		
14	0.67		
1	0.66		
2	0.64		
6	0.64		
12	0.63		
8	0.62		
16	0.60		
10	0.56		
15	0.55		
9	0.52		
11	0.47		
20	0.42	0.36	
22		0.63	
18		0.59	
21		0.56	
17		0.52	
19	0.39	0.42	
23		0.40	
5			0.70
4			0.60
3			0.56

Factor loadings > 0.30 are listed.

explained 48.3% of the variance. The factor loadings were ≥ 0.33 and no item failed to load on a factor. Factor one contained eight items and was labeled "Social presence" (Sp), factor two contained the seven items of the AG subscale, thus it was labelled "Agoraphobia," factor three had three items and was labelled "Performance" (Perf) and the fourth factor contained five items and was labelled "Interaction" (Int). One item (item 3) cross-loaded in the factors one and three. Given that this item contains two interconnected statements that semantically fit in both factors it is reasonable to have this cross-loading. This solution was considered as best fitting to the data but, also, reflects the general direction in the literature regarding social fear subtypes. Lastly, Cronbach's alphas for all extracted factors of all solutions and correlations were calculated (Table 5).

Confirmatory factor analyses

A series of CFA models (Table 6) using AMOS 27.0 were evaluated to test previous studies, theory and current study's EFAs. To evaluate the models the following indices were utilized: χ^2 and df to assess overall fit, Root Mean Square Error of Approximation (RMSEA) in which a value <0.08 and preferably <0.05 show good fit (Hu and Bentler, 1999), Comparative Fit Index (CFI) where a value >0.90 indicates good fit, Akaike's (1987) Information Criterion (AIC), Consistent AIC (CAIC) and Bayes Information Criterion (BIC) which assess model parsimony and smaller values indicate better fit.

Model 1 was a two-factor model consisting of an SP factor and an AG factor. The purpose of this model was to test whether this shortened version of the questionnaire that does not include quadruple questions as the full version would replicate previous studies and that items would load in their respective factor. Items 1–16 loaded on a social phobia factor and items 17–23 on an agoraphobia factor. Fit indices were not acceptable, CFI was below recommended standards and RMSEA was higher than recommended standards. It is, therefore, assumed that these results replicate previous findings of inadequacy of a two-factor solution (SP and AG).

Models 2 and 3 evaluated a distinction of the SP items into more specific "situation" factors. In model 2, two factors were

TABLE 4 Results of a four factor solution from unrestricted EFA using principal axis factoring (PAF) and oblique rotation.

SPAI-23 item	Factors and factor loadings			
	Social Presence	Agoraphobia	Performance	Interaction
2	0.77			
7	0.73			
1	0.64			
6	0.59			
16	0.41			
8	0.35			
9	0.33			
15	0.32			
22		0.65		
18		0.60		
21		0.56		
17		0.55		
19		0.52		
20		0.47		
23		0.46		
5			0.65	
4			0.60	
3	0.40		0.47	
12				0.74
10				0.67
13				0.66
11				0.65
14				0.55

Factor loadings > 0.30 are listed.

TABLE 5 Correlations between factors for each solution and Cronbach's alphas for each extracted factor.

Solution	1		2			3			
Factor	SP	AG	SA	AG	Perf	Sp	AG	Perf	Int
1									
2	0.55								
1									
2			0.58						
3			0.46	0.14					
1									
2						0.47			
3						0.33	0.16		
4						0.63	0.58	0.33	1
Cronbach's α	0.91	0.80	0.91	0.75	0.78	0.86	0.78	0.78	0.82

specified for the 16 SP items, distinguishing performance given in front of an audience ("fear of performance") with 3 items and generic presence in a social context ("fear of presence in a social context") with 13 items. An AG factor was specified for the 7 AG items. Fit indices were not acceptable despite an improvement compared to model 1. Model 3 included a further division of the SP items and 3 factors were specified, "fear of performance," "fear of interaction" and "fear of presence in a social situation." This

TABLE 6 Confirmatory factor analyses results.

Model	Fit indices						
	χ^2	Df	CFI	RMSEA	AIC	CAIC	BIC
1	1586.829**	229	0.80	0.093	1680.82	1940.36	1893.36
2	1343.686**	227	0.83	0.085	1441.68	1712.26	1663.26
3	1129.133**	224	0.86	0.077	1233.13	1520.28	1468.28
4	755.167**	201	0.91	0.064	905.16	1319.32	1244.32
5	706.903**	192	0.92	0.063	874.90	1338.75	1254.75

**$p < 0.001$.

TABLE 7 Correlations between personality characteristics and SPAI-23 and subfactors.

	Cronbach's α	AFQ	CASI	BIS	BAS
Full SPAI-23	0.92	0.43**	0.42**	0.33**	0.15**
Social Phobia	0.92	0.49**	0.53**	0.38**	0.15**
Fear of Performance	0.78	0.42**	0.43**	0.36**	0.17**
Fear of Interaction	0.83	0.37**	0.41**	0.25**	0.05
Fear of presence in a social context	0.87	0.47**	0.49**	0.35**	0.15**
Agoraphobia	0.78	0.37**	0.47**	0.29**	0.08*

AFQ, Avoidance and Fusion Questionnaire; CASI, Child Anxiety Sensitivity Index; BIS, Behavioral Inhibition Scale; BAS, Behavioral Activation Scale; SP, Social Phobia; AG, Agoraphobia; *$p < 0.05$, **$p < 0.01$

model proved to be more parsimonious, based on information criteria, than the previous two and had acceptable fit indices apart from CFI which did not exceed 0.90.

Following this, bifactor models were specified to test the idea that SA severity falls along a continuum that is influenced by a number of feared situations and severity in those fears (Bögels et al., 2010). As a result, model 4 included the factors of model 3 and in addition, a general SP factor containing all 23 items. Model fit was acceptable but loadings on the "fear of presence in a social situation" were not significant and for this reason an additional model was specified, which separated the items of this factor in more coherent, thematically, categories. Model 5 had a generic SP factor including all items of the scale, 5 SP factors ("fear of small groups," "fear of performance," "fear of large groups," "fear of interaction" and "anxious thoughts") and 1 AG factor. Fit indices surpassed acceptable standards and were superior to the other models, this model was more parsimonious than all previous models and factor loadings were significant.

Correlates of social anxiety subfactors

Pearson correlation coefficients were computed (Table 7) to assess the relationship between SPAI-23 and subfactors of it with measures of psychological inflexibility, anxiety sensitivity and the behavioral inhibition/behavioral activation system. All subfactors correlated significantly with the AFQ, CASI and BIS with *r* fluctuating between 0.29 and 0.49 whereas correlations with the BAS scale were much lower, between 0.8 and 0.17, and also non-significant, i.e., with fear of interaction. At the same time, when examining correlation between SPAI-23 and these scales, all relationships are positive and significant but, again, BAS has the lowest correlation coefficient ($r = 0.15$, $p < 0.01$). It was, additionally, tested how the Social Phobia factor as a whole would relate to AFQ, CASI, BIS and BAS. Correlations were positive and moderate, between.15 and.49 ($p < 0.01$) with BAS having the lowest value ($r = 0.15$).

Discussion

This research was conducted in response to the prevalence and persistence of SA, from a young age through adulthood, which emphasizes the need for early and valid diagnosis to prevent later dysfunction. There is a need for cost-and time-effective screening tools to assist practitioners in personalizing treatment approach and to assist researchers in further understanding SA through extensive screening of the general population, as well as individual assessment to identify personalized difficulties and needs. In this study, the factor structure of the Greek version of SPAI-23 was examined and this is the first study, to our knowledge, in which it was administered to a community sample of adolescents. The aim of this study was manifold: to validate the SPAI-23 in the Greek language in a community sample of adolescents, to identify dimensions of social fears in adolescents that explain the heterogeneity of difficulties observed in SA, to compare them with dimensions of social fears observed in adults and to provide insights on the developmental trajectory of SA. An additional goal was to investigate risk factors that represent correlates of social fears and may contribute in the development and maintenance of SA.

A series of EFA were carried out to replicate previous findings from adult studies and explore the factor structure of SPAI-23 in a Greek speaking adolescent community sample. The first solution was in accordance with the structure of SPAI-23 (Roberson-Nay et al., 2007), meaning that all items of the Social Phobia subscale loaded in one factor and all items of the Agoraphobia subscale loaded in a second factor. Next, it was decided to further investigate potential subgroups of items that measure distinct clusters of SA behaviors, which emerged in a previous study (Schry et al., 2012) and the results were replicated for the most part. The "agoraphobia" factor emerged identical and a "social anxiety" factor that contained the same items apart from two was also replicated; a third factor referring to performance (in front of an audience or group of people) contained the same items as the "public speaking" factor found by Schry et al., apart from one. The unrestricted EFA revealed a factor structure resembling some of the most commonly identified social fears but due to the reduced number of items it does not include specific situations that are reported in more severe cases of SA (Crome and Baillie, 2014), suggesting that SPAI-23 is a tool suitable for large scale screenings.

Furthermore, a series of CFAs were conducted to test the EFA results as well as replicate previous findings and theory. Model fit of Model 1 did not meet acceptable standards, and, thus, does not support a two-main-factor structure and suggests instead that additional factors may improve fit, which is in accordance with Panayiotou et al. (2017). Models 2 and 3 showed an improvement without reaching acceptable levels but confirmed the idea that additional factors may better explain the data. As a next step, bifactor models were specified because severity of SA correlates with the number and range of social fears (Bögels et al., 2010; Skocic et al., 2015). As a result, two models with a general Social Phobia factor in which all items loaded and additional subfactors were specified; Model 4 with four subfactors and Model 5 with six subfactors. The decision for a larger number of factors was based on Panayiotou et al. (2017), who defined models with multiple situation factors. Model fit was similar and surpassed acceptable standards in both occasions, indicating that variance not explained by more specific subfactors is accounted for by a general factor. These findings partially support Osman et al. (1995) that all SP items load a single factor but, also, the contrasting findings of Olivares et al. (1999) who rejected a single factor solution and proposed rather a multifactorial structure. In addition, the scale as a whole and the individual factors had very good internal consistency suggesting that SPAI-23 has sufficient reliability to be administered for research and screening purposes to adolescents. In all models the Agoraphobia factor was retained as is, because one of the primary aims of the study was to examine the psychometric properties of the questionnaire, and, thus, it was necessary to keep intact all parts and test all items.

Expression of SA varies depending on feared contexts (Panayiotou et al., 2017). Whether these map onto subtypes of SAD (Kodal et al., 2017), and what their characteristics are has been a persistent debate in the clinical literature. The debate resulted in the proposal for a general performance-only specifier (Bögels et al., 2010; American Psychiatric Association, 2013), rather than the support of different subtypes. Expression of SA varies also depending on symptom type and severity. It has been reported that symptoms such as taking exams or being interviewed indicate mild SA whereas fear of more specific interactions such as arguing with unfamiliar people indicate more severe cases (Crome and Baillie, 2014). Crome and Baillie (2014) suggest that fear of activities that are more likely to occur in everyday life (such as eating in public) compared to rarer activities (such as speaking in front of an audience) cause more difficulties in a person's life and also that the more severe SA is, the more irrational the fears are. It is therefore, debatable, whether an abbreviated questionnaire can capture accurately more severe SA cases when it does not contain items with such specificity. Nevertheless, the observed variation in social fears and symptoms (type and severity) may lead to unique profiles, that need to be considered when designing more personalized interventions. Lastly, not only patients but also individuals who do not surpass diagnostic thresholds and are experiencing debilitating distress, impairment and, possibly, comorbidity (Fehm et al., 2008) may present distinct profiles based on their SA symptoms, which is also supported by the conception of SA as a dimensional construct (Crome et al., 2010).

Pairwise comparisons between SPAI-23 factors and measures of personality and temperamental characteristics indicate positive relationships of low to moderate strength, with the only exception being Behavioral Activation with which correlations were too low, though significant, with most factors. Pairwise correlations do not allow for interpretations regarding mechanisms of development and maintenance of social fears but suggest instead that further research is required to examine these relationships. In particular, the connections between SA factors and temperament need to be further addressed because this gap in the literature is even more pronounced in community youth studies, whereas the relationship between temperament and SAD is thoroughly being investigated. Here, the results were as expected, based on the extensive literature suggesting that Behavioral Inhibition is a predictor of SA as well as a vulnerability factor for SAD, Anxiety Sensitivity is also an important contributor in the development of SA in adolescence and Experiential Avoidance acts as a mediator (Berman et al., 2010; Fox and Kalin, 2014; Panayiotou et al., 2014; Pérez-Edgar and Guyer, 2014; Papachristou et al., 2018). Previous studies approach SA as a unitary construct mostly and do not cover relationships of specific dimensions/SA factors with temperament, which may offer us valuable information in personalizing interventions. For example, in our results, the relationship between "fear of Performance" and temperament shows us that anxiety sensitivity and experiential avoidance are more related with it than BI, which could have implications for early interventions. Similarly, if we assume that there are individual profiles distinct from one another and based on the number and type of fears and severity of symptoms, one would expect a different approach in each case. This requires an understanding of the relationships between temperament and specific SA dimensions.

The current results suggest that SPAI-23, and specifically the Greek-translation, can also be used for large scale screenings in the general population and it has the capacity to detect common dimensions of social fears. Furthermore, social fears in Greek-Cypriot adolescents are similar to those in other countries and they have similar links with temperamental characteristics. This, supports the idea that SA is a construct cross-culturally invariant along with other characteristics in the general population at that age-group. Further research is required to investigate potential groups of community adolescents exhibiting distinct fears that may cluster together, forming profiles of SA, and comparing them with respect to temperamental characteristics.

A limitation of this study is that an abbreviated version of a questionnaire was used to investigate dimensions of SA and it is unlikely that a reduced number of items can reflect all dimensions reported in the literature where longer versions of questionnaires are used. Moreover, SPAI is a widely used instrument and many of the findings supporting the existence of certain dimensions may stem from studies that used the same instrument – which may not always emerge when using the abbreviated form of the questionnaire. Subsequently, this indicates a smaller pool of empirical findings with which the present results can be compared with. Further research is required, with additional samples from around the world, to conclude on the most replicable subdimensions of social fears. Also, large epidemiological studies will need to examine the prevalence and overlap of these fears in youth and adults, of various ages, and different levels of SA severity. Moreover, the correlation analyses do not offer novel information on the relationships between SA factors and temperament and they mostly replicate previous findings; their main contribution is that temperamental characteristics may contribute in a unique way to different social fears. Another shortcoming of this study is that it used a community sample of adolescents. The results do not represent adolescents with clinical levels of SA, even though our sample was randomly selected, and therefore could potentially include subjects with clinical levels of SA. Results should be replicated using large subclinical and clinical samples. Yet, considering a dimensional approach that places individuals along a continuum depending on the severity of the symptoms, such as the RDoC (Insel et al., 2010), our results should be considered representative of adolescents in the "normal" side of that continuum. There are additional studies assessing the dimensionality of SAD and approach it as non-categorical (Crome et al., 2010; Ruscio, 2010; Fuentes-Rodriguez et al., 2018; Zsido et al., 2021), which poses important implications for future research, assessment and intervention design.

Examining dimensions of SA and SAD and identifying clusters of social fears intends to improve detection and intervention methods and, thus, has primarily clinical implications (Vriends et al., 2007; Kodal et al., 2017). Specifically, the presence of more social fears (i.e., a more generalized disorder) indicate increased severity of SAD, more comorbid disorders, increased dysfunctional attitudes, poorer mental health and more functional impairment overall (Stein et al., 2000; Vriends et al., 2007). Moreover, it has been shown that people with more severe SA symptoms may experience also a wider array of inter-correlated symptoms (Panayiotou et al., 2017). Further research on the prevalence and overlap of the identified dimensions of social fears will allow for an assessment whether the current classification adequately captures disorder presentations, or whether further subtyping is required. Previous findings especially those derived from studies using SPAI-C, suggest the existence of at least three dimensions that relate to "performance," "interaction" and "being observed" (Bögels et al., 2010; Kodal et al., 2017). Our study confirms these findings or the presence of at least these categories of social fears.

In conclusion, a degree of uncertainty in the definition of subtypes is expected given the heterogeneity of SA (Kopala-Sibley et al., 2014; Binelli et al., 2015; Kodal et al., 2017). Not only are there too few studies exploring this topic in youth to draw firm conclusions, but these are also characterized by methodological differences in terms of population characteristics and assessment of SA. The resulting divergence in findings hinders interpretability and utilization of the results in clinical/ therapeutic settings. Nonetheless, having a broader understanding of SA manifestations has the potential to improve the clinical/therapeutic utility of the current diagnostic tools and overcome limitations of the categorical approaches, while being consistent with dimensional approaches in psychopathology (Hyett and McEvoy, 2018), such as the Research Domain Criteria (RDoC) (Insel et al., 2010).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Cyprus National Bioethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

GP conceptualized and designed the study. MT and KN conducted the research. MA analyzed the data and wrote the manuscript. MT and GP revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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The link between emotion regulation and size estimation of spiders pictures among women with fear of spiders

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Introduction: Fear is associated with perceptual biases. People who are afraid of spiders perceive spiders as larger than people without this fear. It is yet unclear, however, whether this effect can be influenced by using implicit (non-deliberate) emotion regulation (ER) processes and explicit (deliberate) ER strategies, such as reappraisal and suppression.

Method: This study examined the link between implicit and explicit ER and size estimation among women afraid of spiders. After performing an implicit ER (cognitive control) task, participants rated the size and valence of spiders, wasps and butterflies shown in pictures. Participants' tendency to use reappraisal and suppression was assessed using the Emotion Regulation Questionnaire.

Results: Results showed no effect of implicit ER on size and valence ratings. A greater tendency to use reappraisal was linked to reduced negative feelings on seeing the pictures of spiders. Greater use of suppression, however, was linked to increased size estimation of the spider stimuli.

Discussion: These results highlight the role of ER in perceptual biases and offer avenues for future ER-based treatments for specific phobias.

KEYWORDS

size bias, spider, cognitive control, reappraisal, suppression

Introduction

Imagine that you are cleaning your cupboard when a small spider suddenly appears. While you are trying to get it out, your brother is screaming terrified, "It's so big!!!" This situation illustrates individual differences in size estimation which is highly subjective (Stefanucci et al., 2011; Reynolds and Subasic, 2016). Many studies have attempted to determine the factors influencing the perception of size (Teachman et al., 2008; Clerkin et al., 2009; Zadra and Clore, 2011; Balcetis, 2014); fear may be one of them (Teachman et al., 2008; Leibovich et al., 2016; Youssef et al., 2016).

Several studies have shown that when individuals experience fear they overestimate the size (Leibovich et al., 2016), height (Teachman et al., 2008), and time (Bar-Haim et al., 2010) of the fear-related object. For example, spider-fearful individuals have been found to demonstrate a wide range of perceptual biases toward spider stimuli (Rachman and Cuk, 1992; Riskind et al., 1995; Teachman et al., 2008; Vasey et al., 2011; Aue et al., 2013a,b; Leibovich et al., 2016; Youssef et al., 2016; Basanovic et al., 2018). These biases can also be seen not only when participants are presented with a picture of spiders (Leibovich et al., 2016), but also when they are exposed to a living spider (Vasey et al., 2011).

Recent findings suggest that individual differences in activation of implicit (non-deliberate) emotion regulation (ER) processes, as well as in habitual use (deliberate) of ER strategies, may alter emotional reactivity. Regarding implicit ER, recent studies have indicated a role for cognitive control (Cohen et al., 2015, 2016; Cohen et al., 2016), a high-order cognitive function which enables goal-directed behavior (Gratton et al., 1988). Recruitment of cognitive control in tasks that requires the inhibition of irrelevant information was found to reduce the effects of emotionally negative stimuli on behavior (Cohen et al., 2012, 2015), physiological arousal (Cohen et al., 2015), and on emotion-related neural activity (Etkin et al., 2006, 2010; Cohen et al., 2015). For example, Cohen et al. (2015) presented an arrow flanker task (Eriksen and Eriksen, 1974), which requires ignoring distracting stimuli, prior to the presentation of negative and neutral pictures. The pictures were followed by a simple discrimination task (deciding whether a square is blue or green). Following congruent flanker stimuli (→ → → → →), the pictures led to emotional interference (i.e., longer RTs for discrimination targets that followed negative vs. neutral pictures). This effect disappeared after incongruent stimuli (→ → ← → →), which require the recruitment of cognitive control (Etkin et al., 2010; Cohen et al., 2011, 2012, 2015). These findings are in line with brain imaging data showing that activation in regions related to cognitive control (e.g., dorsolateral prefrontal cortex, anterior cingulate cortex) is associated with reduced activity in the amygdala, a region implicated in emotional processing (Etkin et al., 2006, 2010; Cohen et al., 2016). Recently, Gil et al. (2021) found that recruitment of inhibitory control (incongruent flanker stimuli) reduces the self-reported negative feeling associated with negative pictures. It is yet unknown, however, whether implicit ER can modulate fear-related responses, such as the fear associated with spider stimuli among spider-fearful individuals.

Regarding explicit ER, most studies focus on two common ER strategies: reappraisal and suppression. Reappraisal, in which a person reinterprets a situation in order to feel better about it (Gross and John, 2003), is considered an adaptive strategy. People who tend to use reappraisal more frequently experience more positive emotions and have better social interactions than those using other ER strategies (Cutuli, 2014; Dryman and Heimberg, 2018) Various lab experiments have shown that reappraisal reduces the valence of negative stimuli and the emotional arousal they elicit (Gross, 1998; Butler et al., 2003; Grisham et al., 2011; McRae et al., 2012; Buhle et al., 2014). This has also been demonstrated with fear-related stimuli such as images of snakes and spiders (Langeslag and van Strien, 2018). Similarly, reappraisal was also found to moderate subjective feelings of anxiety during a speech task among healthy individuals (Hofmann et al., 2009), as well as among individuals with math anxiety (Pizzie et al., 2020). Therefore, it seems that reappraisal may promote resilience by mitigating the relationship between stress and mental distress (for review see Riepenhausen et al., 2022).

In contrast to reappraisal, suppression is considered to be a less beneficial ER strategy (Butler et al., 2003; Gross and John, 2003). Rather than distraction, in which the person directs his or her attention away from the emotional information (Kalisch et al., 2006), when people use suppression, they inhibit their emotional responses and do not express them behaviorally (Gross, 2002). In many cases, suppression does not provide emotional relief and may increase physiological arousal (Gross and Levenson, 1993, 1997). People who tend to use suppression experience fewer positive emotions and are more likely to experience negative emotions than people using other ER strategies (Gross and John, 2003). Despite this, when combined with other strategies, suppression is associated with low symptoms of anxiety and depression among adolescents, and has been found to be effective in regulating arousal and anxiety (Keng et al., 2017; Gross and Cassidy, 2019; Yuan et al., 2020; Santos et al., 2021). These presumably contradicting findings are in line with recent theories which emphasize the importance of strategy-situation-fit (Haines et al., 2016), or emotion regulation flexibility (Kashdan and Rottenberg, 2010; Bonanno and Burton, 2013; Aldao et al., 2015). According to these two theories, well-being is a function of the "goodness of fit" between emotion regulation efforts and contextual characteristics rather than the greater widespread use of particular emotion regulation strategies (Conway and Terry, 1992; Doré et al., 2016). These ideas were contextualized following findings from ER studies showing that personal and situational factors, such as situation intensity and controllability, determine the effects of the emotion regulation attempt on the regulator's mood (Sheppes et al., 2011, 2014; Troy et al., 2013; Scheibe et al., 2015; Wenzel et al., 2019; Shabat et al., 2021), as well as the choice or tendency to implement a specific emotion regulation strategy (Sheppes et al., 2011, 2014; Matthews et al., 2021; Shabat et al., 2021). As such, reappraisal and suppression may both be adaptive or maladaptive, depending on individual differences and situational demands (Doré et al., 2016).

Very little is known about the links between implicit and explicit ER and perceptual biases and it is still unclear whether using ER can modulate the perceptual biases associated with fear-provoking stimuli. The current study examined the links between ER and perceptual bias toward spider pictures among women highly afraid of spiders. Specifically, we tested whether implicit ER (recruitment of cognitive control) and explicit ER tendencies (habitual use of reappraisal and suppression) are associated with the size estimation and valence ratings of spider pictures.

As recruitment of cognitive control was found to reduce negative emotions (Etkin et al., 2006, 2010; Cohen et al., 2012, 2015; Gil et al., 2021), we predicted that both valence and size ratings of the spider pictures would be lower when the participants recruited cognitive control (i.e., trials in which an incongruent flanker stimulus precedes a spider picture) than when they did not (i.e., trials in which a congruent flanker stimulus precedes the picture). We also predicted that higher habitual use of reappraisal will be associated with lower size ratings and with fewer negative feelings upon watching the spider images. Furthermore, following finding showing that increased use of suppression is associated with an increase in physiological arousal (Butler et al., 2003), as well as reported negative affect (Dalgleish et al., 2009), we predicted that higher habitual use of suppression will be associated with larger size ratings and more negative feelings toward the spider pictures.

To assess whether the predicted effects are specific to the fear-related stimuli, we recruited women with high fear of spiders and compared the valence and size ratings of the spider pictures to those of butterflies and wasps. Wasps and butterflies were chosen as control stimuli based on Leibovich et al. (2016). Specifically, wasp stimuli were chosen as they are threatening for most individuals, but are not self-relevant for spider-fearful individuals. Butterflies were chosen as neutral stimuli.

Materials and methods

Participants

Participants were students at the University of Haifa. This study was approved by the institutional review board of the Faculty of Education, University of Haifa (No. 059/19). All methods were carried out in accordance with standard human research ethics guidelines (Declaration of Helsinki) and regulations. Written informed consent was obtained from the participants.

A power analysis using G*Power (Faul et al., 2007) revealed that a total of 34 participants are required to assess within variables interactions (i.e., Animal × Congruity) with a power >80% and *a-priori* alpha set at $p = 0.05$. Based on prior studies which showed medium to high effect size for the interaction between flanker type and picture valance (Cohen et al., 2012, 2016), we used an effect size estimate of partial $\eta^2 = 0.10$.

The Spider Phobia Questionnaire (SPQ; Klorman et al., 1974) was distributed on social networks and was filled out by 181 individuals. Among these individuals, 81 participants received a score of above 11 and were therefore invited to participate in the study (based on Leibovich et al., 2016). The study sample included 40 women (age range 18–35 years). Data from three women were removed due to a high error rate in the flanker task (above 15% errors, as in previous studies; Cohen et al., 2014), and data from five women were removed due to a low valence rating of the spider pictures (lower than 1 SD below the mean valence ratings of the sample). The final sample thus included 32 women.

Stimuli

Flanker stimuli

Congruent and incongruent flanker stimuli were used. Congruent stimuli consisted of a row of five arrows pointing to the same direction (→→→→→), while incongruent stimuli consisted of a row of five arrows in which the center arrow pointed in the opposite direction to the flanking arrows (→→←→→). Participants were asked to indicate the direction of the central arrow. In incongruent stimuli, participants recruit cognitive control, while the congruent stimuli were not expected to elicit cognitive control.

Pictures

The animal stimuli included colored pictures of spiders, butterflies, and wasps (10 different pictures of each) in the same physical size (32 pixels), taken from Google Images.

Questionnaires

The Fear of spiders Questionnaire (SPQ; Klorman et al., 1974). This is a 31-item self-report questionnaire assessing fear of spiders (e.g., "When I see a spider, I feel tense and restless"). We also added similar questions about butterflies and wasps. Cronbach alpha here for the spider-related questions was $\alpha = 0.89$.

Emotion Regulation Questionnaire (ERQ; Gross and John, 2003). This questionnaire consists of 10 statements that assess two ER strategies: reappraisal (e.g., "I control my emotions by changing the way I think about the situation") and suppression (e.g., "I keep my feelings to myself"). Participants are asked to rate whether they strongly agree or disagree with each statement on a scale from 1 to 7 (1 = strongly disagree, 7 = strongly agree). Cronbach alpha here was $\alpha = 0.86$ for reappraisal and $\alpha = 0.61$ for suppression.

Procedure

Individuals who were eligible to participate in the study based on the screening questionnaire (SPQ) were invited to the lab and performed the experiment in front of a computer screen. The experiment was based on Leibovich et al. (2016) study and included a size estimation task and a valence task, and was administered *via* OpenSesame (Mathôt et al., 2012). On each trial of the task, participants were presented with a cognitive control target (congruent or incongruent flanker stimulus) that was followed by a picture of an animal (spider, wasp, or butterfly). In the first block, participants were asked to rate the perceived size of the animal appearing in the picture (size task), while in the second block they were asked to rate how bad they feel (valence task). Following this task, participants were asked to rate the unpleasantness they feel for each one of the pictures. Then,

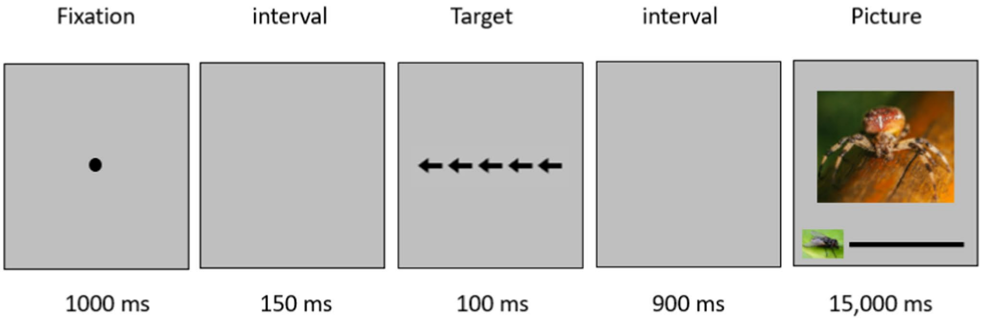

FIGURE 1
Each trial started with a fixation point shown for 1,000ms, followed by a blank screen for 150ms. The flanker stimulus appeared on the screen for 100ms, followed by a 900ms interval in which the response could be made. The animal picture along with the VAS remained until a response was made but not longer than 15,000ms.

participants completed a questionnaire assessing habitual use of reappraisal and suppression, were debriefed, and thanked for their participation. The total duration of all tasks and questionnaires was about 40 min. Participants received monetary compensation or course credit for their time. All task data and materials are available at OSF: https://osf.io/vzpqc/.

Size estimation task

Each trial consisted of viewing a flanker stimulus followed by a size estimation task. When presented with the flanker stimulus, participants were asked to click the right mouse button if the central arrow pointed to the right, while they were asked to click the left button if the central arrow pointed to the left. Half of the trials included a congruent flanker stimulus, while half included an incongruent stimulus. The flanker stimulus was presented for 100 ms followed by a 900 ms interval, after which a picture of a spider, butterfly, or wasp was presented alongside a visual analog scale (VAS) and remained visible until a response was made but not longer than 15,000 ms. In the size estimation task, participants rated the perceived real-world size of the animal on a scale ranging from 0 to 100 with a fly on the left of the screen serving as a reference point (see Leibovich et al., 2016 for a similar design). Participants were instructed to rate the size of the animal as it appears in reality, relative to the fly presented on the left side of the line. The size task thus contained two within-subject factors: flanker type (congruent, incongruent), and animal (spiders, wasps, and butterflies). Twelve practice trials were given followed by 144 experimental trials divided into three blocks.

Valence task

The valence task was similar to the size task but, instead of rating the animal's size, participants were asked to rate how bad they felt on seeing the picture. To do this they used a VAS ranging from not bad at all (left side) to very bad (right side). The valence task contained two within-subject factors: flanker type (congruent, incongruent) and animal (spiders, wasps, and butterflies). The task consisted of 144 trials divided into three blocks.

Unpleasantness ratings

In the third section of the experiment, to verify that the spider pictures were associated with unpleasant emotions, participants rated the degree of unpleasantness they felt when watching the pictures using a VAS ranging from not at all to very unpleasant. The task consisted of 30 trials (3 animals X 10 pictures per animal).

Data analysis

As in previous studies (Cohen et al., 2012), trials with errors ($M = 4.9\%$, $SD = 3.1$) as well as trials with extremely fast RTs (below 200 ms; $M = 2.3\%$, $SD = 6.2$) in the flanker task were removed from the analysis. All analyzes were done using IBM SPSS Statistics (version 25). Repeated measures Analysis of Variance (ANOVAs) were used to examine the interactions between animal (spider, wasp, butterfly) and flanker type (congruent and incongruent). Dependent measures included size estimation and valance ratings. Unpleasantness ratings were analyzed to make sure that the spider-fearful individuals indeed rated the spider pictures as more unpleasant than wasps and butterflies. Pearson correlations between spiders' size and valance ratings and habitual use of emotion regulation strategies (reappraisal and suppression) were also calculated.

Results

Unpleasantness

As expected, participants rated the spider pictures as more unpleasant than the butterfly and wasp pictures, $F(1,32) = 8.323$, $p < 0.01$, $\eta^2_p = 0.212$ (see Table 1 for the mean unpleasantness values of each animal).

Congruity effect

To verify that the flanker task functioned as expected, reaction times (RT) were subjected to a repeated analysis of variance (ANOVA) with congruity as an independent factor. As expected, a main effect for congruity was found, $F(1,32) = 107.557$, $p < 0.001$, partial $\eta^2 = 0.776$, with slower RTs for incongruent than for congruent stimuli ($M = 418.071$ ms, $SD = 55.559$ for incongruent trials, and $M = 378.281$ ms, $SD = 59.690$ for congruent trials).

The effect of implicit ER on size estimation

Mean size estimation values were subjected to a repeated ANOVA with two independent variables, congruity and animal (see Table 2 for the mean animal size ratings). The results replicated those of Leibovich et al. (2016) showing an overestimation of spiders' size compared to butterflies and wasps, $F(1,32) = 15.243$, $p < 0.001$, partial $\eta^2 = 0.330$. *Post-hoc* tests showed that participants rated the spiders as larger than the butterflies, $F(1,32) = 16.156$, $p < 0.001$, partial $\eta^2 = 0.343$, as well as the wasps, $F(1,32) = 44.174$, $p < 0.001$, partial $\eta^2 = 0.588$ (see Figure 2B). However, we did not find a main effect for congruity on size estimation, $F(1,32) = 2.165$, $p = 0.151$, partial $\eta^2 = 0.065$, nor an interaction between congruity and animal, $F(1,32) = 1.047$, $p = 0.314$, partial $\eta^2 = 0.033$.

TABLE 1 Descriptive statistics of the unpleasantness results.

	N	M	SD
Butterfly unpleasantness	32	419.346	117.721
Spider unpleasantness	32	775.054	217.404
Wasp unpleasantness	32	529.906	282.102

M, mean; SD, standard deviation.

TABLE 2 Descriptive statistics of the animals' size and valence ratings.

	Butterfly	Spider	Wasp
	M (SD)	*M* (SD)	*M* (SD)
Size	31.3 (18.3)	45.3 (25.8)	22.3 (18.3)
Valance	11.9 (19.1)	89.8 (9.1)	56.0 (28.9)

M, mean; SD, standard deviation.

The effect of implicit ER on valence ratings

Mean valence ratings were subjected to a repeated ANOVA with two independent variables, congruity and animal (see Table 2 for the mean animal valence ratings). There was a main effect for animal $F(1,32) = 75.678$, $p < 0.001$, partial $\eta^2 = 0.709$, indicating that participants rated their feelings on seeing a spider as more negative than after seeing butterflies $F(1,32) = 476.686$, $p < 0.001$, partial $\eta^2 = 0.939$ and wasps $F(1,32) = 569.848$, $p < 0.001$, partial $\eta^2 = 0.948$ (see Figure 2A). There was no main effect for congruity, $F(1,32) = 0.604$, $p = 0.443$, partial $\eta^2 = 0.019$, nor an interaction between congruity and animal, $F(1,32) = 2.762$, $p = 0.107$, partial $\eta^2 = 0.082$.

The links between explicit ER, size, and valence ratings

Habitual use of reappraisal was negatively correlated with valence rating for the spiders ($r = -0.45$, $p = 0.01$), but not with the estimation of spiders' size ($r = 0.08$, $p = 0.65$). These findings imply that participants who reported using reappraisal more frequently felt less negative when looking at the spider pictures (see Figure 3A).

Suppression was positively correlated with the estimated sizes of the spiders ($r = 0.469$, $p < 0.001$), but not with the spiders'

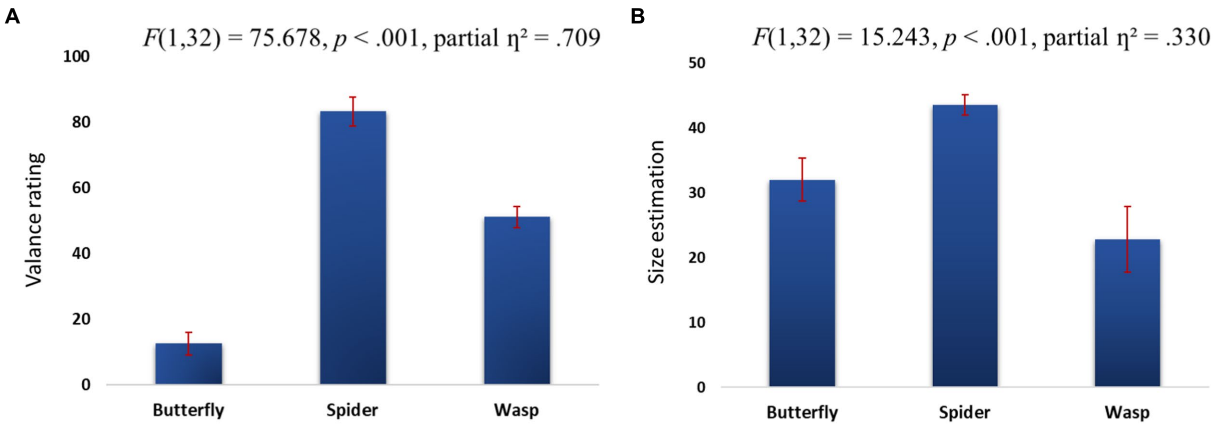

FIGURE 2
Valence ratings **(A)** and size estimation **(B)** for butterflies, spiders, and wasps. Vertical lines represent standard error.

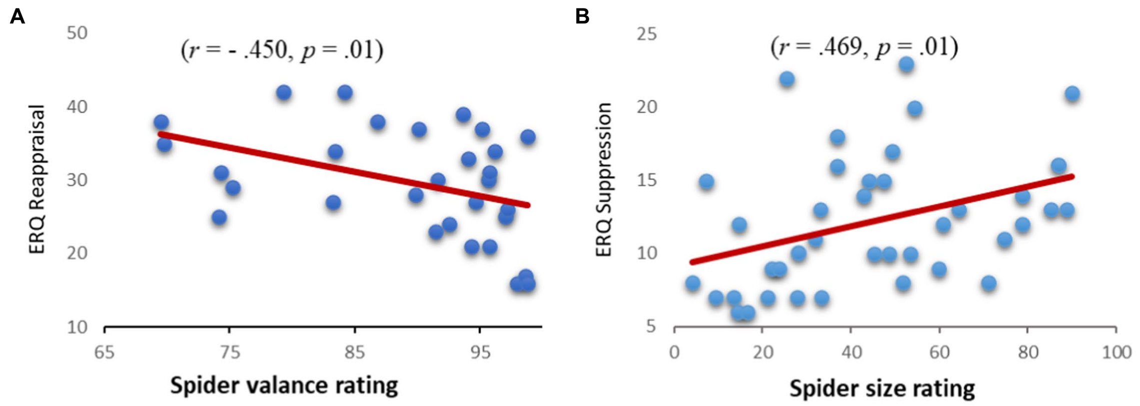

FIGURE 3
Correlation between reappraisal and spiders' valence rating **(A)** and between suppression and the estimation of spiders' size **(B)**.

valence ratings (r =0.08, p =0.65). That is, participants who reported using suppression more frequently perceived the spiders as larger (See Figure 3B).

Discussion

This study examined the links between emotion regulation (ER) and size and valence ratings of spider pictures by women greatly afraid of spiders. We found that women afraid of spiders showed perceptual biases toward spider stimuli, rating them as larger than butterflies and wasps (see also Rachman and Cuk, 1992; Teachman et al., 2008; Vasey et al., 2011; Leibovich et al., 2016; Basanovic et al., 2018). In contrast to our prediction, implicit ER was not associated with either size estimation or valence ratings. Higher use of reappraisal was linked to less negative feelings toward the spider pictures. Higher use of suppression was linked to the estimation of spiders as larger.

Despite previous research showing that cognitive control can serve as an implicit ER process (Etkin et al., 2006, 2010; Cohen et al., 2012, 2015), we did not observe any effect of cognitive control on size estimation and valence ratings. Specifically, size and valence ratings were similar following congruent and incongruent stimuli, indicating that they were not influenced by the recruitment of cognitive control. Several factors related to the current task design may explain these findings. First, the size estimation task required implicit emotional processing. Prior findings indicate that emotional processing of negative pictures is not influenced by cognitive control (Cohen et al., 2016), making it possible that recruitment of cognitive control also in the current task was ineffective in modulating the spiders' size ratings. This, however, cannot explain why the flanker task did not affect the valence ratings. A second possibility for the lack of flanker effect on the size and valence ratings may be the interval from the flanker stimulus to the ratings. In previous studies, an interaction between congruity and valence was observed when a simple discrimination target was used (RTs of around 400 ms; e.g., Cohen et al., 2012, 2015). Here, participants' average RT in the rating tasks was 1.4 s which differs significantly from the average reaction time reported in prior implicit emotion regulation tasks (around 400 ms; e.g., Cohen et al., 2012, 2015). Therefore, the relatively long time passing between the flanker stimulus and the response may have eliminated the effect of the flanker stimulus on size and valence ratings. A third account for the lack of effect of implicit ER on size and valence ratings may be related to the cognitive load that characterizes the processing of the spider stimuli. Specifically, spider phobia is not only characterized by fear of spiders, but a lot of these individuals also feel disgusted toward spiders (Mulkens et al., 1996; Olatunji et al., 2017). Disgust is known to be associated with relatively large recruitment of cognitive resources (Xu et al., 2015; Fink-Lamotte et al., 2021). As a result, cognitive abilities such as inhibitory control may be impaired or decreased (Xu et al., 2015). Regarding the current study, the recruitment of cognitive resources due to disgust may have led the implicit emotion regulation task (i.e., incongruent flankers) to be less effective in modulating the valence and size ratings of the spider pictures. Furthermore, the depletion of cognitive resources due to disgust may have caused the null effect regarding the correlation between reappraisal (which is a costly strategy) and spiders' size. In the current study, we measured only the valence and unpleasantness associated with the spider pictures, and therefore cannot tell whether disgust played a role in the effects observed. This could be tested in future studies by asking participants to rate their level of disgust.

Finding a link between the tendency to use suppression and perceptual bias toward spider stimuli supports the idea that using suppression may be maladaptive and can even harm individuals with specific fears or phobias (Gross and Levenson, 1997; Butler et al., 2003; Asnaani et al., 2013). It is still unclear whether the tendency to use suppression is directly linked to size estimation or, alternatively, whether individuals with this tendency experience higher levels of fear and as a result see the spiders as larger. The fact that we did not find a correlation between suppression and valence ratings supports the hypothesis that suppression is not associated with a reduction of negative emotions for fear-related stimuli. Indeed, the effectiveness of suppression in reducing negative emotions is still controversial (Levitt et al., 2004; Campbell-Sills et al., 2006; Dunn et al., 2009; Kalokerinos et al., 2015; Keng et al., 2017; Katsumi et al., 2018; Yuan et al., 2020).

The link between reappraisal and low valence ratings has been widely supported in previous studies (Troy et al., 2018). These studies, however, mostly reported a reduction in negative affect following an instructed reappraisal assignment. For example, Langeslag and van Strien (2018) found that reappraisal can change emotional responses to fear-related stimuli such as images of spiders or snakes. In addition, Shurick et al. (2012) found that the reappraisal of snake and spider images resulted in a decrease in experiential and autonomic fear responses measured through electrodermal activity, which lasted 24h after the reappraisal manipulation. There are almost no studies examining whether habitual use of reappraisal is associated with reduced affect ratings for fearful stimuli (Li and Graham, 2021). Although participants in our study were not given any instruction related to reappraisal, it is likely that those tending to use reappraisal more frequently also used this strategy during the experiment, leading to lower valence ratings.

The fact that we did not observe a link between reappraisal and size estimation contradicted our hypothesis. One explanation may be the specific characteristics of the size estimation task. As mentioned above, this task may have led to recruitment of cognitive control and spatial perception processes (Moustafa et al., 2017), known to exhaust the cognitive resources needed for reappraisal (Sheppes and Meiran, 2008; Gan et al., 2017). Furthermore, implicit processing of the spider images in this task (i.e., participants were required to process a non-emotional attribute of the stimulus) may have made the pictures more aversive (e.g., Cohen et al., 2016), making reappraisal less preferable and effective strategy (Suri et al., 2015; Scheffel et al., 2021). Therefore, although the participants were not instructed to perform reappraisal, it is possible that the automatic tendencies to use reappraisal were compromised in the size estimation task. Specifically, the size estimation task, which involved the implicit processing of spider stimuli, may have depleted the available cognitive resources required for the execution of reappraisal (Sheppes and Meiran, 2008; Hofmann et al., 2012; Sheppes et al., 2014; Suri et al., 2015; Ortner et al., 2016; Gan et al., 2017; Keng et al., 2017; Troy et al., 2018; Goldin et al., 2019). This idea fits Li and Graham (2021) study which showed that a short practice of reappraisal did not affect the size estimation of spider pictures.

The current study has several limitations. First, we manipulated implicit ER using the flanker task, which is based on recruitment of inhibitory control. Possibly using other cognitive control tasks, such as working memory or set-shifting, would have produced an effect on size estimation and/or valence ratings (Xiu et al., 2016). Second, for explicit ER we focused only on reappraisal and suppression. Other ER strategies, such as acceptance and distraction, have also been found to be effective in fear reduction (Swain et al., 2013). Third, the current study assessed only the habitual tendency to use reappraisal and suppression. We did not examine whether participants used these strategies during the task. Thus, future studies may include a question asking participants whether they have tried to implement a certain emotion regulation strategy during the experiment or instruct participants to use these strategies during the task. Namely, to examine whether suppression and reappraisal influence perceptual bias, these two strategies can be directly manipulated during a size estimation task. For example, participants may be asked to avoid showing their feelings toward the spider pictures (suppression manipulation) before rating the spiders' size (e.g., Burns et al., 2007; Yuan et al., 2020), or to think about the pictures from a perspective of another person (reappraisal manipulation; Keng et al., 2013).

Taken together, the current study provides evidence for a link between emotion regulation and perceptual biases, as well as valence ratings. Specifically, the findings suggest that spider-fearful individuals tending to use suppression more frequently perceive spiders as larger. Furthermore, spider-fearful individuals who tend to use reappraisal more frequently experience less negative affect when seeing spider stimuli. These findings may aid the development of novel and easy-to-implement ER-based interventions designed to treat specific fears.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/vzpqc/.

Ethics statement

The studies involving human participants were reviewed and approved by the questionnaires and methodology for this study was approved by the Ethics Committee of the Faculty of Education at the University of Haifa. The participants provided their written informed consent to participate in this study.

Author contributions

YB-B, NC, and TL-R developed the experimental design. YB-B performed the data collection. YB-B performed the data analysis under the supervision of NC and TL-R. YB-B drafted the article. All authors approved the final version of the article for submission.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Spider vs. guns: expectancy and attention biases to phylogenetic threat do not extend to ontogenetic threat

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Introduction: Attention bias plays an important role in specific fears and phobias. Previous studies revealed that *a-priori* expectancies affect attention toward neutral stimuli but not threatening stimuli. The aim of the current study was to test whether this selective influence of expectancies on attention is specific to phylogenetic threat (i.e., spiders) or whether it can be generalized to ontogenetic threat (i.e., guns). Correspondingly, we directly compared expectancy effects on attentional allocation to phylogenetically vs. ontogenetically threatening stimuli.

Method: Expectancies were manipulated by presenting a cue indicating the likelihood of the appearance of a deviant picture in a visual search array. The array included eight distractors and one neutral (phone/bird) or threatening (gun/spider) deviant picture. In a comprehensive design, we examined the effects of stimulus type (phylogenetic/ontogenetic) and visual background (white and sterile/complex and ecological). Individual differences such as intolerance of uncertainty and spider fear were also measured.

Results: Results showed that attention bias toward spiders does not extend to threatening ontogenetic stimuli (i.e., guns). Our previous findings on attention bias toward spiders were replicated and a small to medium positive correlation was found between reaction time to bird targets and pre-existing fear of spider levels. Cues were used to detect threatening as well as neutral targets on both background types, except for spider targets on a complex background, replicating previous results. A small to medium positive correlation was also found between fear of spiders and intolerance of uncertainty.

Discussion: Together, these results suggest that expectancy and attentional processes may differ between ontogenetic and phylogenetic threat. Importantly, the effects of expectancy on attentional allocation depend on an interaction between the type of threat (ontogenetic/phylogenetic), visual factors, and individual differences.

KEYWORDS

attention bias, expectancy bias, phylogenetic threat, ontogenetic threat, specific fear

Introduction

Cognitive biases and spider fear and anxiety

Anxiety disorders are characterized by cognitive biases exhibited toward anxiety-relevant stimuli. For instance, individuals with spider phobia can exhibit selective attention toward spiders (e.g., Öhman et al., 2001), overestimate the risk of encountering them (e.g., Aue and Hoeppli, 2012), and even misinterpret beetles as spiders (e.g., Becker and Rinck, 2004). Cognitive biases can also be found in healthy populations, as they, too, often find anxiety- and fear-relevant stimuli aversive (Aue and Okon-Singer, 2020). The present study focused on two well-established biases: attention bias and expectancy bias. *Attention bias* reflects faster engagement with feared than with neutral stimuli (Cisler and Koster, 2010; Okon-Singer, 2018; Abado et al., 2020b). *Expectancy (encounter) bias* reflects the overestimation of the likelihood of encountering the fearful stimulus.

Only a few studies investigated the interplay between expectancy bias and attention bias. These studies examined the interaction of the two biases in individuals with spider phobia and in individuals without spider phobia (Aue et al., 2013, 2016, 2019; Abado et al., 2020c). In these studies, expectancy bias was manipulated using a verbal cue indicating the likelihood of the appearance of a certain target stimulus in the following visual search array. These cues included a spider cue ("spider 90%"), a neutral cue ("bird 90%") and an ambiguous cue ("spider-bird 50%"). Following the cue, a visual search array was presented. The array included one target: either a bird or a spider, which appeared among pictures of non-threatening distractors (butterflies). As expected, participants exhibited a general attention bias toward spider targets by detecting them faster than bird targets. Interestingly, an interaction was found between cue and target, as cues had an impact on the detection of bird targets, while the detection of spider targets was unaffected by the cues (Aue et al., 2013, 2016, 2019). These findings suggest that attention deployment to spiders appears somewhat impenetrable to *a-priori* expectancies.

Previous studies have suggested that attention bias toward spiders exists for evolutionary reasons (Seligman, 1971; see also Coelho et al., 2019 for a recent discussion on alternative theories). According to the biological preparedness hypothesis, avoidance of spiders may be considered an adaptive behavior, as it is found in healthy populations as well – sometimes to a lesser and sometimes to an equal extent compared with participants with phobia (Aue and Okon-Singer, 2020). This argument further receives support from studies showing it is difficult to extinguish fear toward phylogenetic threat (Seligman, 1971; for reviews, see Marks and Nesse, 1994; Öhman and Mineka, 2001).

Ontogenetic threat describes threatening stimuli that are based on socio-cultural learning instead of being rooted in human evolution. More recent investigations suggest similar extinction processes for both phylogenetic and ontogenetic threatening stimuli (e.g., Flykt et al., 2007; Luck et al., 2020). Thus, the debate on whether humans are predisposed to be afraid of certain stimuli and whether this fear is indeed particularly difficult to extinguish, is still ongoing (for a recent systematic review which suggests that there is not enough evidence to support the biological preparedness hypothesis, see Åhs et al., 2018; for a recent commentary which suggests that there is indeed enough evidence to support the biological preparedness hypothesis, see Del Giudice, 2021).

In order to examine the role of evolutionary considerations in cognitive biases to threat, several studies compared phylogenetic threat (i.e., evolutionary relevant, such as spiders and snakes) with ontogenetic threat (i.e., modern threat, such as guns and knives). In the case of biased expectancies, for instance, studies examined participants' *a-priori* expectancies regarding the pairing of the presentation of different kinds of stimuli (e.g., spiders and guns) with different kinds of outcomes (e.g., electric shock and neutral sound). Such studies also measured participants' post-experimental estimation of how often a certain stimulus was paired with a certain outcome during the experiment. In reality, the pairings between each stimulus and outcome are equally distributed, wherefore no bias in favor of negative outcomes for spiders should arise. For instance, Mühlberger et al. (2006) measured *a-priori* and *a posteriori* covariation bias in participants with spider phobia or flight phobia. For *a-priori* estimates, results showed that each fear group exhibited expectancy bias for its disorder-specific threat. However, post-experimental disorder-specific covariation bias emerged only in the spider phobia group and not in the flight phobia group. Overall, studies on expectancy/covariation biases toward phylogenetic and ontogenetic threat yield mixed results and suggest that several factors may affect bias toward any type of threat, such as pre-existing fear levels and methodological considerations (for a review on covariation biases toward ontogenetic and phylogenetic threat, see Wiemer and Pauli, 2016; see also Muris et al., 2005, 2007, for differing results on expectancy bias in phylogenetic vs. ontogenetic stimuli).

Studies that examined attention bias toward phylogenetic and ontogenetic threat also yielded mixed results. For instance, some studies found that even simple, abstract and schematic pictures of phylogenetically threatening animals can quickly capture attention and cause interference in performance (e.g., Forbes et al., 2011; LoBue, 2014; New and German, 2015). Other investigations revealed that ontogenetic threat is detected faster than phylogenetic threat and that event-related potentials (ERPs) differentiate between threatening and neutral ontogenetic stimuli but not between threatening and neutral phylogenetic stimuli (Cinq-Mars et al., 2022; see also Subra et al., 2018, for similar behavioral results in a paradigm in which threatening pictures were used as cues, not as targets). While some studies point to the possibility of different mechanisms underlying the processing of phylogenetic vs. ontogenetic threat, other studies found comparable processing of phylogenetic and ontogenetic threat. These inconsistencies have led to the suggestion that the determining factor of attention bias is the potential danger that could be posed by a stimulus, regardless of its evolutionary relevance (e.g., Brosch and Sharma, 2005).

Recently, Zsido et al. (2019a) compared attention processing between phylogenetic and ontogenetic stimuli in ecological contexts. Specifically, phylogenetic and ontogenetic stimuli were presented on forest backgrounds or on street backgrounds. Participants were asked to find different targets. In Experiment 1, participants were asked to detect exemplars of each type of stimulus (e.g., snakes and cats as phylogenetic threatening and neutral stimuli, respectively, and guns and pens as ontogenetic threatening and neutral stimuli, respectively). Results showed that all types of threatening stimuli were found more quickly than neutral stimuli, regardless of evolutionary relevance. In Experiment 2, more exemplars were added, and neutral targets were found faster on mismatched trials (i.e., evolutionary relevant targets on modern backgrounds or vice versa). These results suggest that visual contexts play a role in attentional deployment.

To summarize, mixed results exist regarding expectancies and attention bias toward ontogenetic vs. phylogenetic stimuli. While some studies found prioritized processing of phylogenetic threat, others found prioritized processing of ontogenetic threat and still other studies found comparable effects for both types of stimuli. Several factors have been suggested to affect the processing of threat, such as pre-existing fear levels and experimental manipulations (e.g., background type, type of expected outcome). It remains unknown how *a-priori* expectancies and attention interact in phylogenetic vs. ontogenetic stimuli and whether this interaction is affected by visual factors or by individual traits.

The current study

In the current study, we aimed to directly compare the effects of expectancy on attention bias between ontogenetic stimuli and phylogenetic stimuli. Thus, attention bias was examined in two ways: by comparing attentional allocation toward threatening vs. neutral stimuli and by examining the effects of *a-priori* expectancy cues on attention allocation toward each stimulus type (threatening and neutral phylogenetic and ontogenetic stimuli). To this end, we used the same paradigm as in our previous studies (e.g., Aue et al., 2013, 2016, 2019) to test ontogenetic (i.e., guns) and phylogenetic (i.e., spiders) stimuli. We examined whether unselected participants react faster to guns/spiders than to non-threatening targets (i.e., old mobile phones/birds), and whether participants use expectancy cues in order to detect each target.

In order to control for potential visual confounds, each type of stimulus was presented on a different background: a white background or a natural background (e.g., spider on a leaf/tree, a gun in a hand). Subjective valence ratings were included at the end of the experiment to validate feelings of pleasantness and unpleasantness toward each type of stimulus. Individual differences were also measured, including fear of spiders, state anxiety and depression, as well as feelings of perceived uncontrollability, unpredictability, danger, and disgust toward spiders. Intolerance of uncertainty (IU) was also measured, as it has been found to a play critical role in anxiety disorders (for reviews, see Grupe and Nitschke, 2013; Abado et al., 2020b). However, its role in cognitive biases and specific fears remains understudied. Lastly, due to inconsistent reliability and within-subject differences in cognitive tasks (Hedge et al., 2018; Parsons et al., 2019), particularly in attention bias toward threat (Rodebaugh et al., 2016), split-half reliability analyses for attention bias were also included.

In the phylogenetic conditions, we expected participants to respond faster to spider targets compared to bird targets, regardless of the type of background. In line with our previous studies (Aue et al., 2013, 2016, 2019), we also expected participants to use cues to detect only bird targets, and not spider targets, on both background types. Due to the mixed effects found in the literature, we did not have specific hypotheses for the ontogenetic conditions. If participants exhibit a similar attention bias to phylogenetic as well as ontogenetic stimuli, we can conclude that evolutionary relevance is not the (sole) determinant of fear responses toward spiders. However, if attention toward ontogenetic threat is affected by expectancies, unlike attention toward phylogenetic threat, then a tentative case can be made for prioritized processing that is specific for phylogenetic stimuli.

Method

Participants

This experiment was approved by the ethics committee of the School of Psychological Sciences at the University of Haifa (approval #341/19). Sample size was determined using G*Power (version 3.1.9.4; Faul et al., 2007), with a medium effect size (0.06) and using the "as in SPSS" setting (see Miles and Shevlin, 2001; Cohen, 2013, for more on effect sizes). The calculation was based on the planned main analysis of two within-subject factors (*cue*: threatening, neutral, ambiguous; and *target*: threatening, neutral – overall 6 within-subject conditions), and two between-subject factors (*stimulus type*: phylogenetic, ontogenetic; and *background type*: white, complex – overall four between-subject groups). Accordingly, 108 participants (27 in each fear group) were needed to reach a power of 0.95 with an error probability of 0.02. Forty participants were recruited per group (160 overall), to counterbalance versions and to account for excluded participants (see exclusion criteria below). Participants were recruited online, using the Prolific Platform.[1]

Inclusion criteria consisted of normal or corrected-to normal vision. Exclusion criteria included a history of neurological disorders or ADHD. As participants with neurological history or ADHD could not be screened in advance on Prolific, participants who indicated neurological history or ADHD history during their participation were excluded post-experimentally. Participants were also excluded post-experimentally if they received a standard (Z) score in either dependent measure (RT or accuracy) that was larger than 2.5 in absolute terms.

Of the 160 participants, 16 were excluded from analysis: One reported a history of neurological disorders, five reported a history of ADHD, and ten were excluded due to slow responses or low accuracy rates, leaving 144 participants in the final analysis. Thus, 34 participants remained in the ontogenetic-white background condition (20 males, mean age = 22.53 ± 3.48), 36 participants in the ontogenetic-complex background condition (24 males; mean age = 26.92 ± 9.28) and in the phylogenetic-white background condition (23 males; mean age = 26.36 ± 8.47) and 38 participants in the phylogenetic-complex background condition (22 males; mean age = 24.92 ± 8.49).

Materials

Before beginning the experiment, participants were asked to fill out the following questionnaires:

1. The Intolerance of Uncertainty Scale (IUS-12) – short form (Carleton et al., 2007): the short form includes 12 items on a five-point scale, ranging from 1 ("not at all characteristic of me") to 5 ("entirely characteristic of me"). Examples of items include: "Unforeseen events upset me greatly" and "Uncertainty keeps me from living a full life." The final score is equal to the summation of all items, so that higher scores indicate higher levels of IU. IU is a transdiagnostic trait, which has been found

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[1] https://www.prolific.co/

to correlate with many disorders and individual traits, especially generalized anxiety disorder (for a review, see Einstein, 2014; for a meta-analysis, see McEvoy et al., 2019).

2. State–Trait Anxiety Inventory (STAI; Spielberger, 2010): we used the state anxiety subscale of the inventory, which contains 20 questions and refers to state anxiety, i.e., how the participant is feeling at the moment of answering the questionnaire (e.g., "I am tense," "I feel calm"). Each item is rated on a 4-point scale (e.g., from "1 – almost never" to "4 – almost always"). The final score is equal to the summation of all items, so that higher scores indicate higher levels of anxiety. The STAI shows high internal consistency (coefficients range from 0.86 to 0.95), as well as high test–retest reliability (0.65 to 0.75).
3. Beck Depression Inventory (BDI; Beck, 1991): the questionnaire contains 21 items. Each item represents a symptom of depression and is rated on a 4-point scale, from 0 to 3. For instance, the first item addresses sadness, and the scale is: "0. I do not feel sad," "1. I feel sad," "2. I am sad all the time and I cannot snap out of it," and "3. I am so sad and unhappy that I cannot stand it." The final score is equal to the summation of all items, so that higher scores indicate higher levels of depression. The BDI shows high internal consistency (alpha coefficients range from 0.82 to 0.88).

Following the experiment, participants were asked to fill the Fear of Spiders Questionnaire (FSQ; Szymanski and O'Donohue, 1995): the FSQ reliably differentiates between individuals with and without spider phobia. It contains 18 items, each rated on a seven-point Likert-scale, ranging from 1 to 7. Examples of items include: "If I came across a spider now, I would get help from someone else to remove it" and "If I saw a spider now, I would think it will harm me." The total score equals the summation of all items, as higher scores indicate higher fear levels. The questionnaire shows high internal consistency (Cronbach's alpha = 0.92; Szymanski and O'Donohue, 1995).

Lastly, participants were asked about perceived disgust, danger, uncontrollability, and unpredictability of spiders (Arntz et al., 1993; Armfield and Mattiske, 1996). The latter 4 dimension were rated on a Likert scale ranging from 1 to 7.

Stimuli

For each condition, 30 threatening target pictures (i.e., guns or spiders), 30 neutral target pictures (i.e., phones or birds) and 100 neutral distractor pictures (i.e., staplers or butterflies) were collected. Pictures were matched for contrast and luminance using MATLAB (MathWorks; version 2017b; all $ps > 0.05$).

Pictures of phylogenetic stimuli on a complex background were the exact same pictures that were used in previous studies (Aue et al., 2013, 2016, 2019; pictures taken from Dan-Glauser and Scherer, 2011). Pictures for all other conditions were collected from the Internet. Pictures of ontogenetic stimuli included guns as threatening targets, old mobile phones as neutral targets, and staplers as distractors. Old mobile phones and staplers were chosen based on their similarity to guns as heavy, thick objects, so as to limit differentiating visual factors. Mobile phones have been used previously in similar experiments featuring visual search arrays containing guns (Brosch and Sharma, 2005; Zsido et al., 2019b), and office supplies have been shown to be neutral (Kurdi et al., 2017). For the ontogenetic stimuli on a complex background condition, four pictures were taken from the International Affective Picture System (Bradley and Lang, 2017) and one picture from the Open Affective Standardized Imaged Set (Kurdi et al., 2017). White background pictures included only the specific object/animal on a white background, while complex background pictures included animals in nature (e.g., on a tree) and objects in realistic settings (e.g., in a hand, on a desk, etc.).

Procedure

Before beginning the experiment, each participant took part in two practice blocks, each one containing ten trials. These practice blocks were not included in the final analysis. Each trial began with a fixation cross (500 ms), after which a cue specifying the probability of the target type on a subsequent search task (e.g., "phone 90%"/"bird 90%," "gun 90%"/"spider 90%," "50% gun phone"/"50% spider bird," "50% phone gun"/"50% bird spider"; 2,500 ms) appeared. The actual congruency rate between cues and targets was 71%, as in our previous studies (Aue et al., 2013, 2016, 2019; Abado et al., 2020c). Then, another fixation cross appeared (500 ms) followed by a search array consisting of eight pictures of staplers or butterflies and one deviant picture (gun/phone in ontogenetic conditions; spider/bird in phylogenetic conditions; 2,500 ms or until response; see Figure 1 for an example of a trial). Each of the two targets had an equal likelihood of appearing in each one of the nine possible locations. Both targets appeared equally often. On 5% of the trials, no deviant picture appeared, so that the search array consisted of nine pictures of distractors (staplers/butterflies). Overall, there were 360 trials. Participants were instructed to determine as quickly and as accurately as possible the category of the deviant stimuli by pressing the P and Q keys for threat and neutral deviants (counterbalanced) or the SPACE bar to indicate no deviant. The participants performed the task in four blocks of 90 trials each.

After 20 practice trials, before the experiment began, participants were asked to rate the probability of encountering the threatening target throughout the experiment using a visual analogue scale (VAS) ranging from 1 to 100%. This measure reflects participants' *a-priori* expectancy of encountering the fearful stimulus. Post-experimentally, participants were asked to rate a-posteriori frequencies of occurrence (i.e., how often they thought that they in fact encountered each type of target). Participants were also asked to answer a short post-experimental questionnaire (see Supplementary materials for details).

Design and analysis

Errors made up 6–9% of all responses in the complex background conditions (*SD*: 3–4%) and 4–5% of all responses in the white background conditions ($SD = 2$–3%). There was no sign for a speed-accuracy tradeoff in any of the conditions (all $ps > 0.05$). Per each participant, individual trials were removed if they were ± 2.5 Z scores larger than the mean RT of each of the four within-subject conditions. This led to the removal of 2.5% of individual trials. Sphericity corrections were applied as needed.

A $3 \times 2 \times 2 \times 2$ repeated measures analysis of variance (ANOVA) was conducted, with the within-subject factors *cue* (threatening, neutral, ambiguous) and *target* (threatening, neutral) and the

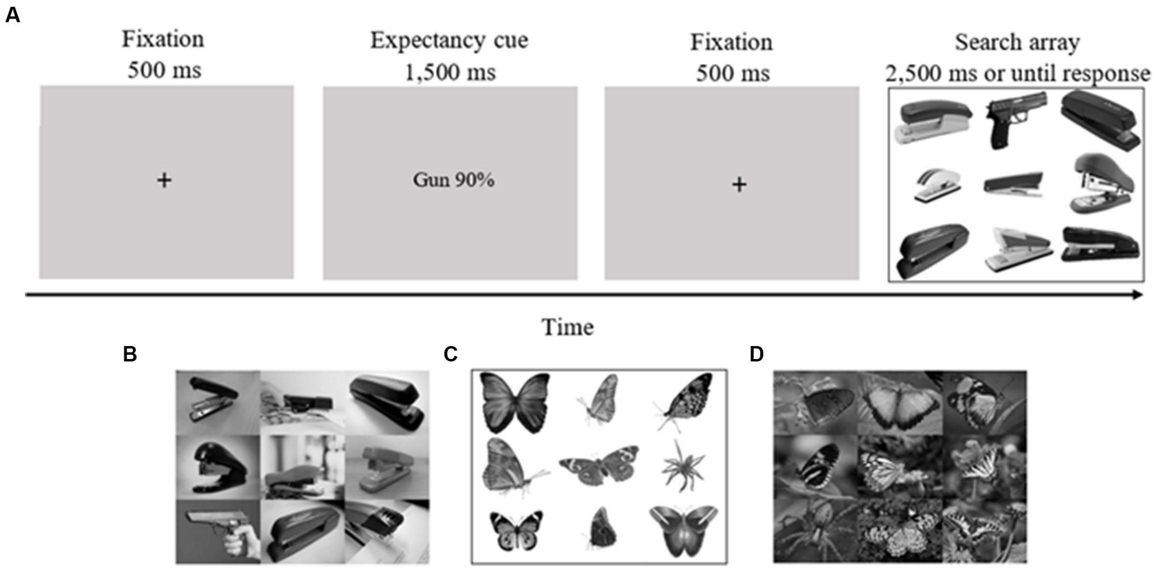

FIGURE 1
Task sequence of the experimental task. **(A)** An example of a valid trial for the guns on white background condition (gun in upper row, middle column). **(B)** An example of an array from the guns on complex background condition (gun in middle row, left column). **(C)** An example of an array from the spiders on white background condition (spider in middle row, right column). **(D)** An example of an array from the spiders on complex background condition (spider in lower row, left column). Pictures were collected from the internet (under Creative Common License) and from Pixabay (https://pixabay.com/). Four pictures of guns on complex backgrounds were taken from the International Affective Picture Systems [(IAPS; Lang et al., 2008); Pictures taken from IAPS (gun on complex background condition): 6190, 6,200, 6,210, 6,240]. In the actual experiments, pictures were matched for contrast and luminance. In the complex ontogenetic stimuli condition, pictures of guns, phones and staplers often appeared in people's hands for ecological validity.

between-subject factors *stimulus type* (phylogenetic, ontogenetic) and *background type* (white, complex).

In addition to the ANOVAs, two regression analyses were performed in order to examine the influence of IU and fear of spiders on attention bias toward threatening targets. Attention bias was calculated by subtracting the mean RT for threatening targets from the mean RT for neutral targets, regardless of the preceding cues, for each participant. A regression analysis was conducted with the 4 questionnaires as independent measures (i.e., fear of spiders and IU as constructs of interest; depression and anxiety were included to make sure that they do not explain additional variance). Regression analyses were performed for each of the between-subject conditions separately. Lastly, split-half reliability analyses were conducted in order to estimate the internal consistency of attention bias toward threat. Analyses were conducted using R (R Core Team, 2022) and the "splithalf" package (Parsons, 2020; for further details, see Supplementary materials). For the design and analyses of reported *a-priori* and a-posteriori frequency estimates and post-experimental questionnaire, see the Supplementary materials.

Results

Reaction time analysis

Reaction time (RT) analysis yielded a significant main effect for cue ($F(2, 277.77) = 7.34$, $p = 0.001$, $\eta^2p = 0.050$), such that participants responded significantly faster when neutral cues appeared ($M = 872.77$ ms), compared to ambiguous cues ($M = 891.28$ ms; $p < 0.001$) and to threatening cues ($M = 883.46$ ms; $p = 0.049$). No other significant differences between cues emerged (all $ps > 0.05$). No significant interactions arose between cue and any between-subjects factor (all $ps > 0.05$). A main effect of target was found ($F(1,140) = 18.07$, $p < 0.001$, $\eta^2p = 0.114$), as participants generally responded faster to threatening stimuli ($M = 861.69$ ms), compared to neutral stimuli ($M = 903.32$ ms). An interaction was revealed between target and stimulus type ($F(1,140) = 173.75$, $p < 0.001$, $\eta^2p = 0.554$). Additional interactions emerged between target and background type ($F(1,140) = 28.18$, $p < 0.001$, $\eta^2p = 0.168$), as well as a triple interaction between target, background type and stimulus type ($F(1,140) = 27.59$, $p < 0.001$, $\eta^2p = 0.165$). Additionally, an interaction between cue and target was observed ($F(1.91, 263.00) = 27.65$, $p < 0.001$, $\eta^2p = 165$). No further interaction between cue, target and any of the between-subject factors emerged (all $ps > 0.05$). As seen in Figure 2, the differences between congruent and incongruent trials were larger in ontogenetic groups. Specifically, Cohen's d effect sizes ranged from 0.100 to 0.525 in the phylogenetic conditions and from 0.432 to 0.764 in the ontogenetic conditions (in the phylogenetic-complex background condition $d = 0.100$ for spider target trials and 0.403 for bird target trials; in the phylogenetic-white background condition $d = 0.434$ for spider target trials and 0.525 for bird target trials; in the ontogenetic-complex background condition $d = 0.448$ for gun target trials and 0.745 for phone target trials; in the ontogenetic-white background condition $d = 0.432$ for gun target trials and 0.764 for phone target trials).

Main effects of each between-subjects factor were found (stimulus type: $F(1,140) = 10.88$, $p = 0.001$, $\eta^2p = 0.072$; background type: $F(1,140) = 141.18$, $p < 0.001$, $\eta^2p = 0.502$), as participants responded

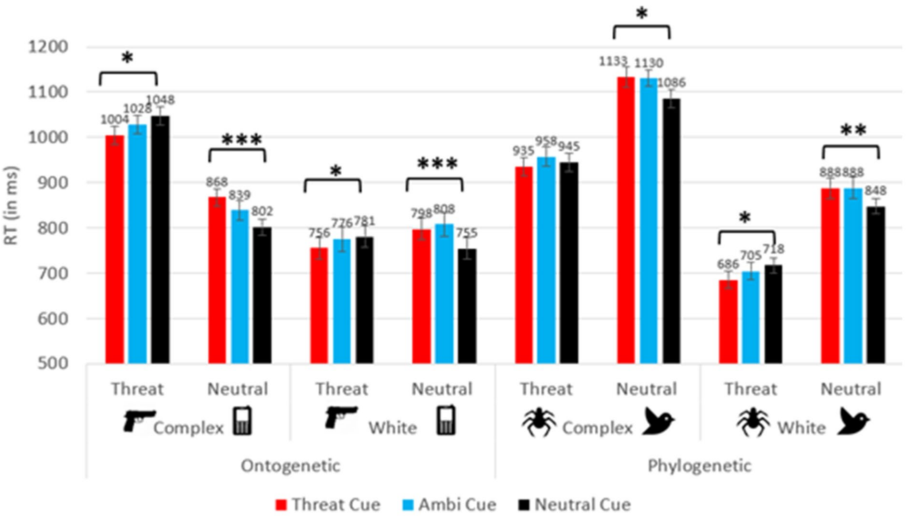

FIGURE 2
RT for the cue × target interaction in each between-subject condition. Error bars depict standard errors. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

faster in ontogenetic conditions ($M = 855.12$ ms) compared to phylogenetic conditions ($M = 909.89$ ms) and in white background conditions ($M = 783.83$ ms) compared to complex background conditions ($M = 981.18$ ms).

To better understand the aforementioned effects and interactions, a 3 × 2 repeated measures ANOVA was conducted on each of the four between-subject factor combinations, with the within-subject factors *cue* (threatening, neutral, ambiguous) and *target* (threatening, neutral). In all four conditions, an interaction of cue and target was revealed (all $ps < 0.05$, except for the phylogenetic-complex condition, in which the congruency effect was not significant: $p = 0.082$; $0.065 \leq \eta^2p \leq 0.249$). In addition, in both background conditions, participants responded faster to spider targets compared to bird targets (complex background condition: $F(1,37) = 41.36$, $p < 0.001$, $\eta^2p = 0.528$; spider targets: 945.94 ± 19.95 ms; bird targets: 1,116 ± 18.96 ms); (white background condition: $F(1,35) = 136.13$, $p < 0.001$, $\eta^2p = 0.795$; spider targets: 703.16 ± 18.44 ms; bird targets: 874.39 ± 20.48 ms). Participants also responded faster to phone targets (835.92 ± 17.46 ms) compared to gun targets (1,026 ± 18.33 ms; $F(1,35) = 91.81$, $p < 0.001$, $\eta^2p = 0.724$) on a complex background. No other effects were found (all $ps > 0.05$).

Planned paired-samples *t*-tests were conducted to analyze the cue × target interaction in each of the four between-subject groups (see Figure 2). The analyses compared between congruent and incongruent conditions, for each type of target on each between-subject level, to examine the influence of expectancy cues on the detection of threatening and neutral targets. Generally, these analyses indicated the presence of congruency effects in all conditions, *except for spider targets on a complex background*. In all other conditions, participants responded faster on congruent trials compared to incongruent trials.

Questionnaires

Correlational analyses were conducted across conditions to examine associations between the different questionnaires (BDI, STAI – state, IUS-12 and FSQ). A small to medium positive correlation was found between fear of spiders (FSQ) and IU (IUS-12; $p = 0.010$, $r = 0.213$), indicating that higher fear of spiders levels were associated with higher levels of IU.

For the attention bias index, none of the four regression models reached significance (all $ps > 0.05$). However, in the phylogenetic-complex background condition, FSQ reached significance ($\beta = 0.412$, $p = 0.021$). To better understand the meaning of the association of FSQ with attention bias, two subsequent regressions were conducted, each time with a different dependent variable: absolute RT toward bird targets and absolute RT toward spider targets in the phylogenetic-complex background condition. Results showed a significant relationship between FSQ levels and RT toward birds ($\beta = 0.327$, $p = 0.045$) but not toward spiders ($\beta = -0.273$, $p = 0.097$). In other words, the higher the fear of spider levels, the longer it took participants to detect bird targets.

Reliability

For each between-subject condition, split-half reliability for the difference between RTs toward threatening targets and neutral targets showed moderate to excellent reliability of attention bias for all between-subject conditions (0.87–0.93; Koo and Li, 2016; for further details, see Supplementary materials).

For the design and analyses of reported *a-priori* and a-posteriori frequency estimates and post-experimental questions, see the Supplementary materials.

General discussion

The current study aimed at examining whether the attention bias previously found toward spiders extends toward ontogenetic threat (i.e., guns). To this aim, ontogenetic and phylogenetic stimuli were directly compared in terms of expectancies and attention. Visual factors were also controlled, as pictures appeared on complex ecological backgrounds or on white sterile backgrounds. Results showed a robust and reliable attention bias toward spiders, as participants detected spider targets faster than bird targets, regardless of the type of background, while no bias toward guns emerged. With regards to expectancy, participants *did not* use the cues to detect spider targets on complex background, thus fully replicating our previous findings (Aue et al., 2013, 2016, 2019). By contrast, in all other conditions, participants *did* use the cues to detect each type of target.

Interestingly, while attention bias toward spiders was shown regardless of fear of spiders, the more participants were afraid of spiders, the longer it took them to detect birds, replicating previous findings (Aue et al., 2013), presumably due to prolonged checking, to make sure that indeed there were no spiders on the screen. Checking behavior is often a characteristic of other disorders, such as obsessive–compulsive disorder (OCD; for a meta-analysis, see Strauss et al., 2020), therefore it would be interesting to develop corresponding paradigms for such disorders. Along the same lines, fear of spiders was further correlated with trait IU. IU has often been linked to OCD (Sarawgi et al., 2013). The current results suggest a link between checking behavior, fear of spiders, and IU. While in the present study no association was found between checking behavior and IU, future studies should more deeply investigate checking behavior and other expressions of cognitive biases as well as their links to trait IU.

In the current study, participants exhibited biased *a-priori* expectancies to encounter spiders only in the complex background condition. This expectancy bias complements the observed attention bias. Specifically, attention bias was found in two forms: first, a general effect toward spiders was observed, as spiders were detected faster than birds, on both background types. This finding is in line with some previous studies, which revealed faster detection of spiders and other types of phylogenetic threat (e.g., Öhman et al., 2001; Waters et al., 2011). Second, in line with our own previous studies, cues were not used in the detection of spiders (on a complex background), even though they were detected faster. Here, attention interacted with expectancy. Together, these two complimentary effects of attentional bias suggest strong and consistent prioritization of spiders. Importantly, the lack of congruency effect seems to be limited to spiders on an ecological background and does not seem to extend to white, unecological backgrounds. Thus, visual factors, especially complex ones, may contribute to participants' attention deployment to threat – including its immunity to prior expectancies – as the threat may seem more real or imminent.

The current study focused on factors that affect attention bias and on the comparison of attentional allocation for different types of stimuli on different visual backgrounds. However, many studies and theories have been written on why certain stimuli, such as spiders and snakes, receive prioritized processing to begin with. Such studies focus mainly on the origin of fear toward such phobic stimuli and situations. For instance, in his theory about phobias and preparedness, Seligman (1971) argued that phobias of a specific set of "biologically relevant" stimuli (e.g., animals, blood, heights) are due to preparedness to fear such stimuli. Meanwhile, according to this hypothesis, phobias of more modern stimuli are less common because humans are less "prepared" to fear them. However, recent evidence and reviews suggest that humans are not predisposed to *fear and avoid* stimuli such as spiders and snakes, but rather that we are predisposed to generally *detect any type* of potential harm (e.g., many types of different animals, including curvilinear shapes that resemble snakes) and that we gradually habituate to animals that are non-threatening (for a review, see Coelho et al., 2019). Along the same lines, in a series of systematic studies, New et al. (2007) suggest that humans exhibit prioritized processing, or an "animate monitoring bias" toward all types of animals, regardless of their respective threat values, but not to objects, even fast and fatal objects, such as moving cars. Thus, the authors conclude that this bias toward animals exists due to ancestral priorities. Nonetheless, in the current study and in our previous studies, we found attention bias to spiders, which did not extend to other animals, namely birds.

It is important to note that while some studies focus on prioritized processing of animals in general or on spiders in particular, other studies make a distinction between spiders and snakes, as objectively, snakes pose a larger threat than spiders and thus it would make evolutionary sense for snakes to receive more cognitive resources (e.g., Soares and Esteves, 2013; Van Strien et al., 2016; for a review, see Öhman et al., 2012). This finding has also been found in snake-naïve Japanese monkeys, which suggests that attention bias toward snakes may have an evolutionary basis, while attention to spiders may be driven by other top-down factors (Kawai and Koda, 2016) or by socio-cultural learning (Luck et al., 2020).

Other researchers also suggest that fear of spiders does not necessarily make evolutionary sense, as the vast majority of spiders are harmless to humans (e.g., Hauke and Herzig, 2017) and thus extreme fear and avoidance of spiders is not evolutionary adaptive in terms of the trade-off between costs and benefits. According to this argument, fear of spiders is a generalized form of fear of a similar looking animal, which are indeed evolutionary-relevant and potentially more dangerous: scorpions (Landová et al., 2021; Rudolfová et al., 2022). According to this argument, fear of scorpions has been generalized to spiders due to their shared visual similarities. This suggestion is in line with studies demonstrating perceptual interpretation biases toward spiders, as participants with spider fear "detected" spider pictures even when they were in fact pictures of beetles (Becker and Rinck, 2004; see also Ginat-Frolich et al., 2019, for more on fear generalization in spider fear). Of note, in addition to inducing fear, spiders are also often rated as extremely disgusting, even in unselected samples (e.g., Polák et al., 2020). Thus, apart from fear, disgust may also play a prominent role in aversion of spiders.

The current study points to the existence of various moderators of attention bias to various types of threat. These can explain why the current study found prioritize processing of phylogenetic threat, while other studies found different results. These various results could be due to the fact that the current paradigm included expectancy manipulations and was different from other studies. While the current study could not address all moderators of attention bias, they include arousal levels (e.g., Zsido et al., 2019b, 2020), perceived danger that the stimulus induces (Brosch and Sharma, 2005), as well as perceived unpredictability and uncontrollability of the stimulus/situation (e.g., Cao et al., 2014; for a review, see Armfield, 2006). Low-level variables, such as the shape of the stimulus, have also been found to affect the detection of threat (e.g., Van Strien et al., 2016; Givon-Benjio and Okon-Singer, 2022). Individual traits, such as disgust propensity, and sociodemographic variables, such as gender, age, level of education, biology background, have also been found to affect the detection of threat (see Polák et al., 2020, 2022, for more on disgust and fear in the perception of animals in non-clinical sample; for reviews on interactions between bottom-up and top-down factors that affect the perception of and attention toward threat, see Sussman et al., 2016; Abado et al., 2020a; Cinq-Mars et al., 2022, for more details on top-down processes in the processing of threat; see Godwin et al., 2016, for more details on expectancy manipulations in visual search).

Recent studies suggest inconsistent reliability and within-subject differences in popular cognitive tasks (Hedge et al., 2018; Parsons et al., 2019). Specifically, the lack of replicability in the case of attention bias toward threat has led to many debates about the importance of measuring reliability (Rodebaugh et al., 2016). For this reason, half-split reliability analyses for attention bias were also conducted here. Our RT results were further validated by the reliability analysis, which indicated moderate to excellent internal reliability of attention bias, measured as the difference in RT between threatening and neutral targets. In addition, our findings have high levels of external validity, as participants were not pre-selected in terms of fear.

The simultaneous assessment of several biases is in line with the combined cognitive bias hypothesis account, which advocates the integrative study of biases and of their interactions. Such an approach could be more valid as well as more informative regarding the complexities of biased cognitive and emotional processes (for a review, see Everaert and Koster, 2020; for a recent study on the combined cognitive bias hypothesis in adolescence, see Parsons et al., 2021). Furthermore, contemporary studies suggest that different disorders can be characterized by a unique pattern of cognitive biases that is exhibited in each disorder (Richter et al., 2020).

As mentioned earlier, one of this investigation's main goals was to examine the role of ecological factors in attention bias toward spiders and to externalize previous findings. It is important to note, however, that our task could benefit from even higher levels of ecological validity. Specifically, the task asks participants to detect a deviant picture among eight distractors, where all pictures are of the same size. This task could be made more ecological by presenting participants with a real-life scene and by tracking their eye-movements. Making the task more ecological can lead to more fine-tuned results and to a better understanding of the interaction between expectancy and attention. Additionally, participants can be provided with the real-life likelihood of encountering spiders in different settings (e.g., in the woods, in urban settings), thereby adapting the experiment more into a cognitive training which assists participants in reducing attention bias levels (for more on cognitive trainings and attention bias modification, see McNally, 2019; Shani et al., 2019; Richter et al., 2020).

To the best of our knowledge, this is the first study to show a correlation between fear of spiders and trait IU in an unselected sample. IU is considered a transdiagnostic trait, which is found in many disorders, including generalized anxiety disorder, social anxiety disorder, panic disorder, agoraphobia, OCD, depression, and eating disorders (for a recent meta-analysis, see McEvoy et al., 2019). While IU has been studied extensively in many anxiety as well as other psychiatric disorders, it has not been studied often in specific fears (for reviews, see Carleton, 2012, 2016; Grupe and Nitschke, 2013; Shihata et al., 2016; Rosser, 2019). As the links between trait IU and cognitive biases are also understudied, future investigations should examine the associations between specific fear levels, cognitive biases, and trait IU, in order to form a more holistic view of IU.

A limitation of the current study consists of the type of pictures that were chosen. Specifically, one difference between the types of pictures that were presented is that guns were presented in people's hands, while pictures of spiders did not include any human body part. While this difference was a part of the experimental manipulation, it may have added a confound, as the presence of human body parts can change how threatening stimuli are processed (e.g., Cao et al., 2014). In the present study, human hands were added to gun pictures in order to make them seem threatening. This is in line with previous observations, which suggest that in order to be perceived as a potential threat, a situation/event needs to be first evaluated as unpredictable, uncontrollable and dangerous (for a review, see Armfield, 2006). While this is usually the case with spiders (e.g., Grill and Haberkamp, 2023), this is not the case with guns or any other object, unless it is actively manipulated by some external force (such as a human being holding it). The findings of Cao et al. (2014) are also in line with the current study, in which pictures of guns were rated as more unpleasant than pleasant, especially in the complex background condition, in which guns were present in human hands. Nonetheless, despite their unpleasantness, no attention bias was found toward guns on either type of background.

These findings could have important clinical implications. For instance, developing a cognitive training procedure which reduces attention bias might reduce fear in the therapeutic context (for a review, see Van Bockstaele et al., 2014; Abado et al., 2020c, for the modification of attention bias using a manipulation of frequencies). Future studies could examine the role of IU in attention bias toward threat, and thus IU targeted attention bias modification procedures could be developed (for IU in CBT, see Dugas et al., 2010; Hebert and Dugas, 2019). Checking behavior may also be related to IU and thus individually tailored and IU targeted treatments may reduce attention bias as well as checking behavior.

To summarize, the current study sought to compare expectancies and attention bias between two types of threatening stimuli, phylogenetic (i.e., spiders) and ontogenetic (i.e., guns), while also taking into account visual factors (i.e., sterile or ecological backgrounds). Whereas attention bias to spiders was found on both backgrounds, no attention bias was found toward guns. Additionally, whereas participants used the cues to detect spiders on a white background, cues were not used to detect spiders on a complex background. Lastly, a small to medium positive correlation was found between the time it took participants to detect birds on a complex background and pre-existing fear of spiders levels. While our results suggest prioritized processing of spiders, the reason for this prioritization, whether evolutionary or socio-cultural, is still unknown.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by this experiment was approved by the ethics committee of the School of Psychological Sciences at the University of Haifa (approval #341/19). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

EA, HO-S, and TA developed the experimental paradigm. EA recruited participants and collected and analyzed the data under the supervision of HO-S. EA, TA, and HO-S drafted the manuscripts. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1232985/full#supplementary-material

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The bigger the threat, the longer the gaze? A cross-cultural study of Somalis and Czechs

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High fear reaction, preferential attention, or fast detection are only a few of the specific responses which snakes evoke in humans. Previous research has shown that these responses are shared amongst several distinct cultures suggesting the evolutionary origin of the response. However, populations from sub-Saharan Africa have been largely missing in experimental research focused on this issue. In this paper, we focus on the effect of snake threat display on human spontaneous attention. We performed an eye-tracking experiment with participants from Somaliland and the Czechia and investigated whether human attention is swayed towards snakes in a threatening posture. Seventy-one Somalis and 71 Czechs were tested; the samples were matched for gender and comparable in age structure and education level. We also investigated the effect of snake morphotype as snakes differ in their threat display. We found that snakes in a threatening posture were indeed gazed upon more than snakes in a relaxed (non-threatening) posture. Further, we found a large effect of snake morphotype as this was especially prominent in cobras, less in vipers, and mostly non-significant in other morphotypes. Finally, despite highly different cultural and environmental backgrounds, the overall pattern of reaction towards snakes was similar in Somalis and Czechs supporting the evolutionary origin of the phenomenon. We concluded that human attention is preferentially directed towards snakes, especially cobras and vipers, in threatening postures.

KEYWORDS

Africa, eye-tracking, snake, Snake detection theory, spontaneous attention

1. Introduction

Snakes seem to evoke a number of specific responses in humans, including a high fear reaction, preferential attention, and fast detection (Öhman and Mineka, 2003; Okon-Singer et al., 2011; Soares et al., 2014; Kawai and Qiu, 2020; Landová et al., 2020; Jensen and Caine, 2021). Each of these phenomena has been previously studied in detail and is described in its own terms and hypotheses. Taken altogether, however, the human mind seems to be specifically equipped to react to snakes in a certain manner (Isbell, 2006, 2009). Further, there are several compelling pieces of evidence that this reaction is at least partially innate (Tierney and Connolly, 2013; Kawai, 2019). First, it is shared amongst distinct cultures across the globe (Alves et al., 2014; Pandey et al., 2016; Landová et al., 2018; Onyishi et al., 2021), second, it can manifest itself very early in human ontogeny (Lobue and DeLoache, 2008; DeLoache and LoBue, 2009; Hayakawa et al., 2011; Borgi and Cirulli, 2015; Bertels et al., 2020), and third, we can observe a similar reaction in apes and other primates (Murray and King, 1973; Shibasaki and Kawai, 2009; Weiss et al., 2015; Kawai and Koda, 2016; Wombolt and Caine, 2016; Zhang et al., 2020). This body of evidence serves as the basis of what is now known as the Snake detection theory (Isbell, 2006 and references therein).

In the last two decades, the research of visual attention mainly focused on whether humans are able to detect a snake faster or more accurately than different types of stimuli in a challenging setup. In a visual detection task, snakes were detected faster than other animals (Lobue and DeLoache, 2008; Shibasaki and Kawai, 2011; Penkunas and Coss, 2013; Soares and Esteves, 2013), even under high perceptual load (Soares et al., 2014; Kawai and He, 2016; Kawai and Qiu, 2020) and regardless of their colouration (Prokop et al., 2018; Fančovičová et al., 2020). Similar results were obtained from a simulated virtual hike (Jensen and Caine, 2021), whilst LoBue (2014) and Kawai (2019) investigated which features facilitated the detection. Additional support for the Snake detection theory also comes from event-related potentials (ERP) studies (He et al., 2014; Grassini et al., 2016; Van Strien et al., 2016; Van Strien and Isbell, 2017) or neurobiological research (Van Le et al., 2013, 2014). Nonetheless, the issue seems more complex as, for example, guns (i.e., evolutionarily irrelevant inanimate objects) are detected as fast or even faster than snakes (Fox et al., 2007; Zsido et al., 2019a,b). Taken all together, there is a strong experimental support for primate brains being fine-tuned for snake detection, however, it seems that not all snakes are prioritised (see, e.g., Rádlová et al., 2019) and not under all circumstances (Subra et al., 2018; reviewed in Coelho et al., 2019).

Importantly, all these experiments assume – although sometimes inexplicitly – that humans and other primates pick on certain visual cues for snake detection provided by the snake's appearance. It is worth pointing out that the snake does not provide these cues with the purpose of being detected; the primates rather take advantage of the cues the snake cannot conceal. In these scenarios, snakes are thought of as predators (Seligman, 1971; Öhman and Mineka, 2001; Isbell, 2006) and as such, they would not profit from being discovered. However, adult primates are rarely snake prey probably thanks to high vigilance, warning calls, and aggressive group defence (Seyfarth et al., 1980; Perry et al., 2003; Eberle and Kappeler, 2008; Etting et al., 2014; Teixeira et al., 2016). In fact, the roles might even reverse, and a snake might end up the prey itself (Headland and Greene, 2011; Falótico et al., 2018). What may have started as a clear predator–prey dynamics in evolutionary history, could now be seen rather as an equal-opponents situation.

Under these circumstances, it might be advantageous to signal one's readiness to fight towards the opponent. This type of signalling is called a threat display. It is almost omnipresent in animals although it may take different forms in different species (e.g., chimpanzees – Nishida et al., 1999; frillneck lizards – Shine, 1990; cuttlefish – Langridge et al., 2007; pelicans – Gokula, 2011; tarantulas – Bennie et al., 2011). In snakes, the most famous example is the threatening posture of cobras – the animal puffs, its body front rises, and its neck-flack spreads (Greene, 1988). Another example comes from vipers – the animal puffs and coils its body in very tight loops with an elevated head held slightly back as if ready to strike (Greene, 1988). Both postures are quite conspicuous, and the animal often accompanies its display with hissing, which further facilitates its detection. The display is clearly intended to be seen by the opponent.

In this paper, we follow the line of thought previously introduced by Isbell's Snake detection theory. We aim to explore whether the human mind is also fine-tuned for a snake's intentional threat signalling rather than just unintentional cues of its presence. To this end, we employ an eye-tracking method utilising a simple design of spontaneous gaze preference when presented with two stimuli at once. We hypothesise that snakes in threatening postures will attract more attention than snakes in relaxed, non-threatening postures. In the past, it was demonstrated that emotions can guide visual attention (Vuilleumier, 2005), and, in particular, that fear-relevant animals are fixated faster, more often, or for longer time periods than fear-irrelevant animal targets (Öhman et al., 2001; Gerdes et al., 2009; LoBue, 2014). Moreover, the importance of snake posture for assessment of danger was previously shown in macaques (Etting and Isbell, 2014; Van Le et al., 2014), and humans (Masataka et al., 2010; Lobue and DeLoache, 2011).

To highlight the ecological aspect of our hypothesis, we focused on Somalis (specifically the population living in Somaliland). Whilst the culture is traditionally pastoral and therefore mobile, according to genetic and linguistic evidence they belong to the core populations of North and Northeast Africa, which have never left the African continent or the savanna environment. Somalis are thus characterised by the near-continuous presence in both the geographic region and the environment of human origin (Stringer, 2016; Gibbons, 2017). Moreover, evidence suggests that the snake species composition of the Horn of Africa has remained largely unchanged during the principal part of human evolution (Kelly et al., 2009; Barlow et al., 2019; Šmíd and Tolley, 2019; Zaher et al., 2019), and we previously found that Somalis consider snakes the most fear-eliciting animals amongst a wide variety of species (Frynta et al., 2023). This makes Somalis uniquely suited for research focusing on the possible co-evolution of snake signalling and human signal detection. In addition, we included participants from Czechia whose ancestors left Africa and, similarly to other Europeans, reached Europe about 30,000 years ago (Prüfer et al., 2021). As there have been virtually no dangerous snakes in Central Europe over the last 40,000 years (only mildly dangerous adder *Vipera berus*), Czechs seem a suitable match to Somalis for cross-cultural comparison. Similar responses across the participants, despite thousands of years of differential exposure to snakes, would suggest that the reaction is at least partially innate and a result of long coevolution between humans and snakes. Contrary, if cultural or more recent selection pressures are involved, clear differences between Somali and Czech participants should emerge. We know of no psychological study focusing on snakes and simultaneously utilising an eye-tracking experimental design in Sub-Saharan Africa.

To summarise, the aims of this study are as follows: (1) To test whether a snake in a threatening posture attracts more attention than one in a relaxed, non-threatening posture, (2) To investigate whether such phenomenon is universal or whether it is specific for certain snake morphotypes as those differ in their threatening postures, and (3) To compare the attention paid to snakes by Somalis and Czechs.

2. Materials and methods

2.1. Selection and preparation of the stimuli

The experimental stimuli were photos of 20 snake species. The selected snakes could be divided into three morphotype groups: vipers (eight species), cobras (eight species), and others (two pythons and two colubrid species). Vipers and cobras, all venomous species, were chosen because of their presumptive relevance for human evolution. During the selection process, the threatening posture of each candidate stimulus species was considered as it had to be visually distinctive enough from the relaxed body posture. This was an especially important criterion for the selection of non-venomous species which tend to have less conspicuous threat display. Lastly, we chose species distributed in Africa or the Middle East (except for two Asian species), the key regions of human evolution. Amongst the included snakes were also some of the most venomous species of the African Horn region: two vipers (puff adder *Bitis arietans* and North-East African Carpet Viper *Echis pyramidum*), two elapids (black mamba *Dendroaspis polylepis* and Egyptian cobra *Naja haje*), and one colubrid (boomslang *Dispholidus typus*). The Somaliland local fauna is additionally represented by two non-venomous species in our set (a colubrid species *Telescopus dhara* and a rock python *Python sebae*). Most stimuli photos came from authors' personal archives but 15 were sourced from the internet. For a complete list of experimental stimuli and their sources, see Supplementary Table S1.

Each experimental image (slide) consisted of a photo of a snake in a threatening posture and a photo of the same specimen in a relaxed (non-threatening) posture. The original photos' backgrounds were cut-off, and the snakes were placed on a shared 20% grey background, each on one side of the image. They were adjusted to be similar in size, hue, and brightness, and positioned so they both were looking towards the image centre. When available, pictures of the same snake individual were used. Twenty images with the threatening posture on the left were supplemented with their horizontally flipped versions (i.e., the threatening posture on the right) accounting for a total of 40 experimental images. In addition, one practise image preceded the experimental ones in the task. The practise image consisted of a drawing of a squirrel on the left and a hyena on the right. For examples of experimental images, see Figure 1.

2.2. The experimental procedure

Before the task itself, respondents were informed about the basic design of the experiment, and they gave written consent with their participation together with some personal information (name, gender, age, nationality). Next, participants were seated in front of the laptop (about 60 cm head to screen distance) with 1,366 × 768 pixels resolution, and they were asked to sit still but naturally and to look at the screen. This was followed by individual calibration of the myGaze eye tracking device. Immediately after a successful calibration, the experimental slide presentation followed. With the first slide (the practise image), they were instructed: "You will see two snakes at each slide, you may look at them as you wish, there is no particular task."

The presentation consisted of 41 images (one practise image and forty experimental images), each displayed for 5 s. Between the images, there were slides with a black fixation cross on the same 20% grey background displayed for 2 s. The images were displayed in one of four pre-defined orders. Each order was a semi-random sequence of images where 10 stimuli (4 cobras, 4 vipers, 1 python, and 1 colubrid) were presented (both left and right versions) before the remaining 10 stimuli. The first and the second order were the same sequence of images, only displayed in reverse (the first image of order one was the last image of order two). The third and the fourth order were the same as order one and two, respectively, only the images were mirrored (left-versioned images were exchanged for right-versioned images and vice versa). Each respondent was assigned an order at random.

2.3. Participants

A total of 71 Somali and 71 Czech respondents participated in the experiment. In both samples, there were 25 women and 46 men. The mean age was 22.37 years (range 19–39) in the Somali sample and 24.63 years (range 18–44) in the Czech sample, the mean age did not significantly differ between the samples (non-parametric Man-Whitney test: Z-value = −1.26, value of $p = 0.209$). Most of the participants in both samples were undergraduate students of various fields. When asked by the investigator, no respondents expressed any extreme attitude towards snakes – neither positive (e.g., great fondness) nor negative (e.g., strong fear). The sample size was based on a similarly designed study (Rudolfová et al., 2022) where 136 participants in total were recommended by *a priori* power analysis using G*Power 3.1 (Faul et al., 2007). We chose a medium effect size ($f = 0.15$), adjusted the α error probability for multiple comparisons amongst categories ($p = 0.0167$), and corrected for a correlation amongst repeated measures ($r = 0.25$).

2.4. Data extraction and curation

MyGaze eye tracking device measures the position of the participants' gaze and records approximately 30 samples per second. We developed our own processing software that converts the data into more intuitive variables which were defined as follows. "Number of sample measurements" is the total number of samples measured during the trial (i.e., approx. 150 in our case). A fixation was defined as all sample measurements that are no farther away than 23 pixels (0.5° visual angle) from a lead (reference) sample measurement. The lead sample measurement was defined as the first recorded measurement during each trial, and then each first measurement in the timeline that did not fall inside of the previous fixation (i.e., the next first measurement that was further them 23 pixels from the previous reference measurement). Moreover, each fixation had to consist of at least two consecutive sample measurements. Following these definitions, we computed the "Number of fixations." Finally, "Fixation time" was defined as the total duration of the participant's gaze. For the purpose of further analyses, we used only mean binocular metrics. Further, we custom-defined three interest areas (IAs) — the left side of the screen, the right side of the screen, and the central part (fixation cross) — and exported all variables separately for each IA. No IA overlapped any other. Left and right IAs covered the snake photos and their vicinity and were the same in size (each covering 37% of the screen). Central IA was very small in comparison (1% of the screen) and covered the area where the fixation cross would have been. Empty image parts too far from snake photos were not included in any of the IAs. To improve accuracy and precision, we used only averaged data from both eyes (Cui and Hondzinski, 2006).

For the subsequent statistical analysis, no participant was fully excluded, however, we eliminated defected measurements (trials) where the gaze was not tracked properly, or the participant was

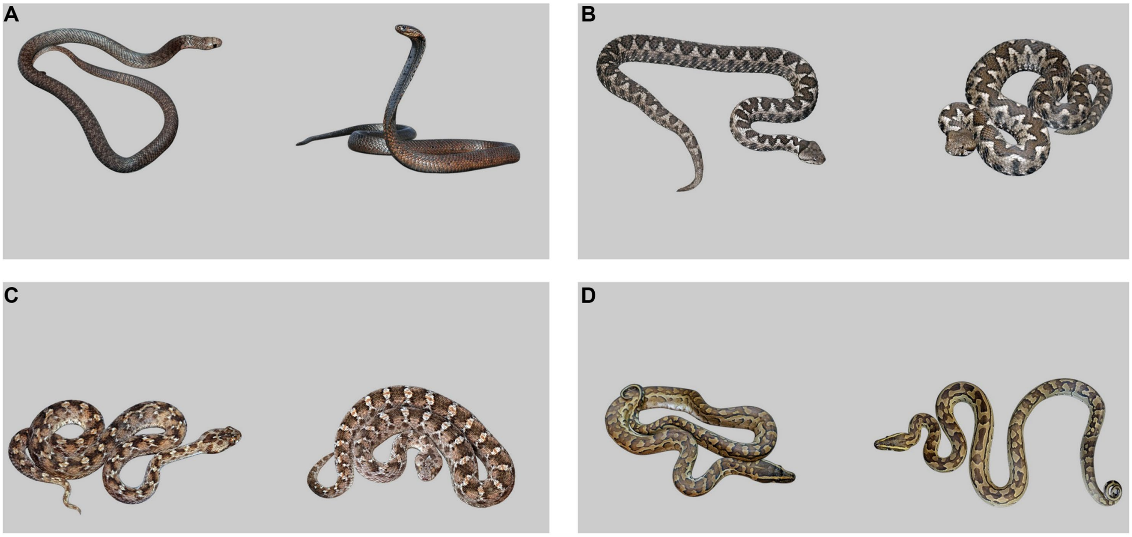

FIGURE 1
Example of experimental slides, the snake in threatening posture is always on the right. **(A)** Cobra morphotype, **(B–C)** viper morphotype, **(D)** other morphotype.

temporarily distracted and did not look at the screen. As a criterion, we chose to exclude observations with combined dwell time on the left and right AOIs under 2000 ms. Based on this criterion, 417 observations were excluded (7.34%). The final dataset, therefore, contained a total of 5,263 observations, 2,558 from Somali respondents and 2,705 from Czech respondents. To compensate for possible side preference, we averaged the data obtained from the horizontally flipped image pairs. In cases where only one slide of the pair was available (because the second one was excluded in the previous step), we used this data but assigned them observation weight "1." Averaged data were assigned observation weight "2." The original data associated with this manuscript are available in Supplementary Table S3.

2.5. Statistics

For the statistical analysis, we used linear mixed-effects models (LMM) as implemented in software R (R Development Core Team, 2022), packages nlme (Pinheiro et al., 2022), and emmeans (Lenth, 2022). Our prime focus was on the number of fixations supplemented by the analysis of dwell times (Orquin and Holmqvist, 2018). For investigation of the effect of threatening posture, we subtracted fixations on the snake in relaxed posture from fixations on the snake in threatening posture (always within the experimental slide) and thus prepared two new response variables – the difference in the number of fixations and the difference in the dwell time. We chose to investigate the difference rather than the absolute values on each posture because (1) it better reflected the pair manner of stimuli presentation and (2) represented specifically the effect of snake body position on participants' spontaneous attention towards the stimuli. In full models, respondents' gender, nationality, and age, and further group, gender-nationality interaction, and group-nationality interaction were used as fixed effects, whilst respondents' ID was used as a random effect. To account for heteroscedasticity, we defined a custom variance structure combining the constant variance structure for respondents' nationality and the fixed variance structure for observation weight. Fixed effects that did not prove significant ($\alpha = 0.05$) were successively reduced. The reduced models and their respective full models were compared with the likelihood-ratio test and on the basis of the Akaike information criterion (AIC). The first method supported the same goodness of fit of both models (the full one and the reduced one), whilst the AIC suggested the reduced models were better because they were simpler (i.e., the full models were overfitted in comparison). Factor coefficients were computed using the restricted maximum likelihood method, for the purpose of full and reduced model comparison, we applied the maximum likelihood method.

2.6. Ethical note

All procedures performed in this study were carried out in accordance with the ethical standards of the appropriate institutional research committee (The Institutional Review Board of Charles University, Faculty of Science, approval no. 2019/2011, granted on 27 March 2019; and The Institutional Review Board of Amoud University, Borama, approval no. AU/AA/0012/2021, granted on 7 January 2021).

3. Results

In the linear mixed effect model for the difference in the number of fixations on threatening versus relaxed posture, only one factor proved significant: snake morphotype ($F_{(2,2,593)} = 24.42$, $p < 0.001$). Other factors were successively taken out of the model since their effect did not prove significant (nationality: $F_{(1,138)} = 0.05$, $p = 0.830$; gender: $F_{(1,138)} = 1.54$; $p = 0.217$; age: $F_{(1,138)} = 0.20$, $p = 0.652$; snake morphotype – nationality interaction: $F_{(2,2,591)} = 2.26$, $p = 0.078$; nationality – gender interaction: $F_{(1,138)} = 0.05$, $p = 0.831$). The odds ratio (assessed with likelihood-ratio test) between the full and

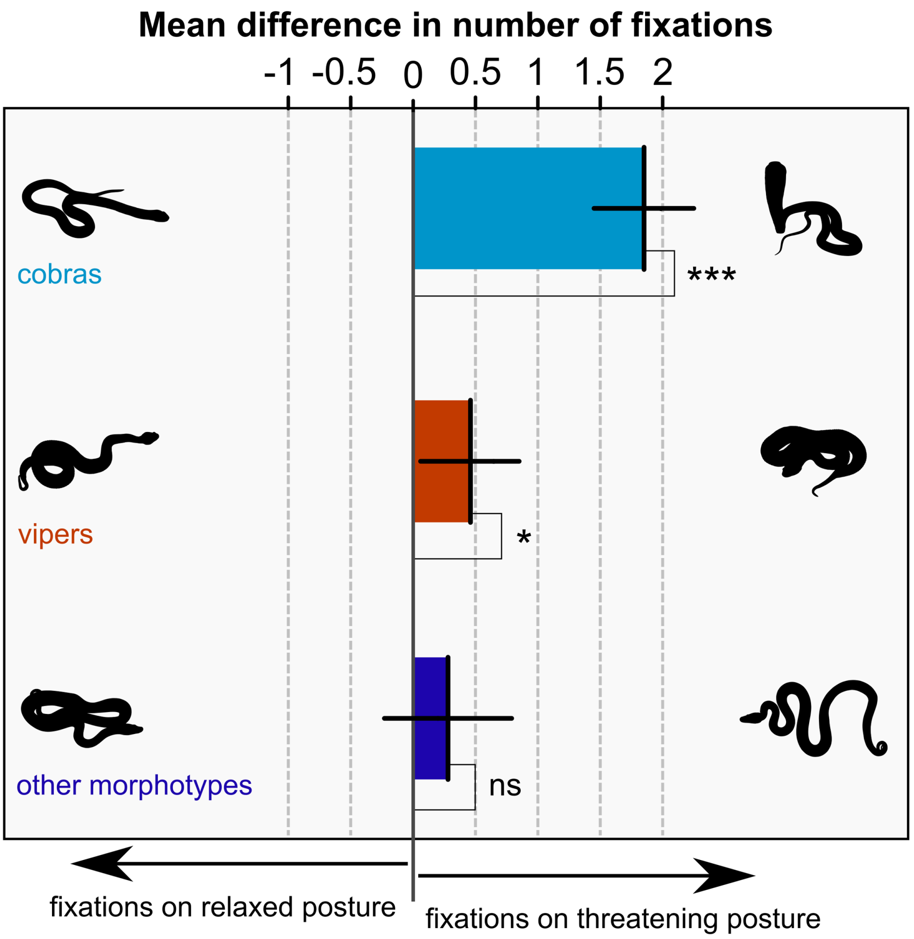

FIGURE 2
Mean difference of the number of fixations on snakes in the threatening versus relaxed posture for three snake morphotype groups. When the difference is positive, participants looked more at the threatening posture, when negative, participants looked more at the relaxed posture, zero difference signifies exactly equal attention on both. Error bars are 95% confidence intervals, means are tested against zero with significances indicated by asterisks (ns – $p \geq 0.05$; * – $p < 0.05$; *** – $p < 0.001$).

reduced model was 7.00, $p = 0.321$. For the estimated differences, the following logic can be applied. When the difference is positive, participants looked more at the threatening posture, when negative, participants looked more at the relaxed posture, zero difference signifies equal attention on both. To this end, we tested each difference against zero. Cobras in threatening posture captured 1.85 more fixations than cobras in relaxed posture (95% confidence interval 1.45–2.25), this difference was significantly different from zero ($t_{(2593)} = 9.12$, $p < 0.001$). Similarly, vipers in threatening posture captured 0.46 more fixations than vipers in relaxed posture (95% confidence interval 0.06–0.85). Whilst the difference was smaller than the one for cobras, it was also significantly different from zero ($t_{(2593)} = 2.28$, $p = 0.023$). Lastly, other snake morphotypes captured 0.28 more fixations in threatening posture than in relaxed posture (95% confidence interval − 0.23 – 0.79), however, this difference was not significantly different from zero ($t_{(2593)} = 1.09$, $p = 0.276$). For context, the average number of fixations per trial across all stimuli and participants was 18.07 for the left and right IAs combined. The results are shown in Figure 2.

There was no difference in the goodness of fit of the full and reduced model for the difference in dwell time ($p = 0.300$), hence we again chose the reduced model as the final model based on the AIC. The odds ratio between the models was 3.66. The final model for the difference of dwell time on threatening versus relaxed posture contained snake morphotype ($F_{(2,2,591)} = 12.57$, $p < 0.001$), nationality ($F_{(1,141)} = 0.94$, $p = 0.333$), and their interaction ($F_{(2,2,591)} = 4.33$, $p = 0.013$). Other factors were successively taken out of the model (gender: $F_{(1,138)} = 3.15$; $p = 0.078$; age: $F_{(1,138)} = 0.50$, $p = 0.504$; nationality – gender interaction: $F_{(1,138)} < 0.01$, $p = 0.975$). The results showed that both Somalis and Czechs gazed at cobras in a threatening posture longer than at cobras in a relaxed posture. In viper and other snake morphotype stimuli, only Czechs dwelled on the snakes in threatening posture longer; Somalis divided their attention equally. For more details, see Table 1 and Figure 3. The average dwell time per trial across all stimuli and participants was 4,368 ms for the left and right IAs combined. For average dwell times per trial of each stimulus species, see Supplementary Table S2.

4. Discussion

To summarise the results, we found that snakes in a threatening posture attracted more attention than those in a relaxed,

TABLE 1 **Results of the model for the difference of dwell time on threatening versus relaxed posture.**

Difference of dwell time (threat. − relax. posture)		Estimate	95% CI	df	*t*-value	Value of *p*
Somalis	Cobras	584.7	380–789	2,591	5.65	**<0.001**
	Vipers	15.4	−186 – 216	2,591	0.15	0.879
	Other morphotypes	148.8	−103 – 401	2,591	1.17	0.243
Czechs	Cobras	475.3	296–655	2,591	5.24	**<0.001**
	Vipers	300.2	121–479	2,591	3.32	**<0.001**
	Other morphotypes	334.5	121–548	2,591	3.10	**0.002**
Somalis vs. Czechs	Cobras	109.4	−162.7 – 381.4	141	0.79	0.428
	Vipers	−284.7	−553.7 – −15.7	141	−2.09	**0.038**
	Other morphotypes	−185.7	−515.9 – 144.5	141	−1.11	0.268

The first six estimates are tested against zero – positive values signify longer dwell time on the threatening posture, negative values on the relaxed posture, and a zero estimate signifies exactly equal attention on both. The estimated means and 95% confidence intervals (95% CI) are in milliseconds. Value of *ps* <0.05 are in bold. Df stands for degrees of freedom.

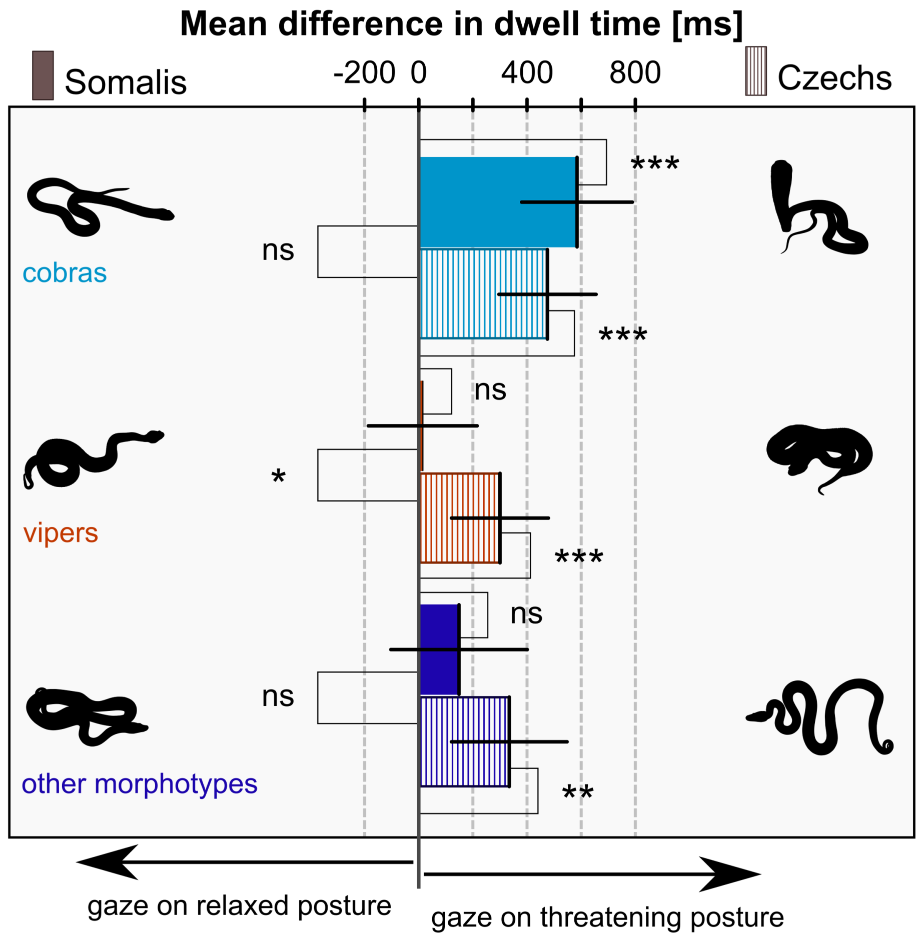

FIGURE 3
Mean difference of the dwell time on snakes in the threatening versus relaxed posture − the effect of snake morphotype and participants' nationality. Positive values signify longer dwell time on the threatening posture, negative values on the relaxed posture, and zero signifies exactly equal attention on both. All means are tested against zero (right) and means of the same morphotype are compared between Somalis and Czechs (left). Error Bars are 95% confidence intervals, significances are indicated by asterisks (ns – $p \geq 0.05$; * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$).

non-threatening posture which was manifested both in the number of fixations and the total dwell time. This was especially prominent in cobras, however, vipers in a threatening posture were also fixated more often than vipers in a non-threatening posture. Additionally, differences in dwell time revealed that Czechs dwelled on snakes in threatening posture longer no matter the snake morphotype. Contrarily, in Somalis, this held true only for the cobra morphotype; in the other two investigated morphotype groups (vipers and others) there was no difference in the attention paid to the snakes in threatening and non-threatening postures. Nonetheless, the only significant difference between Somalis and Czechs was in their reaction to vipers and specifically only in the dwell time, not the fixation count. Hence, we consider the overall pattern of reaction towards snake threatening postures relatively consistent across nationalities. We found no effect of gender.

In the last couple of years, researchers paid special attention to what features are crucial for the recognition of a snake. An early candidate in question was a curvilinear body shape. Whilst this feature can play an important role (Wolfe et al., 1992; LoBue, 2014), alone, it is most probably not sufficient as worms (of a similar curvilinear body shape) evoked a smaller reaction in an ERP study (Van Strien et al., 2016). Next, the effect of body posture was investigated. Lobue and DeLoache (2011) suggested that a snake's coiled body shape is responsible for the faster detection of snakes in relation to distractors. However, Masataka et al. (2010) argued that the striking (vs. relaxed) body posture rather enhanced the speed of detection but was not its basis *per se*. This notion was supported by Etting and Isbell (2014) in their rhesus macaque behavioural study. Recently, the topic of recognition-relevant features of snakes was reviewed by Kawai (2019). In concordance with the most current results, he concluded that snake scales are the key characteristic (He et al., 2014; Van Strien et al., 2016; Isbell and Etting, 2017; Van Strien and Isbell, 2017; Kawai, 2019). Interestingly, the importance of snake scales could be illustrated already in hominids, as some palaeolithic engravings likely represent a snakeskin (Coss and Charles, 2021). Although we agree with the studies on the importance of snake scales, this feature cannot explain the results of this study since it is the key for snake identification only in the context of other animals. Therefore, we propose to take a step back and look at the bigger picture once more.

Above, we suggested that the primate visual system is not only adapted for faster detection of snakes (Isbell, 2006, 2009) but also fine-tuned for the snake's threat display. Notably, some snake-typical features which were previously found to enhance the speed of snake detection seem to be exaggerated in snakes' threat display. In the case of vipers, such feature is the coiled shape (Lobue and DeLoache, 2011; Etting and Isbell, 2014), which is very tight under the threat creating many loops, whilst in cobras, the risen body front exaggerates the snake's curvilinear body shape (Wolfe et al., 1992; LoBue, 2014). These exaggerated features typical for threat display might be behind the larger spontaneous attention paid to snakes in threatening postures. Moreover, the erect posture (seen in threatening cobras) is very conspicuous, and many animal species take advantage of it when wanting to intimidate an opponent. Indeed, people perceive animals in an erect posture as more fear-eliciting (Prokop et al., 2021). This, however, opens a question of whether the attentional privilege of snakes in threatening posture is driven by visual or affective features. It has been previously shown that emotions can modulate attention towards a stimulus. Soares et al. (2009) reported that participants found the animal they were afraid of faster than non-feared but fear-relevant animals. Similar results were also found by Miltner et al. (2004) or Lipp and Waters (2007). The arousal might also affect visual attentional performance (reviewed in Zsido, 2023). For instance, Zsido et al. (2022) showed that stimulus arousal might be an important cue facilitating target recognition in a memory test. As for now, however, we do not have enough data to decide the extant visual and affective features of snakes in threatening posture modulate attention and it might even be that these two types of features are inseparable in nature.

Although the overall pattern of reaction towards snakes was similar for both Somalis and Czechs, we would also like to shortly address the found difference. Czechs dwelled longer at the snake in threatening posture no matter the morphotype, but the same was true only for cobras in Somalis. Could it be that Somalis differentiate (in a perceptual sense) between threatening and non-threatening postures only in cobras simply because the difference is the most conspicuous? This explanation would not fit well into the evolutionary framework and indeed, it is not the case. In a complementary study, individual photos of snakes very similar to photos used in this experiment were presented to Somalis and they were asked to order them according to elicited fear from the most to the least fear-eliciting (Frynta et al., in prep.). In this forced-choice experiment, six out of eight viper species were rated as significantly more fear-eliciting when in the threatening posture than in the non-threatening posture (Frynta et al., in prep.). We instead suggest that Somalis attribute the same level of threat to vipers no matter their body posture leading to the same observed dwell time. LoBue (2014) previously showed that knowledge or expectations can interact with low-level features of the stimuli in visual search tasks. In our case, the (communal) knowledge of the nature of cobra and viper attacks seems to be the key. Cobras are active in their defence; they either flee or display to the opponent and strike only afterwards. Vipers, on the other hand, are passive; they often rely on their cryptic coloration and motionless stance and strike when the opponent (usually unknowingly) comes too close. Even though the majority of Somali participants were university students now living in a city, most of them came from rural areas and pastoral families. We find it very likely that they personally knew someone that was bitten by a snake. When we asked local villagers, at least one person was willing to share their experiences in every village. No communal knowledge can be expected in Czechs since local snake fauna is not dangerous to humans and, moreover, participants were mostly from urban areas. This finding might be of importance for future studies since it illustrates that not all snakes are the same (see also Landová et al., 2018, 2020; Janovcová et al., 2019; Rádlová et al., 2019; Frynta et al., this issue).

To conclude, our results show that human attention is directed more towards cobras and also vipers in threatening postures. We hypothesise that it is a result of primate-snake coevolution during which not only snakes represented a danger to primates but also primates represented a danger to snakes. To be clear, we do not argue that snakes evolved specific threatening postures in response to predator pressure from primates. That is very unlikely because of multiple reasons including primates are not snake's primary predators, and the threatening postures are not addressed uniquely to primates but to a variety of other potential predators, e.g., mongooses (Herpestidae) or birds (the secretarybird *Sagittarius serpentarius*, crested seriema *Cariama cristata*, or others). We simply argue that at some point in evolutionary history, the primate-snake relationship must have become less one-sided since this is the situation we witness today (Headland and Greene, 2011; Falótico et al., 2018; see also Harris et al., 2021). As a part of their defensive behaviour, snakes would be displaying threat and these threat signals would in turn become associated with intense danger leading to prioritised attention toward threatening displays. The features of the threat display could not be reliably used for the detection of snakes because the threatening posture is a defensive behaviour and hence is not displayed when hunting for prey. Nonetheless, prioritised attention is still adaptive as the threat display signals the immediate danger of a ready-to-strike snake. Although the prioritised attention towards snakes was previously tested in several different cultures, this is the first study investigating a population from Sub-Saharan Africa – a key region with regards to the evolutionary Snake detection theory.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by The Institutional Review Board of Charles University, Faculty of Science and The Institutional Review Board of Amoud University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DF and EL: conceptualization. IŠ: data curation. IŠ and DF: formal analysis, writing – original draft, and writing – review & editing. DF: funding acquisition and supervision. IŠ, MJ, VR, HE, KR, DK, DS, DB, PF, and DF: investigation. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1234593/full#supplementary-material

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Are vipers prototypic fear-evoking snakes? A cross-cultural comparison of Somalis and Czechs

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Snakes are known as highly fear-evoking animals, eliciting preferential attention and fast detection in humans. We examined the human fear response to snakes in the context of both current and evolutionary experiences, conducting our research in the cradle of humankind, the Horn of Africa. This region is characterized by the frequent occurrence of various snake species, including deadly venomous viperids (adders) and elapids (cobras and mambas). We conducted experiments in Somaliland and compared the results with data from Czech respondents to address the still unresolved questions: To which extent is human fear of snakes affected by evolutionary or current experience and local culture? Can people of both nationalities recognize venomous snakes as a category, or are they only afraid of certain species that are most dangerous in a given area? Are respondents of both nationalities equally afraid of deadly snakes from both families (Viperidae, Elapidae)? We employed a well-established picture-sorting approach, consisting of 48 snake species belonging to four distinct groups. Our results revealed significant agreement among Somali as well as Czech respondents. We found a highly significant effect of the stimulus on perceived fear in both populations. Vipers appeared to be the most salient stimuli in both populations, as they occupied the highest positions according to the reported level of subjectively perceived fear. The position of vipers strongly contrasts with the fear ranking of deadly venomous elapids, which were in lower positions. Fear scores of vipers were significantly higher in both populations, and their best predictor was the body width of the snake. The evolutionary, cultural, and cognitive aspects of this phenomenon are discussed.

KEYWORDS

fear, evolutionary psychology, cross-cultural comparison, ophidiophobia, specific phobias

1. Introduction

Humans, and presumably other primates, are capable of rapid threat detection through visual perception and specific attention (Kawai, 2019; Kawai and Qiu, 2020), and many theorists consider humans to be predisposed to respond emotionally also to snakes. From this perspective, the fear of snakes has been an evolutionarily relevant reaction to the potential threat of dangerous snakes (Öhman and Mineka, 2003; Isbell, 2006, 2009; Kawai and He, 2016; Landová et al., 2018a). Öhman and Mineka (2001) argue that humans have an evolutionary predisposition to recognize ancestral threats, including snakes. It was proposed that such threats may elicit a complex automatic neurobehavioral response involving early detection through prioritized attention and emotional fear response, followed by an associated rapid behavioral response called the fear module (Öhman and Mineka, 2001, 2003).

However, recent neurobiological studies on non-human primates and those measuring non-invasively human brain activity when participants see snake pictures show that not only subcortical neural systems involving thalamic regions (*superior colliculus* and *pulvinar*, as well as the *amygdala*) responsible for automatic processing are activated, but also cortical neural circuits (mainly involving the right anterior cingulate cortex and medial prefrontal cortex) are specifically engaged during the fear and visual processing of snake stimuli. Moreover, there is high subcortical–cortical connectivity showing that both automatic (LeDoux, 2012), and conscious emotional and cognitive processes are at play (reviewed in Pessoa and Adolphs, 2010; Dinh et al., 2021; see also Nicula, 2020). The amygdala itself was proposed as an important center evolutionary designed to detect and avoid prior interactions with dangerous stimuli, such as snakes (Amaral, 2002; see also LeDoux, 2000, 2012). Bilateral lesions of that nucleus in adult macaques lead to a lack of fear of snakes (Amaral, 2003). The amygdala, together with the pulvinar and superior colliculus, was also activated in response to snake stimuli in tasks involving both implicit (automatic) as well as explicit (goal-directed, experience-influenced) visual and emotional processing of snake stimuli in the human brain (reviewed in Almeida et al., 2015). The metanalysis of fMRI studies reveals that the core fear network comprises the amygdala, pulvinar, and fronto-occipital cortical regions. Both implicit and explicit fear processing share this network, along with the decline of the cerebellum, fusiform gyrus, and middle frontal gyrus. Explicit fear processing activates the pulvinar and the hippocampal gyrus more, which might be related to the context of stimuli presentation and the regulation of fear prominent in explicit fear processing (Tao et al., 2021). Interestingly, Van Le et al. (2013) showed in their single-cell recording study on macaques that some pulvinar neurons are specifically responsive to snake stimuli themselves or to snake stimuli in defensive postures (Van Le et al., 2014).

Apart from the neural substrate for fear processing of snakes as threats (e.g., specific brain activation pattern in ERP studies, Van Strien and Isbell, 2017; Beligiannis et al., 2022; and fMRI studies, Almeida et al., 2015; for details see above), there have also been detailed studies on preferential attention toward snake stimuli (Öhman et al., 2001; Okon-Singer et al., 2011; Langeslag and Van Strien, 2018) that subsequently enables their fast detection (Hayakawa et al., 2011; LoBue and DeLoache, 2011; Soares et al., 2014; Kawai and Qiu, 2020; but see Coelho et al., 2019) and proper recognition (Meno et al., 2013a,b). Various psychological and physiological methods have been used to demonstrate that snakes evoke a significant fear reaction. This includes studies on facial expression (Dimberg and Thunberg, 1998), skin resistance and heart rate (reviewed in Landová et al., 2020), different aspects of the psychophysiological fear reaction (reviewed in Hyde et al., 2019), and subjective evaluation of photographs on elicited fear and disgust emotions (Rádlová et al., 2019, 2020). Interestingly, Morris and Morris (1965) found that not only is the fear of snakes prevalent, but also the attitude toward snakes is negative among both children (27% of them stated that snakes are the animals they dislike the most) and adults (24% of them would not care about snake conservation at all). This negative attitude may contribute to the evaluation of snakes as potential threat (for negative attitude toward snakes, see Prokop et al., 2009; Yorek, 2009; Ballouard et al., 2012; Pandey et al., 2016; but see also Alves et al., 2012 for positive aspects of human attitude toward snakes).

Isbell's (2006, 2009) snake detection theory (SDT) elaborates on this topic and postulates that during human evolution, snakes represented a substantial selection factor that influenced the evolution of primate vision as well as the human brain. This selection resulted in higher efficiency in detecting this particular type of threat. Isbell (2006, 2009) suggests that venomous snakes in particular played a pivotal role in the later stages of the shared evolution between snakes and monkeys, apes, and human ancestors that shaped the primate visual system and its connections to specific brain regions.

The evolutionary importance of snakes as threat-relevant stimuli is supported by studies demonstrating the innate recognition of snakes as dangerous stimuli in some primates born in captivity (e.g., macaques – Weiss et al., 2015), as well as studies conducted with other animals (birds – Smith, 1977, 1980; geckos – Landová et al., 2016). Strong evidence for pre-existing biases toward snakes comes from human studies with children and infants, which show the existence of non-associatively acquired fear in children (Coelho and Purkis, 2009). Some evolutionary relevant treats, such as snakes, can also become objects of "privileged" learning, as showed in some developmental studies (reviewed in LoBue and Rakison, 2013). LoBue and DeLoache (2008) showed that pre-school children (ages 3–5) exhibit shorter detection time in visual search tasks when identifying snake images, even among morphologically similar caterpillars. Both American (ages 2–5) and Indian children (ages 3–8, from rural and urban areas) discriminate snake and lizard pictures more quickly in similar visual search tasks and have shorter reaction times to snake stimuli (Penkunas and Coss, 2013a,b). Even very young children (8–14 months old) turned more quickly to the threatening stimuli, which included snakes and angry faces than to the neutral ones (LoBue and DeLoache, 2010; see Bertels et al., 2018 for similar results). In comparison with frogs and caterpillars, snakes also generated a specific and higher pattern of brain activity in the occipital region in 7–10 months old infants (Bertels et al., 2020). In their subsequent EEG study, Bertels et al. (2023) showed that both color as well as greyscale pictures of snakes evoked a specific pattern of activation and that this snake-specific response strengthens with age, likely reflecting the refinement of the developing visual system (Bertels et al., 2023).

The process of responding to the threats that snakes, whether in general or specific species in certain situation, may represent, is a complex process. It involves snake detection, recognition (or recognition of a particular snake category), accompanied by subjectively perceived emotions, and decision-making when it is necessary to choose an appropriate reaction toward the threat that the particular snake stimulus represents. The question is how non-human primates, as well as humans, deal with assessing snake appearance and what morphological traits contribute to subjectively perceived fear (level of threat) as well as to the detection and recognition of snakes.

Among reptiles, snakes possess a distinctive morphotype that contributes to snake recognition (Janovcová et al., 2019). In particular, one study reports that an important characteristic of threat detection is the curvilinear body shape itself, especially if the participants know that there might be a snake or when they are primed by another fear stimulus (LoBue, 2014). However, the curvilinear shape of snakes still evokes a stronger brain response than the curvilinear shape of the worms (as shown in an ERP study, Van Strien et al., 2016). When respondents subjectively evaluated the fear elicited by picture stimuli covering the full scope of morphological variability among snake subfamilies, the most salient traits of the snake were body width and head length (Rádlová et al., 2019). When respondents evaluated live kingsnakes (*Lampropeltis*), the body size and the black color were the salient stimuli (Landová et al., 2012). The typical snake scales, as well as the different patterns that scales form on the snake's body, are important features for early selective visual processing, as shown in studies using the event-related potentials in humans (Van Strien and Isbell, 2017; see also Kawai, 2019). Even very young children (7–15 months old) poked more at plastic cylinders with snake scale patterns, and even younger children (5 months old) gazed longer at them compared to those with geometric shapes or plain colors (Coss and Charles, 2021). Ethological studies on non-human primates also report that vervet monkeys (*Chlorocebus pygerythrus*) are able to detect and recognize snakes based on small pieces of snakeskin only (Isbell and Etting, 2017). Similarly, Colombian white-faced capuchin monkeys (*Cebus capuchinus*) respond more intensively with antipredator behavior if scales were present on a snake model (Meno et al., 2013a). Interestingly, the color of snake stimuli (except for a minor effect of color contrast) did not facilitate a specific pattern of brain activation in very young infants (Bertels et al., 2023). Even the aposematic coloration of some snakes does not increase the fear of snakes (Prokop et al., 2018).

We suggest that the source of natural selection (being endangered by venomous snakes) that contributed to the rapid detection of snakes may persist in modern times (at least in some areas, see below). Many modern human populations have current as well as evolutionary experience with different types of snakes; some of these snakes represented danger mainly in the evolutionary past, while others (namely venomous snakes, reviewed in Landová et al., 2021) continue to pose a serious threat to people even today (Akani et al., 2013; Pandey et al., 2016; Onyishi et al., 2021; Staňková et al., 2021). As the evaluation of the threat that animals may represent encompasses implicit automatic reactions, as well as long-term goal-directed cognitive and emotional evaluations labeled as explicit processes (Effting et al., 2016), we can assume that both processes collaborate in the subjective evaluation of fear elicited by particular animal species. This level of subjectively perceived fear may be related to overall decision-making about the potential level of threat, and it is also connected with the subsequent behavioral reaction (see Landová et al., 2023, for how the subjective fear evaluation of pictures and individual fearfulness are related to overall brain activity). This raises the question of whether modern humans can distinguish venomous snakes from non-venomous snakes based on the degree of subjectively perceived fear and how this degree of subjectively perceived fear is affected by the risk that venomous snakes pose today and in the evolutionary past (Bertels et al., 2023).

There are some pieces of evidence indicating that people are able to recognize dangerous venomous snakes. In our previous papers, we selected from a wider variability of snake species those that evoked high fear (while evoking low disgust) when presented to the participants in the picture. Many of these species were vipers (Rádlová et al., 2019, 2020). Subsequently, these fear-evoking snakes elicited stronger psychophysiological emotional reactions measured as a change in skin resistance and heart rate (Landová et al., 2020). In a cross-cultural comparison between the Czech population (where the risk of snakebite is low) and the Azerbaijani population (where the risk of envenomation is relatively high), we found that both populations fear the cobra (but only when presented in a threatening posture) and vipers the most. Interestingly, there was a high cross-cultural agreement on the subjective emotional evaluation of pictures, even though the attitude toward snakes was generally more negative in Azerbaijan. However, only one species of cobra was included in this set of picture stimuli, hence the potential discrimination between cobras, vipers and non-venomous snakes could not have been tested (Landová et al., 2018a).

From a cognitive perspective, the task of ranking multiple snake species according to the level of fear they evoke becomes a categorization task, especially when some of the snakes are or were dangerous to the investigated population in their evolutionary past while others are (were) not. Categorization of emotionally relevant stimuli is a cognitive process (Meriau et al., 2006; Brosch et al., 2010; Wieser and Brosch, 2012; Harnad, 2017), in which both the perceptual similarity of the objects and emotional sensitivity to the feared objects play important roles (Landová et al., 2021). This cognitive process involves transforming a real object that triggers emotions into a percept, representing the accessible subjective experience associated with the activation of a certain category in the mind (Brosch et al., 2010). Furthermore, this process influences extended attention toward evolutionarily relevant threatening stimuli (Grassini et al., 2019).

This cognitive process is influenced by the evolutionary past, the current risk represented by the snakes in the respective countries, and the local culture. In cross-cultural comparisons, these three major factors may influence both investigated populations similarly (such as the evolutionary past) or their effect may substantially differ (such as the risk of envenomation that could correlate with the abundance of deadly venomous species or the various cultural backgrounds). Each of these key factors is applicable to modern humans in general, and their specific effects on Somali and Czech populations need to be introduced. Firstly, we will delve into the evolutionary history of human ancestors, beginning with the earliest hominids. We will focus on the two regions of interest relevant to this paper (i.e., the Horn of Africa and Central Europe) in order to establish the extent of shared evolutionary history. We will also introduce the evolutionary history of venomous snakes in Africa and the regions through which current Europeans migrated with the intent of establishing the approximate length of sympatry between respective human populations and region-relevant fauna of venomous snakes. Secondly, we will estimate the current risk that the venomous snakes represent in Somaliland and the Czech Republic. Thirdly, we will describe the attitudes toward snakes specific to Somali and Czech cultures based on unstructured interviews with locals as well as our own experiences in these locations.

1.1. Primate evolution in Africa

Phylogeographic analyses suggest that the common ancestor of Hominoidea (gibbons, great apes, and humans) and Cercopithecoidea (Old World monkeys) was living in the Asian continent (Springer et al., 2012). The divergence time between these two superfamilies of

Old-World primates (Catarrhini) was estimated to be the Oligocene period (Springer et al., 2012), during which the first fossils of the monkey *Aegyptopithecus zeuxis* are reported from the Egyptian oasis Fayum (Simons et al., 2007). This fossil is currently interpreted as stem catarrhine (Urciuoli et al., 2021). In the Miocene, multiple ape species were distributed across Africa, Arabia, S and SE Asia, and even Europe (Almécija et al., 2021). Some authors have emphasized the hominin affinities of certain European Miocene hominids (Begun et al., 2012; Fuss et al., 2017; Kirscher et al., 2021), suggesting a potential role for Europe and the Near East in human evolution during that period. Nevertheless, hominines, i.e., gorillas and chimpanzees, ~7–6 million year-old fossils of *Sahelanthropus* and *Orrorin*, ~4–3 million year-old australopith fossils, and early *Homo* are found exclusively on the African continent (Senut et al., 2001; Almécija et al., 2021). Thus, it is more parsimonious to consider that human evolution took place there. The split between gorillas and the human-chimpanzee clade is currently estimated to be ~11 million years ago (Langergraber et al., 2012). This provides the shortest estimate of the time our ancestors spent in the African environment. For this long period, they were exposed to the pressure of local snakes. Nevertheless, for a considerable portion of this time, our ancestors, including the last common ancestor with chimpanzees (~9.3–6.5 my, Moorjani et al., 2016), inhabited forest habitats rather than savannas (Andrews, 2020).

1.2. Evolution of human ancestors in the African horn

African continent, namely its eastern part including the African Horn is usually declared as the cradle of humankind. The African Horn and adjacent parts of East Africa belong to the regions with the best-documented fossil record of early hominines including australopithecines, as well as *Homo ergaster/erectus* (Clark et al., 1994; Abbate et al., 1998; Asfaw et al., 2002; Profico et al., 2016; Gallotti and Mussi, 2017) and ancestor of modern humans usually referred to as *H. heidelbergensis/H. rhodesiensis* (e.g., locality Bodo, 600 thousand years ago; Conroy et al., 2000; Rightmire, 2009). This also concerns early modern humans. Fossils of the earliest anatomically modern humans are exclusively of African origin (Stringer, 2016). There are fossil records, e.g., from Ethiopian Awash (locality Herto, 154–160 thousand years ago, White et al., 2003,) and Omo (locality Kibish, 195 thousand years ago, McDougall et al., 2005). Some scholars are placing even older Mid-Pleistocene fossils from various African sites to this lineage (Gibbons, 2017), this especially concerns those of Moroccan Jebel Irhoud (~300 thousand years ago, Hublin et al., 2017; Richter et al., 2017).

Taken together, this suggests a continuous presence of human ancestors in the African Horn and more generally speaking the Ethiopian and East African Rift Valley, which clearly suggests that human evolution occurred in this region. This means that animal species present during this evolutionary history in this landscape had a chance to interact extensively with human ancestors. However, the original hypotheses suggesting that savannas east of the Rift Valley represent the only area of human evolution were already falsified by the presence of multiple fossils outside this region in other parts of Africa (Hublin et al., 2017; Richter et al., 2017). Moreover, genetic data revealed multiple admixture events within Africa during the Mid-Pleistocene period, e.g., ghost archaic introgression in African populations (Durvasula and Sankararaman, 2020) and human immigration flow from South Africa to East Africa ~70 thousand years ago (Rito et al., 2013, 2019). Archeologic and paleoclimatic data suggest that human populations during the Mid-Pleistocene were at least strongly divided temporarily by environmental barriers (Saharan region – Scerri et al., 2014, Eastern versus Southern Africa – Rito et al., 2019).

The region of the African Horn also represents the suggested source area for colonization of the Arabian Peninsula and Asia by anatomically modern humans via the Bab Al-Mandab (for Out of Africa scenarios, see Groucutt et al., 2015).

1.3. Sources of human populations in Central Europe

After crossing the border of the African continent (>50,000 bp, Bergström et al., 2021), modern humans immigrated to the Arabian Peninsula and the Middle East area, where they hybridized with the Neanderthals (*Homo sapiens neanderthalensis*). Then they rapidly colonized South Asia and Sahul (New Guinea and Australia). The first wave of modern humans reached Central Europe ~45, 000 years bp. However, genetic data clearly showed that current Europeans are not descendants of these early Palaeolithics (Prüfer et al., 2021). European populations are a mixture of at least three source populations: (1) The Western hunter-gatherers, descendants of the second wave of European Palaeolithics, (2) the Western early farmers (Anatolian neolithics), and (3) the Ancient Euro-Asians (Lazaridis et al., 2014, 2016). In the contemporary populations of Central Europe, the third component is dominant (Haak et al., 2015). It can be attributed to massive immigration from the Russian steppes around 4,800 years bp that substantially changed the genetic composition of the human populations in Central Europe (Olalde et al., 2018; Papac et al., 2021).

1.4. Venomous snakes of Africa

Many snakes and some lizards belonging to the clade Toxicofera (Reptilia: Squamata) produce toxins (Fry et al., 2009, 2012; Dobson, 2022), but truly venomous snakes possess also specialized fangs. Besides vipers (Viperidae) and rattlesnakes (Crotalidae) with specialized solenoglyphous fangs, there are two families – Atractaspididae and Elapidae – that evolved proteroglyphous fangs (Portillo et al., 2019; Westeen et al., 2020). Moreover, there also are a few highly toxic colubrids, like African boomslangs of the genus *Dispholidus*, which are equipped with fangs morphologically closely resembling those of elapids (Westeen et al., 2020). Except for pit vipers (Crotalinae), which are distributed solely in Asia and America, all the other families of venomous snakes are represented in Africa and therefore are relevant to potential interactions with human ancestors.

1.5. Phylogeography and evolutionary history of African venomous snakes

Viperids diversified during the Eocene/Oligocene boundary, but their ancestral area is not well-resolved (Asia/Arabia/Africa). The earliest split separates the purely African genus *Causus* from the remaining viperids. Next Early Oligocene split separates Asian and/or

European vipers from the Afro/Arabian clade consisting of five genera that split in the Oligocene. While the clade comprising genera *Proatheris*, *Atheris,* and *Bitis* is exclusively African, the other one, consisting of *Cerastes* and *Echis* is distributed in both Africa and Arabia/Asia (for details see Pook et al., 2009; Šmíd and Tolley, 2019). Thus, it is still uncertain whether the genus *Echis* evolved in Africa or Arabia and thus, we are unable to set precise dating of its evolutionary interactions with human ancestors living in the African continent. Nevertheless, *Echis* was likely present in Africa from the Miocene, most probably from the Middle Miocene period (~16 million years, Šmíd and Tolley, 2019). In contrast to *Echis*, the long-term continual presence in Africa, biogeography and ecology of its diversification are well-documented in the case of the genus *Bitis* (Barlow et al., 2019). These vipers are currently distributed across Sub-Saharan Africa (+Morocco and S Arabia) from lowlands to high mountains and from wetlands to xeric habitats. The position of the giant species of *Bitis* on the phylogenetic tree suggests that large-bodied forms possessing high amounts of venom are not of recent origin.

Elapidae belongs to the clade Elapoidea which evolved and radiated in Africa during the late Eocene and comprises also families Lamprophiidae, Pseudoxyrhophiidae, Atractaspididae, and Psammophiidae (Kelly et al., 2009; Zaher et al., 2019). Elapids radiated initially in Asia during Oligocene. African mambas represent a sister clade of Asian King cobras (*Ophiophagus*). African cobras form a distinct clade also including some Asian species. Both these clades, i.e., mambas and cobras, evolved in Africa during the Miocene period (ca 20 million years ago, Kelly et al., 2009).

Atractaspididae is of African origin. The Guinean-Congo region is probably an ancestral area of this clade that further radiated, namely in the Zambezian region, during the Oligocene and Miocene periods (Portillo et al., 2018, 2019).

We can conclude that venomous snakes (solenoglyphous vipers, and proteroglyphous elapids and atractaspidids) currently inhabiting the African continent and representing a risk for humans have been already present in Africa for the last 30–20 million years. Also, the remaining principal clades of African caenophidian snakes have a long history on this continent as exemplified by the genus *Telescopus* of the family Colubridae (Šmíd et al., 2019) and families belonging to Elapoidea.

1.6. History of interactions between the Europeans and venomous snakes

On the way from Africa to Central Europe, ancestors of the Europeans were exposed to multiple viper species. While the snake fauna of the Arabian Peninsula and adjacent areas resembles that of North-Eastern Africa, the Middle East has its own vipers of the genera *Macrovipera*, *Montivipera*, *Daboia,* and *Vipera*. Especially, the Levant viper (*Macrovipera lebetinus*) is large-sized, deadly venomous, and widely distributed across the region. The Volga River region of Russia which represents the source area of the Eneolithic migration wave to Europe (see above) is inhabited by the Karaganda pit viper (*Gloydius caraganus*). It is a small-sized moderately venomous species belonging to the genus *Gloydius* of Central Asian origin that diverged about 2.5 million years ago (Asadi et al., 2019). Smaller insectivorous species of adders from the *Vipera ursini-renardi* complex (Mizsei et al., 2017) resemble other viper species, but due to their smaller size, they are much less venomous. They have a highly fragmented distribution, ranging from Eastern France to Western China (Nilson and Andrén, 2001). Fossil records are known from the lower Pleistocene (0.8–1.8 million years) from the Czech Republic (Szyndlar, 1991). This *ursini-renardi* complex was not of interest because it did not represent a risk for humans. The adder or Northern viper (*Vipera berus*) is the only venomous snake currently reported from the central and northern parts of Europe. The geographic range of this adder is the largest among snake species, it extends from Western Europe to Siberia and the Far East, and even crosses the Polar Circle in the North. All northern populations of the adder across Eurasia are genetically similar forming a single clade (Cui et al., 2016). The evolutionary roots of the species are in Southern Europe as suggested by the presence of the distinct mitochondrial clades in the Balkan Peninsula and Northern Italy, and the occurrence of related species of the genus *Vipera* there (Ursenbacher et al., 2006). Recently, palaeontological data confirmed the presence of the adder in Central Europe during the late Pleistocene glacial period (Ivanov and Čerňanský, 2017). Thus, the adder has been present there since the appearance of the first populations of modern humans.

1.7. Conclusion on the history of interactions between venomous snakes and Somalis and Czechs

It seems certain that the genus *Homo* evolved in Africa. Based on the split between gorillas and human-chimpanzee clade, humans and human ancestors have inhabited the African continent for at least the last 11 million years. During this whole time, highly venomous snakes including African mambas, cobras, and vipers of the genera *Bitis* and *Echis* were already present on the continent as these clades came to Africa no later than 16 million years ago (Barlow et al., 2019; Kelly et al., 2009; Šmíd and Tolley, 2019). Thus, at least 11 million years long evolutionary interaction between human ancestors and these groups of venomous snakes can be expected. There is no reason to suspect that Somali ancestors ever left the African continent (or adjacent Arabian Peninsula) thus their evolutionary experience with investigated snake stimuli is uninterrupted.

Contrarily, Czech ancestors at some point left the African continent. While the precise date is currently not known, it was probably between 100,000 and 50,000 years ago (Groucutt et al., 2015; Bergström et al., 2021). It is assumed that they spent a significant amount of time in the wider Middle East area before migrating further north and finally arriving in Central Europe by different routes, mainly through the Russian steppe around 5,000 years ago. The ophiofauna of the passed-through regions has been increasingly less diverse. While there are still several highly venomous species of vipers and cobras in the Middle East, only "moderately" venomous viper and pit vipers are present in Siberia and the Russian Steppes. Finally, only one "moderately" venomous viperid (*Vipera berus*) and no elapid species can be found in Central Europe. It can be concluded that Czech historical experience with vipers, in general, is also uninterrupted, although, during the last several thousand years, the viper diversity and objective fear relevance significantly decreased. Since leaving the Afro-Arabian region, Czech ancestors have not been exposed to elapids furthermore. However, some animal studies show that caution and antipredator behavior toward predators may persist even after thousands of years of relaxed natural selection due to the absence of their former predators (Coss, 1991, 1999; Blumstein, 2006).

1.8. Current significance of venomous snakes as a selective pressure upon human populations

Snake bites have been considered only a marginal source of human mortality until recently. The annual number of envenomations and deaths in the entire Sub-Saharan Africa was estimated to be 314,078 and 7,331, respectively (Chippaux, 2011). Recent update reports 268,471 cases of envenomation, 12,290 deaths, and 14,766 amputations (Halilu et al., 2019). This results in a health burden comparable to other neglected tropical diseases (Habib et al., 2015). The real snake bite-envenomation burden is probably underestimated due to incomplete reporting. Moreover, the mortality of patients who do not attend modern health centers is roughly four times higher (Chippaux, 2011). In recent years, studies reporting the incidence of snake bites and consequent human mortality were performed also in the Philippine Agta (Headland and Greene, 2011), an indigenous community in Southeast Nigeria (Onyishi et al., 2021), or the countries of African Horn (e.g., Aga et al., 2014; Fekadu, 2016). Unfortunately, most snake bites are carried out during the night and relevant determination of the snake is missing in most cases (e.g., Nhachi and Kasilo, 1994).

1.9. Deadly venomous snakes in the African horn and Central Europe

In Somaliland, both vipers and elapids represent a considerable source of envenomation and mortality. Northeast African carpet viper (*Echis pyramidum;* Figure 1A) and puff adder (*Bitis arietans*) are deadly venomous viperids and they both belong to common snakes in Somaliland (Lanza, 1990). Although the range of the Egyptian saw-scaled viper is geographically restricted to lowland semi-deserts and dry-savannas, it is locally highly abundant in certain areas of Somaliland. All elapid species living in the territory of Somaliland are highly venomous (Ainsworth et al., 2018), especially the black mamba (*Dendroaspis polylepis;* Figure 1B), but also the Egyptian cobra (*Naja haje*), the red spitting cobra (*N. pallida*), and the giant spitting cobra (*N. ashei*).

The European common viper (*Vipera berus*) is the only venomous snake reported from the central and northern parts of Europe. In the Czech Republic, cases of envenomation are rare, and fatalities have not been reported for at least two decades (Valenta, 2010). The current risk of envenomation and subsequent injury or death is still substantial in Somaliland but negligible in the Czech Republic.

1.10. Cultural attitude toward snakes in Somaliland and the Czech Republic

Attitudes toward snakes differ between the two studied populations. Preliminary interviews with Somali pastoralists and students revealed that their attitude toward snakes is very negative. They relate negatively to all snakes and, for example, have a hard time believing that some people may like snakes and consider them beautiful. Their attitude toward animals in general is strongly driven by their potential use and snakes are considered useless at best. They do not hesitate to deliberately kill a snake in case of an accidental encounter. Most participants were able to recognize a few snake species, usually the most dangerous or the most common. For example, the Northeast African carpet viper is small and difficult to notice but also abundant and highly venomous, making it probably the most lethal snake of Somaliland. This species is well known among the people and Somali participants frequently recognize it among images shown to them.

The attitude of the Czech population is rather ambivalent. On the one hand, children are already taught in elementary school what a viper looks like and that it is venomous. On the other hand, all snakes are protected by Czech law and their value for the ecosystem is also taught. The predominant reaction is to keep a distance from the snake due to fear. Although most people reported the experience of encountering a snake in nature, very few people have ever killed or seen someone kill a snake. In cases when they reported this experience, it mostly happened in the context of traffic or other accidents (Landová et al., 2018a). There is a small but not insignificant number of Czechs that keep snakes as their pets. Moreover, a large part of the population can appreciate the beauty of at least some snakes (Janovcová et al., 2019).

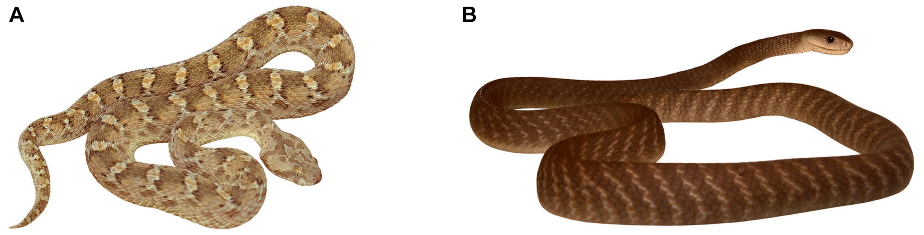

FIGURE 1
The most dangerous snakes of the African Horn. **(A)** Northeast African carpet viper *Echis pyramidum*, authors of the original photo Daniel Frynta and Petra Frýdlová. **(B)** Black mamba *Dendroaspis polylepis*, author of the photo Martin Smrček. These photos were used with the permission of the authors.

1.11. Aims and predictions

The aims of this paper are as follows: (1) To assess whether participants exhibit more subjectively perceived fear of deadly venomous snakes compared to non-venomous or slightly venomous ones. As there are two clearly distinct categories of deadly venomous snakes in Africa and adjacent Eurasia, the vipers and the elapids, we included both these groups. Non-venomous snakes were also represented by two categories: the sand boas and the non-elapid Elapoidea + Colubroidea. If participants do not differentiate between the snakes in terms of subjectively perceived fear elicited by the stimuli (null hypothesis), there should be a low agreement among participants regarding which snake is subjectively perceived as the most fear-evoking. Conversely, if there is high congruence, we will analyze whether the respondent's subjective fear is associated with particular species or group(s), and further, whether any morphological features of the snakes are correlated with the propensity of elicited fear. (2) To compare the fear ranking of Somali and Czech participants. Cross-cultural agreement in the subjective fear evaluation of snakes would provide additional support for the findings of developmental studies (see above), suggest strongly that the mechanisms regulating fear are innate. Specifically, such a result might reflect an innate modulation of higher cognition resulting from exposure to snakes during human evolutionary history. Conversely, an opposite result would favour the role of current experience and/or local culture.

2. Materials and methods

2.1. The Somali respondents

We performed the research at the campus of Amoud University in Borama. Most of the respondents were undergraduate students of various fields who agreed to voluntarily participate in the experiment. The students came not only from the Borama region itself but also from other provinces of Somaliland and adjacent Somali-speaking countries. A total of 155 Somali respondents finished the task (for the data see Supplementary Table S1). They were 122 men and 33 women. The mean age was 21.95 years (median = 22, range 18–27).

2.2. The Czech respondents

We gathered the respondents among students, mostly of technical and other non-zoological disciplines. Although all students and staff were tested at universities in the capital city of Prague, they come from different parts of the Czech Republic, from smaller towns and villages. They were 90 men and 54 women. The mean age was 19.65 years (median = 19, range 18–42).

2.3. The stimuli

We selected 48 snake species belonging to four distinct groups, each represented by 12 species/subspecies. The first two groups comprised highly venomous snakes: (A) The vipers of the family Viperidae belonging to the genera *Bitis*, *Cerastes*, *Echis*, *Macrovipera*, *Montivipera* and *Vipera*. Two representatives of each viperid genus were included. (C) Cobras and mambas of the family Elapidae including 9 cobras of the genus *Naja*, as well as the Cape coral cobra (*Aspidelaps lubricus*), and the black mamba *(Dendroaspis polylepis)*. Moreover, we included into this category boomslang (*Dispholidus typus*), a highly venomous colubrid morphologically resembling the elapids. The remaining two categories comprised non-venomous (or only mildly venomous) snakes. (B) Sand-boas of the genus *Eryx* (11 species) and rubber boa (*Charina bottae*) represented a category of fossorial boids, while the remaining species (further referred to as "colubrids") belong to (D) families Colubridae (*Crotaphopeltis, Philothamnus*, *Telescopus,* two species of *Platyceps* and *Dasypeltis*), Psammophiidae (two species of *Psammophis*) and Lamprophiidae (two species of *Boaedon* and *Limaformosa capensis*). For a complete list of the species and scientific names of the stimuli see Supplementary Table S2.

2.4. Stimuli preparation

For each species from the list, we selected a relevant picture. The source photographs were adopted from the authors' archives and archives of Tomáš Mazuch; half of the species were from online sources (see Supplementary Table S2). To avoid possible effects of the background and size of the stimulus on rankings, we digitally placed the animals on a white background. We also resized them so that the pictured animals were of a similar size. For the example of experimental stimuli, see Figure 2. Then we printed the final stimuli as photographs 100 × 150 mm in size. We previously showed that fear evaluation of standardized pictures highly correlates with that of live animals (Landová et al., 2012).

2.5. Extraction of morphological characteristics

To analyze the shapes of snakes that evoke the greatest fear in humans, we extracted 9 morphological characteristics. Using Image Tool (Wilcox et al., 2002), the measured traits were total body length, body width, head length and width, neck width, tail width and eye diameter, all traits are in millimeters and were not further modified for analysis. Additional characteristics were extracted using the Image J (Rasband, 2016) program, specifically perimeter and body area (silhouette), both measured in pixels. The body area was square-root transformed for analysis, the perimeter was not modified. All morphological characteristics (Supplementary Table S3) were measured on standardized photos of the stimuli because we were interested in how people perceived the depicted snakes. For this reason, the real body dimensions of the included species were not used.

2.6. The task

At the beginning of the task, a respondent was standing in front of a well-lit table. We provided him/her with a set of 48 pictures packed in random order. We asked the respondents to imagine the pictures as real animals. Then we asked him/her to place all stimuli on the table in a random assemblage. This sometimes required assistance

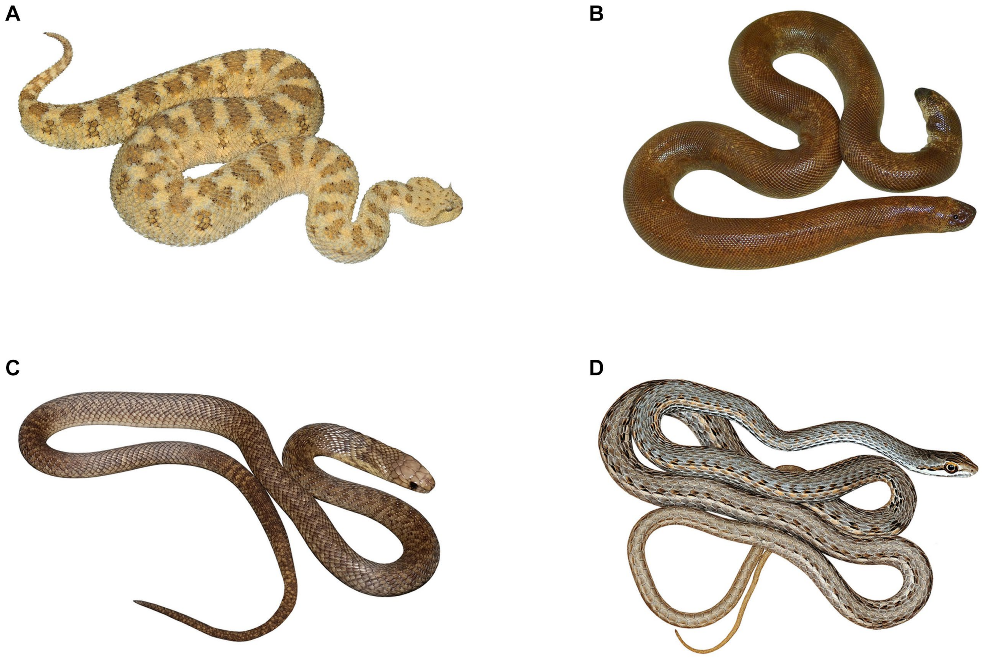

FIGURE 2
The example of experimental stimuli. The set of photos of snakes (48 stimuli) contains four distinct categories, differing in the level of danger and body shape. Category **(A)** – vipers (desert horned viper *Cerastes cerastes*, authors of the original photo Daniel Frynta a Petra Frýdlová), category **(B)** – sand boas (red sand boa *Eryx johnii*, author of the photo Markéta Janovcová), category **(C)** – elapids (Egyptian cobra *Naja haje*, authors of the photo Daniel Frynta a Petra Frýdlová) and category **(D)** – "colubrids" (Tanganyika sand snake *Psammophis tanganicus*, author of the photo Tomáš Mazuch). These photos were used with the permission of the authors.

to ensure that the stimuli were oriented properly, i.e., the top margins of the stimuli were oriented toward the top of the table. The task was to pick up the picture of an animal that was the most fear-evoking, then to pick up the second most fear-evoking one, until he/she picked up the least fear-evoking stimulus on the table. In the end, the respondent had a whole pack of pictures in his/her hand. Finally, each respondent was asked for age information and their gender was recorded. The entire task took most respondents approximately 15 min. The picture order in the pack was then coded from 1 (the most fearful one) to 48 (the least fearful one), further referred to as ranks.

We previously applied this rank-order method in multiple studies evaluating either the beauty of animal stimuli (e.g., Marešová et al., 2009a,b; Frynta et al., 2011, 2013; Lišková and Frynta, 2013; Landová et al., 2018b) or emotions evoked by animals (e.g., Rádlová et al., 2019). It maximizes the informative content of the respondents' judgment by covering the full ordination scale (Lišková et al., 2015). We repeatedly demonstrated that mean ranks were highly correlated to scores produced by the 5- or 7-point Likert scale (e.g., Frynta et al., 2010; Rádlová et al., 2020).

We are confident that we are measuring subjectively perceived fear by this method. In previous research, we established a correspondence between the evaluation of the level of subjectively perceived fear elicited by pictures of snakes or spiders, psychophysiological reactions (such as skin resistance and heart rate), and the intensity of brain activity that we measured in fMRI. The majority of these parameters related to the level of subjectively perceived fear, elicited by snake or spider photographs, also closely aligned with the behavioral parameters measured in the behavioral approach test (Landová et al., 2020, 2023). Furthermore, in non-human primates, realistic photographs (in size and color) placed in the natural context, stimulate anti-predator behavior in capuchin monkeys (Meno et al., 2013a,b). Therefore, using photos of snakes should yield similar results as presenting actual snakes. Hence, this method can serve as an efficient protocol to initiate decision-making in perceivers regarding any particular snake species based on their subjectively experienced emotions.

2.7. Ethical note

The study was approved by the Institutional Review Board of Charles University, Faculty of Science (approval no. 2019/2011, granted on 27 March 2019) and Amoud University, School of Postgraduate Studies & Research (approval no. AU/AA/0012/2021, granted on 7 January 2021).

2.8. Data analysis

As the data were ranks, we adopted non-parametric statistics which are appropriate for analyzing these datasets. In order to quantify agreement among the respondents, we computed Kendall's coefficient W, as implemented in the package irr (Gamer et al., 2012). To compare the mean ranks of individual stimuli we first calculated the Friedman test enabling us to prove the significant effect of species. Then we employed the *post-hoc* Friedman-Neményi test permitting reliable multiple comparisons among the stimuli. The output was a matrix of *p*-values. These tests are available in PMCME and PMCMRplus packages (Pohlert, 2014). In addition, we employed RDA (Redundancy Analysis), as implemented in the package vegan (Oksanen et al., 2020), to assess the variance in the original data which is constrained by country, gender, age and their interactions. All these calculations we carried out in R-environment (R Development Core Team, 2012).

We calculated the means and median values of ranks for each stimulus/species. The values were further analyzed. To obtain more intuitive values increasing with fear (not decreasing as original ranks and its means) and ranging from 0 to 100, we calculated the following index: Fear = 100–(100 * (median rank – 1)/(the number of examined stimuli – 1)).

To compare fear elicited by different groups (categories) of snakes, we ran the Kruskall–Wallis test with *post-hoc* comparisons. We also employed a cluster analysis to uncover groups of stimuli treated by the respondents in a correlated way. We extracted the dissimilarity matrix from the ranking dataset (1-Pearson's r) and applied Ward's method of clustering. These calculations were performed in Statistica 9.1 (StatsSoft Inc, 2010).

3. Results

3.1. Agreement among the respondents

We found significant agreement among 155 Somali respondents as well as among the 144 Czech ones. Kendall's coefficients of concordance (Wt) were 0.131 (chi-square$_{(47)} = 951$, $P << 0.0001$) and 0.269 (chi-square$_{(47)} = 1818$, $p << 0.0001$; men: $n = 90$, $Wt = 0.280$; women: $n = 54$, $Wt = 0.263$), respectively. The descriptive statistics for each stimulus are given in Supplementary Table S4.

The RDA with permutation test revealed that the effects of gender and age on the evaluation of the stimuli are negligible. The best model (AIC = 2667.74) includes the country (Somali vs. Czech) as the only factor constraining 4.03% of the variation in the entire data set (anova: $F_{(1,297)} = 12.48$, $p < 0.001$).

3.2. *Post-hoc* comparisons among stimuli species

Friedman tests proved that the effect of the stimulus on perceived fear was highly significant in both Somali and Czech datasets ($p << 0.0001$). Thus, we calculated Friedman-Neményi comparisons among stimuli (= snake species). Out of 1,128 *post-hoc* comparisons among the stimuli, 458 (40.6%) and 610 (54.1%) were significant in the Somali and the Czech datasets, respectively ($p < 0.05$, for the matrices of p-values, see Supplementary Tables S5, S6).

3.3. The patterns of elicited fear among the stimuli

In the Somali sample, vipers appeared to be the most salient stimuli. They occupied all the first eight as well as the 10th, 11th, 17th, and 18th positions according to subjective fear. Thus, 10 of 12 viperids were placed above the upper quartile. This strongly contrasts with the fear ranking of elapids. The only elapid placed above the upper quartile was *Naja mosambica* on the 9th position. Interestingly, 8 out of 12 species below the lower quartile were deadly venomous elapids, the black mamba (*Dendroaspis polylepis*) being at the bottom of the fear ranking (Figure 1B; Supplementary Table S4).

In the Czech sample, the privileged position of the vipers is even more pronounced, they occupy all 12 places above the upper quartile. They are followed by the sand boas occupying eight of the remaining 12 positions above the median fear (i.e., in between the upper quartile and median). Elapids, except of *Aspidelaps lubricus*, *Naja pallida* and *N. mosambica*, are below the median fear value.

3.4. Comparing categories of examined snakes

The distribution of subjectively perceived fear among the four *a priori*-defined groups of snake stimuli is visualized in Figure 3. Kruskall-Wallis test revealed a strong effect of the snake group on elicited fear (Somali: $H = 25.89$; Czech: $H = 31.75$, both $p < 0.0001$). Within both data subsets, the subjective fear scores of vipers were significantly higher than those of sand boas (Somali: $z = 3.22$, $p = 0.0076$; Czech: $z = 2.88$, $p = 0.0239$), elapids (Somali: $z = 4.71$, $p < 0.0001$; Czech: $z = 4.88$, $p < 0.0001$) and "colubrids" (Somali: $z = 3.97$, $p = 0.0004$; Czech: $z = 2.83$, $p < 0.0001$).

3.5. Clustering species according to correlated fear ranks

The tree extracted from fear ranks provided by the Somali respondents has two main branches, each comprising 24 snake species. One contains 11 vipers, 6 sand-boas, 5 elapids and two "colubrids." The other one, just 1 viper, 6 sand-boas, 7 elapids and 10 "colubrids" (see Supplementary Figure 1).

The tree extracted from the Czech dataset reflects our groups of species more closely. The main branching of the tree corresponds almost precisely to a split between vipers + sand-boas, and elapids + "colubrids." While elapids and "colubrids" are fairly intermixed within the latter branch, the former one further splits into two distinct branches. One of them includes all vipers, while the other one all sand boas. The position of *Naja mosambica,* belonging to elapids, within the clade of the sand-boas, represents the only violation of this clear pattern (see Supplementary Figure 2).

3.6. Correlates of the fear

We calculated Pearson Product–Moment correlation coefficients between fear and visceral traits of the stimuli photographs. The results showed that body width is a good predictor of fear, this relationship we found in both the Somali ($r = 0.799$, $df = 47$) and the Czech ($r = 0.815$, $df = 47$) datasets (see Table 1; Supplementary Figures 3, 4).

3.7. Cross-cultural agreement

We detected a considerable correlation between fear indices (see under the Materials and Methods) of the examined snake stimuli assessed in the Somali and the Czech respondents (Pearson

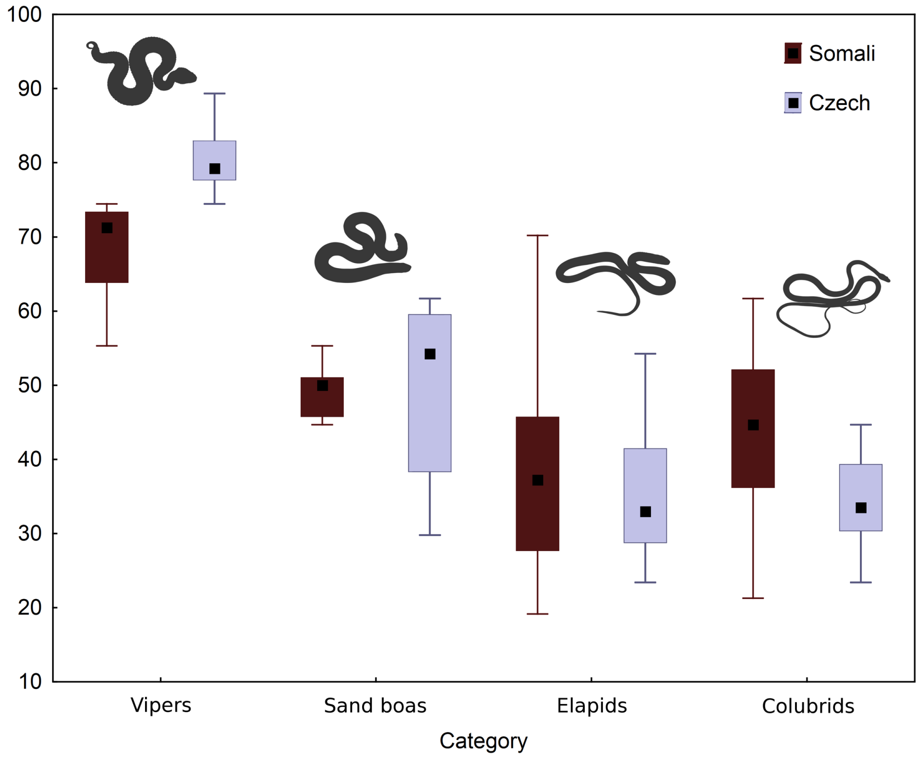

FIGURE 3
The fear evoked by four categories of snakes in Somali and Czech respondents. Means, quartiles and ranges are provided. The fear index was computed from median values (see under the Material and Methods).

TABLE 1 Spearman coefficients of correlation between the fear index and 9 measurements of the stimuli.

	Somali		Czech	
	Spearman *r*	*p*-value	Spearman *r*	*p*-value
Total length	−0.1919	0.1915	−0.4018	0.0046
Head length	0.5709	<0.0001	0.3618	0.0115
Head width	**0.7278**	**<0.0001**	**0.6335**	**<0.0001**
Neck width	0.5231	0.0001	0.4846	0.0005
Body width	**0.7994**	**<0.0001**	**0.815**	**<0.0001**
Tail width	0.5001	0.0003	0.3843	0.007
Eye diameter	0.2306	0.1148	−0.0166	0.9108
Perimeter	−0.4726	0.0007	−0.4287	0.0024
Body area	**0.716**	**<0.0001**	**0.6047**	**<0.0001**

The values were calculated separately for Somali and Czech datasets.

Product–Moment $r = 0.738$, df = 47, $p < 0.0001$, see Figure 4). The cross-cultural agreement is, however, probably mediated by the shape of the snake stimulus. This agreement disappeared when the effect of the Body Width of the stimuli was removed by the inclusion of this predictor into the linear model ($F_{(1,45)} = 3.518$, $p = 0.067$).

4. Discussion

Our first aim was to assess whether participants exhibited more fear of deadly venomous snakes than of non-venomous or slightly venomous ones. The question of whether humans can distinguish between venomous and non-venomous snakes based on the level of subjectively perceived fear elicited by particular species had not been tested directly, although there have been indications alluding to this question in prior studies (Landová et al., 2018a,b; Janovcová et al., 2019; Rádlová et al., 2019). The selected stimuli were chosen to fit into two groups: venomous snakes represented by the vipers and elapids, and non-venomous snakes represented by the sand boas and “colubrids.” However, this division was not reflected in the relative subjective fear the snakes elicited. Although both vipers and mambas/cobras (elapids) are life-threatening venomous snakes, only the vipers

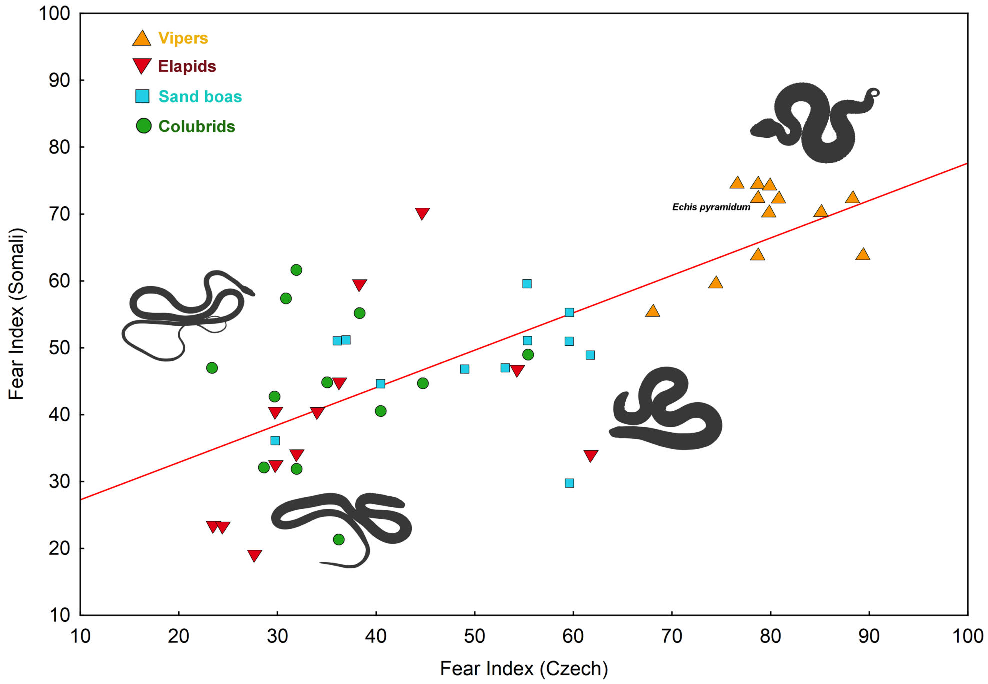

FIGURE 4
Cross-cultural agreement in the fear evaluation of 48 snake stimuli (Pearson correlation coefficient: $r = 0.738$, $p < 0.0001$). The fear index was computed from median values (see under the Material and Methods).

were consistently ranked among the most fear-eliciting stimuli. Contrarily, the vast majority of elapids were placed in the lower half of the scale. We found this important pattern of ranking in both Somalis and Czechs.

4.1. The contrasting ranking of viperids and elapids

The discrepancy between the subjective-fear ranking of vipers and elapids contradicts the null hypothesis that all categories of snakes elicit comparable magnitudes of perceived subjective fear. It is reasonable to assume that the sources of selection for quick detection and appropriate behavioral response (mediated by emotional response) were of a similar propensity elicited by both these groups of venomous snakes, at least within the Somali population. Thus, both mambas/cobras and vipers should have been subjectively ranked among the most fear-eliciting snakes. Our data, therefore, do not support the evolutionary-gained specific adaptive emotional response uniform to all venomous snakes. The most important point here is that both Czech and Somali respondents evaluated viperids as the most dangerous snakes according to the subjectively perceived fear. The probable explanation for this phenomenon is the *shared* evolutionary history in Africa, where vipers have posed a serious risk of envenomation. This explanation is compatible with an innate recognition mechanism for the viperid morphotype. An alternative explanation might be that the participants' ranking reflects an individually learned response, either influenced by personal experiences (shaped by current envenomation risk) or local culture. This alternative also explains well the position of vipers since they are the most (or among the most) dangerous snakes in the home regions of all participants. The low ranking of elapids by Somali participants (except the Mozambique spitting cobra), however, remains puzzling.

What, then, lies behind the relatively higher fear consistently elicited by vipers? We hypothesize that, unlike many other venomous species, vipers are easily recognizable among other snakes and that in this sense, the viperid morphotype is very conspicuous. Several visceral features characterize vipers as a group. Firstly, vipers have a rather short but thick and robust bodies. They have a well-defined triangular head that is separated from the rest of the body by a thinner neck. The majority of viperid snake heads are reminiscent of a pear-shaped arrowhead, featuring relatively sharp angles. Bar and Neta (2006) showed that people perceive objects with sharp-angled contours as potentially more threatening than objects with curved features. This may be another low-level perceptual feature for conscious as well as non-conscious identification of viperids as a potential threat. Their relatively large eyes are prominent and are often accentuated by modified scales. Secondly, the contrasting pattern of dark spots or lines on a light grey or beige background is often present. Thirdly, vipers have large and prominent scales all over the body (the importance of scales for snake detection and recognition was shown by, e.g., Isbell and Etting, 2017; Van Strien and Isbell, 2017; Kawai, 2019; Coss and Charles, 2021). Consequently, vipers appear to have a rugged texture, and their contrasting color pattern (when present) is emphasized. Moreover, all species within the viperid family exhibit a relatively uniform appearance, which facilitates their visual categorization. In essence, vipers possess a distinct morphotype that is conspicuously different from other snakes. It might be that the presence of easily recognizable features is the key factor for forming and fixating the association between these dangerous snakes and the fear response.

4.2. The effect of snake morphotype

To further investigate whether a snake's appearance is associated with its fear ranking, we focused on the analysis of some basic morphological features. Out of all measured parameters, the snake's body width is the most highly correlated with its fear ranking (Table 1). We also found a moderately high correlation with head width and body area. Moreover, the total body length and body perimeter negatively correlated with perceived fear which means that longer snakes were ranked as relatively less fear-eliciting than shorter snakes. Although these morphological parameters are principally intercorrelated, this result points toward the importance of the snake's robustness for its emotional evaluation. In our sample, vipers and sand boas represent the robust morphotype with shorter and thicker bodies. As discussed above, the vipers were indeed consistently placed among the most fear-eliciting stimuli and sand boas (when examined as a group) were the second most fear-eliciting (see Figure 3; Supplementary Table S4). Nonetheless, there are some other features that are shared by most vipers and sand boas but absent in most examined elapids and "colubrids." The most important one is the presence of a scale pattern in contrast to a uniform coloration. It might be that the "conspicuous" scale pattern, not the snake robustness, is the key feature factored by the participants. This question should be addressed in future research.

4.3. The differences in ranking of Somalis and Czechs

Our second aim was to compare the subjective-fear ranking of Somali and Czech participants. We found that the cross-cultural agreement on the ranking of all 48 species was 0.738 (df = 47, $r^2 = 0.545$) which is relatively high. In our previous work, we compared fear elicited by European and Middle Eastern snakes in Azerbaijani and Czech populations. The cross-cultural agreement on the ranking of these 37 species was 0.826 (df = 36, $r^2 = 0.683$; Landová et al., 2018a). The higher cross-cultural agreement can be likely attributed to the closer mutual relationship between Czech and Azerbaijani populations, as opposed to Czech and Somali populations, in terms of their population ancestry, culture, and local ophiofauna. Notably, the shape of the snake also played a pivotal role in this study – slender-bodied snakes (colubrids and a cobra in resting position) elicited lower fear than vipers in both Azerbaijanis and Czechs (Landová et al., 2018a). In a different study comparing the ranking of snake beauty among eight populations from five continents, the cross-cultural agreement varied from 0.493 to 0.901 depending on the compared populations (Marešová et al., 2009a; Frynta et al., 2011). Our current result falls within this range. Regarding the attitude toward snakes, we previously identified a more negative attitude among Azerbaijanis in comparison to what was reported by Czech participants (Landová et al., 2018a). However, another study assessing various aspects of attitudes toward snakes among Slovak (also Central Europeans) and Turkish students found no substantial differences in negative attitudes toward snakes, even though these populations differ in diversity and presence of venomous snakes (Prokop et al., 2009).

Nonetheless, an interesting cross-cultural difference comes from the results of cluster analyses. The analyses revealed that vipers formed a relatively distinct cluster separate from other snakes in Czechs and also Somalis. This suggests that the viper stimuli were truly perceived as members of a group and that the group membership (i.e., if the stimulus fits or does not fit into the "viper category") noticeably affected the species ranking. Contrarily, elapid and "colubrid" snakes got intermixed and did not form any interpretable clusters in either Somalis or Czechs. This shows that the snakes of both groups were perceived as one and that neither Somali nor Czech participants differentiated between them with regard to the elicited fear. Note that all these snakes – both relatively harmless "colubrids" and highly dangerous elapids – were generally ranked below the median. Finally, the sand boas appeared to form its own category only in Czechs; in Somalis, the species were split between the two main clusters. This suggests that in Somalis, the sand boas were evaluated on an individual basis taking into consideration characteristics that do not define sand boas as a group. In fact, the overall structure of the cluster tree was less interpretable in Somalis suggesting that Somali participants took more of an "individual approach" to each snake's evaluation while Czech participants tended to rank the species based on the group they presumably belong to. Since Somali participants have at least some personal experiences with the stimuli species, they might have evaluated them differently, while Czechs had to rely more on categorization when confronted with these exotic snake stimuli. Alternatively, Czechs might be simply more used to categorizing since semantic categories are ubiquitous during their school education. These two explanations are not mutually exclusive.

4.4. The effect of evolutionary past, current snakebite risk, and culture on species' fear ranking

We outlined three factors that might affect the subjective-fear ranking of the venomous and non-venomous snakes: evolutionary past (i.e., the evolutionary sympatry with dangerous snakes), the current risk of snakebite, and cultural influences (e.g., myths, passed down experiences, media portrayal, education). Nevertheless, none of these three factors on its own can fully explain the observed pattern of ranking. Instead, it appears to us that these factors are not mutually exclusive and that they have all contributed to the fear ranking to varying degrees in both populations.

As large constrictors like pythons have been regular predators of primates (reviewed in Headland and Greene, 2011; Ribeiro-Júnior et al., 2016), and probably also predators of early hominids (Coss, 2003; Isbell, 2006, 2009), the general fear elicited by snakes should be traced back to this deep evolutionary past. However, unlike pythons, venomous snakes are not significant predators of larger primates, and accidents involving envenomation frequently occur when humans step on a hidden snake (Valenta, 2010). Venomous snakes do not actively pursue apes and humans, and some of them (e.g., Indian cobras, *Naja naja*) display face-like patterns with eyespots on the ventral and dorsal sides of their expanded hoods that alarm intruders and potential predators (Ditmars, 1931; Coss, 1968; Ramakrishnan et al., 2005); nevertheless, overlooking them remains risky. It is therefore important for humans not only to detect a hidden snake but also to accurately estimate the risk of a possible bite. An innate wariness specifically toward venomous snakes could be advantageous in this respect.

While our data do not support the existence of an innate fear response uniform for all venomous snakes, they do support the innateness of a stronger fear response toward vipers. Since vipers are morphologically homogenous within the clade consisting of viperid and rattlesnakes but distinct from most other snake groups, forming and fixating an innate "idea" (possibly prototype) of what a dangerous snake looks like might have been advantageous because it would have led to relatively few false alarms. Cobras and mambas, on the other hand, could be easily confused with mostly harmless colubrids leading to a waste of time because of false-positive misidentification or the risk of injury or death because of false-negative misidentification. It might be argued that humans should have hence evolved a fear response toward all vipers, elapids and "colubrids" since false-negative misidentification is clearly much more serious than a false-positive one. Indeed, this is reflected in predominantly negative attitudes toward all snakes across cultures (e.g., Alves et al., 2014; Pandey et al., 2016; Landová et al., 2018a; Onyishi et al., 2021). In this study, the elapids and "colubrids" were among the least fear-eliciting simply because the task was the stimuli ranking, i.e., we assessed only fear in relational context and not a single fear judgment.

The existence of an innate "prototype" of a dangerous snake might be supported by the high ranking of completely harmless sand boas. They were ranked as the second most fear-eliciting group also by Czech participants even though Czechs do not have an opportunity to encounter them in real life (and have not had it for at least 5,000 years). Their high ranking might be attributed to their relative similarity to vipers, a possible morphological key feature might be the relative body robustness but other options like the presence of a coloration pattern are also possible. Somali respondents ranked some sand boas also relatively high; others however were ranked quite low (the highest-ranked sand boa scored 60, the lowest-ranked scored 30 on the fear index scale). Elapids (scoring 70 and 19, respectively) and "colubrids" (scoring 62 and 21, respectively) were also ranked ambiguously. This "individual approach" toward the snake stimuli contrasted with higher reliance on categorization by Czechs. We interpret this result as Somalis adjusting their rating based on their personal experience or second-handily learned information. However, this interpretation should be explored in a follow-up study focusing on a full range of Somali snake species.

The cultural influence on the fear ranking of examined species cannot be easily measured. The higher ranking of vipers than of sand boas might have been caused by their closer resemblance to the possible innate "prototype" of a dangerous snake or alternatively by the culturally transmitted knowledge that vipers are dangerous. In the Czech Republic, already children at school are taught what Northern viper looks like and that it is venomous. The most lethal Somali species, the Northeast African carpet viper, is well known among the people and Somali participants regularly recognized it among the stimuli. While the highest ranking of vipers in both Somalis and Czechs might be explained solely by their characteristic appearance and the historically uninterrupted interaction between this snake family and tested human populations for the last at least 11 million years, from our experience it seems to us that the culture reassures or even amplifies the specific fear reaction toward them.

4.5. Comparison with animal studies

Consistent differences in responses to snakes of various species or morphotypes are not surprising in light of previous studies conducted on non-human primates and rodents. For instance, wild Bonnet macaques (*Macaca radiata*) and moor macaques (*M. maura*) exposed to realistic snake models responded differently to each examined snake species (Ramakrishnan et al., 2005; Hernández Tienda et al., 2021). Colombian white-faced capuchins (*Cebus capuchinus*) failed to differentiate between the venomous neotropical rattlesnake (*Crotalus durissus*) and the non-venomous *boa constrictor* (*Boa constrictor*), yet they distinguished highly patterned boas from an unpatterned harmless snake (Meno et al., 2013a,b; Coss et al., 2019). In contrast to capuchins, rodents such as California ground squirrel (*Otospermophilus beecheyi*) and rock squirrel (*Otospermophilus variegatus*) were able to distinguish their venomous rattlesnake and non-venomous gopher-snake predators (Towers and Coss, 1990; Owings et al., 2001).

It is noteworthy that the California ground squirrels' ability to distinguish both snake predators has persisted under prolonged relaxed selection for more than 300,000 years, following a predator–prey relationship spanning at least 10 million years (Coss, 1991, 1993, 1999). This persistence is analogous to our findings, given that the evolutionary interaction between human ancestors and venomous snakes in Africa lasted for several million years and fear response to snakes (and specifically to viperids) currently occurs in European populations even after migration to areas where venomous snakes are rare or absent (< 60,000 years ago).

Another parallel to our results can be found in the ability of moor macaques (*M. maura*) to generalize their previous experience with local vipers to a novel viper species (Hernández Tienda et al., 2021). The authors attributed this ability to the triangular shape of viper heads. Further, moor macaques only poorly responded to cobras and kraits (*Bungarus* spp.); they paid the most attention to large constrictors (pythons) regularly preying on macaques (Shine et al., 1998; Headland and Greene, 2011). This aligns with other studies conducted on monkeys, reporting a preference for emitting alarm calls in response to large pythons (Van Schaik and Mitrasetia, 1990; Ramakrishnan et al., 2005; Coss et al., 2007). These alarm calls are not exclusive to pythons and boas (their acoustic characteristics do not possess unique attributes for constrictors). Instead, they reflect the level of threat and are further influenced by the animals' experiences with encountered predators. They may also serve as highly contagious alerting signals directed at the other members of the group (Crockford et al., 2012; Coss et al., 2019).

Differences in responses to constrictors and venomous snakes, as demonstrated by some studies in non-human primates and other animals, are mostly overlooked in humans. Large ancestral pythons coincided temporally with early hominids 4.5 million years ago and likely posed a predation risk to them, even though no paleontological evidence exists (see Coss, 2003; Headland and Greene, 2011). Our study showed that the subjectively perceived fear of sand boas was lower than that of vipers, but large pythons were not included. However, a previous study comparing subjectively perceived fear revealed that out of 40 randomly selected representatives of extant snake subfamilies, viperids occupied the 1st (Crotalinae), 2nd (Viperinae) and 4th (Azemiopinae) position while subfamilies comprising large constrictors were 6th (Boinae), 17th (Sanziniinae) and 19th (Pythoniinae) (for details see Rádlová et al., 2019, and its Supplementary material 1). Nonetheless, additional research is needed to uncover potential differences in various aspects of human fear reactions to venomous snakes and large constrictors.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Institutional Review Board of Charles University, Faculty of Science and Amoud University, School of Postgraduate Studies & Research. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DF conceived and designed the research, analyzed the data, and funding acquisition. DF, PF, HE, IŠ, VR, KR, DK, DS, and DB recruited the respondents and administered the tasks in Somaliland. MJ, IŠ, PF, VR, and EL administered the tasks in the Czech Republic. MJ curated the data and prepared the stimuli. DF and PF photographed the stimuli. DF, EL, IŠ, PF, VR, and MJ wrote a first draft of the manuscript. DF, EL, IŠ, and PF reviewed the text. All authors approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1233667/full#supplementary-material

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The influence of single-session reward-based attentional bias modification on attentional biases towards threat as measured by the N2pc component

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Attentional biases toward threatening faces have repeatedly been studied in the context of social anxiety, with etiological theories suggesting exacerbated biases as a possible cause for the latter. To counteract these postulated effects, research has focused on the concept of attentional bias manipulation (ABM), in which spatial contingencies between succeeding stimuli are traditionally employed in training paradigms designed to deliberately shift automatic attention processes away from threat-related stimuli. The ABM research field has been faced with various methodological challenges, such as inconsistent results, low reliabilities of dependent variables and a high susceptibility to moderating factors. We aimed to combine several recent approaches to address these issues. Drawing upon theories of value-driven attention, we explored reward-based contingencies in a Dot Probe task to improve the training's efficacy, combined with neurophysiological measures for greater reliability compared to reaction times, while evaluating the moderating effect of explicitness in the instruction. In a healthy sample ($N = 60$) and within a single session, we found a general attentional bias toward angry faces present across all conditions as indicated by the N2pc, which was, however, marked by large intrinsic lateralization effects, with submeasures exhibiting opposing polarities. This prompted us to explore an alternative, intrahemispheric calculation method. The new N2pc variant showed the attentional bias to have disappeared at the end of the training session within the explicit instruction group. Reliabilities of the main dependent variables were varied from excellent to questionable, which, together with the exploratory nature of the analysis, leaves this result as preliminary.

KEYWORDS

attentional bias modification, attentional bias for threat, N2pc component, EEG, single-session, reward-based, healthy participants

1 Introduction

In a naturalistic environment, a multitude of stimuli of possible relevance are present at any moment. This entails the need for selective (visual) attention, a process that governs the distribution of limited cognitive resources, focusing them on the most relevant stimuli within the environment (Desimone and Duncan, 1995). The outcome of which particular stimuli succeed at capturing our attention is driven by various factors, broadly distinguished into top-down factors such as personal goals and context (Bacon and Egeth, 1994; Oliva et al., 2003), and bottom-up factors like a stimulus' physical features and salience (Theeuwes, 1992; Itti, 2005). Here, we attempt to systematically manipulate the extent to which certain stimuli automatically capture participants' attention by utilizing a related but separate construct, that of value-driven attention (Chelazzi et al., 2013; Bucker and Theeuwes, 2017). If successful, this procedure has potential implications for a field of research focusing on the etiology of social (in addition of other types of) anxiety disorder as well as its therapy.

Social anxiety disorder (SAD), also known as social phobia, is the most common anxiety disorder (Stein and Stein, 2008) with a lifetime prevalence of 4.0% across multiple countries in different geographical regions (Stein et al., 2017). Social anxiety disorder is marked by strong and persistent distress in social situations and fear of scrutiny by others, with respective situations being actively avoided. At the same time, the fear of (negative) social evaluation acts as a barrier to conventional treatments such as psychotherapy, and often prevents those afflicted from seeking treatment (Olfson et al., 2000).

It is therefore worth investigating alternative forms of intervention that do not rely on personal interaction and can be administered via computer-based training sessions, thereby lowering thresholds and making treatment more accessible and convenient. A possible such candidate is Attentional Bias Modification (ABM), a procedure based on the idea that emotional stimuli – such as threatening faces (Gamble and Rapee, 2010; Staugaard, 2010) – automatically capture attention (Bradley et al., 1997). These attentional biases are thought to be exacerbated in anxious individuals, and are postulated to play a role in the etiology and maintenance of (social) anxiety disorder (Rapee and Heimberg, 1997; Mathews and MacLeod, 2005; Van Bockstaele et al., 2014). ABM conventionally employs contingencies between target stimuli and differently valenced distractors to allow for measurement and manipulation of those biases, with the rationale that decreasing an inflated bias to normal levels should alleviate the symptomology of social anxiety disorder (MacLeod and Clarke, 2015). For measurement of attentional biases, the dot probe task (DPT) was developed by MacLeod et al. (1986), in which participants react to simple visual target stimuli replacing either threatening or neutral distractors with equal probability. Attentional bias is then operationalized as the difference in reaction times between the two conditions. For manipulation, a modified version of the DPT (MacLeod et al., 2002) is commonly used, which introduces spatial contingencies between distractors and targets such that targets appear at the location of neutral compared to negatively valenced distractors with higher probability.

While there has been a steady amount of interest in the field of ABM since its conception, it has been regarded more critically in recent years due to later studies often producing null results (e.g., Julian et al., 2012; Everaert et al., 2015), bringing its general effectiveness into question. In a meta-analysis, Heeren et al. (2015) found an overall small but significant effect of ABM methods on social anxiety symptoms, but criticized the quality of the studies as substandard, concluding that "ABM is not yet ready for wide-scale dissemination as a treatment for SAD in routine care."

Multiple approaches to improve upon the procedure have been made since, two of which will mainly be focused upon here. Firstly, conventional measures of attentional bias (i.e., reaction time differences) have been criticized in terms of psychometric unreliability (e.g., Waechter et al., 2014; Waechter and Stolz, 2015). In an effort to identify reliable neurophysiological markers, a variety of event-related potentials have been investigated (Carlson, 2021). Among these, the N2pc component of the electroencephalogram (EEG), as first employed in an ABM approach by Osinsky et al. (2014), seems well suited due to its property of reflecting covert allocation of selective spatial attention between multiple stimuli (Eimer, 1996). Specifically, it has been shown to be elicited by task-irrelevant fearful faces (Eimer and Kiss, 2007), making it suitable for application in the dot probe task. The N2pc is typically observed as a transient negative deflection at occipitotemporal electrodes contralateral to the position of an attended stimulus 200 to 300 ms after stimulus onset (Luck, 2011). Its reliability to capture attentional biases in social anxiety was demonstrated by Reutter et al. (2017, 2019), indicating its potential usefulness as a measure in ABM training.

The other novel approach that will be focused on here is concerned with improving the efficacy of the attentional training task. Generally, it has been found that external (e.g., monetary) rewards can increase intrinsic motivation on low-interest tasks (Cameron et al., 2001), as which conventional ABM training has been frequently described by participants (Beard et al., 2012). More importantly though, rewards have been shown to impact visual selective attention, such that even task-unrelated stimuli increasingly capture attention after having been consistently associated with (higher) rewards (Libera and Chelazzi, 2006; Chelazzi et al., 2013). This effect may persist months after the initial training (Anderson and Yantis, 2013).

The underlying process, termed value-driven attention, is distinct from the top-down and bottom-up attentional systems mentioned previously and has the potential to act independently and even counteract these (Anderson, 2013; Bourgeois et al., 2017). It can thus be postulated that employing reward contingencies instead of the conventional spatial-probabilistic contingencies should (more) reliably achieve the desired effect of modifying attention to favor the higher rewarded stimuli in an ABM paradigm. The advantage of orienting attention toward the neutral distractor would therefore be the higher reward for correct reactions to a target following it, and not the higher possibility of the target appearing behind it. This idea has been tested in a first, albeit small, sample by Sigurjónsdóttir et al. (2015) who showed a reward-based training to be highly effective at manipulating attentional biases, while there was no effect of probability contingencies. In addition, and with regard to this method's compatibility with the previously discussed approach, existing research demonstrates that these value-driven changes in attention can be captured by the N2pc component (Kiss et al., 2009). Changes in the N2pc's amplitude have been shown to reflect preferential processing not only of simple stimuli associated with high rewards, but also that of complex objects (Donohue et al., 2016). It furthermore allows for tracking attentional adjustments caused by changing value-contingencies within a single experimental session (Oemisch et al., 2017).

Another moderating factor that has been studied in the context of ABM concerns the instruction given to the participants before performing the training task, in particular whether this instruction contains any explicit reference to the presence of a contingency between the stimuli. While the original ABM procedure did not inform participants of the contingency, as it was designed to address subconscious cognitive processes, some more recent studies have found an explicit instruction to be more effective in reducing attentional biases (*cf.* Krebs et al., 2010; Grafton et al., 2014; Nishiguchi et al., 2015). However, it has also been cautioned that explicit ABM, while more effective at lowering bias scores, might no longer have an impact on participants' anxiety levels themselves (Grafton et al., 2014).

The present study aims to replicate and combine these novel approaches – improving upon both measurement and manipulation aspects of ABM – by measuring changes in the N2pc component in participants undergoing a reward-based attentional training. To maximize the generalizability of the results, we chose to study a healthy sample in a single training session (as opposed to preselecting for social anxiety or increasing the number of sessions). Lastly, as previous research has provided inconclusive results about the effects of informing participants about the presence of contingencies in the training condition, we also investigated the impact of implicit versus explicit instructions on the training's efficacy.

2 Materials and methods

2.1 Participants

Sixty students (50 female; mean age = 21.9; SD = 2.4; one person's demographic information missing) participated in the study and were reimbursed with course credit (where applicable) and monetary compensation, the latter of which was contingent on their individual performance in the task (around 15€). Power analysis performed in G*Power 3.1.9.7 (Faul et al., 2009) indicated that for the critical 3 × 3 mixed ANOVA using a significance criterion of $\alpha = 0.05$, this sample size achieved a power of 0.99 when assuming a large effect size (Cohen's $f = 0.4$) and a power of 0.86 when assuming a small to medium effect size (Cohen's $f = 0.2$). According to self-reports, none of the participants had neurological or psychological conditions or were currently undergoing psychological treatment.

The study project was approved by the ethics committee of the University of Osnabrück and participants gave written informed consent.

2.2 Stimulus material and procedure

Stimulus presentation and behavioral data recording was controlled by PsychoPy (v2020.1.3) software (Peirce et al., 2019). The task consisted of a dot probe paradigm (MacLeod et al., 1986) that was modified to include (monetary) rewards for fast and correct responses. Barring this modification, stimuli and procedure were similar to those of Reutter et al. (2017). The stimulus material consisted of angry and neutral faces taken from the Karolinska Directed Emotional Faces database (Lundqvist et al., 1998). Six female and six male models (AF01, AF09, AF19, AF20, AF22, AF26, AM02, AM05, AM10, AM11, AM14, AM29) were chosen and their respective angry and neutral expressions were used. A high perceptibility of the particular emotions on these specific models has been ascertained by Goeleven et al. (2008). Each trial started with a white fixation cross (whereas the background of the screen was gray) presented on its own for 500 ms. After this time period, two faces ("distractors") were displayed horizontally on either side of the fixation cross (center at 3.72° visual angle, with a width of 4.75° and height of 6.41°). The two faces belonged to the same model but varied in their emotional valence with the three possible conditions being neutral/neutral, angry/neutral and neutral/angry (an angry/angry condition was not present). The distractors were displayed for another 500 ms, after which they disappeared and a colon ("target") replaced either one of them with equal probability (50/50 chance of appearing in either the left or the right location). Participants were instructed to report via button press whether this colon was oriented vertically (:) or rotated by 90° (• •). Button assignments were counterbalanced across participants. The maximum response time started at 700 ms for each participant but was adapted according to individual performance, with a correct response lowering the limit by 50 ms and a wrong or late response extending it by 100 ms (up to a minimum/maximum of 400/1,200 ms). This adaptive response time limit was intended to enforce fast responses at the limits of participants' reaction capacity. The target remained on screen for the full duration of the current response time limit or until a button press was made. Subsequently, a feedback was displayed in the middle of the screen (replacing the fixation cross). This feedback consisted of a phrase ("Correct," "False" or "Too slow") and, in brackets, the amount of money that had been or could have been received in this trial (e.g., "False (5 ct)"). In the case of a correct response, the text was colored green, otherwise it was white. The feedback was displayed for 1,000 ms, after which it disappeared and the screen was blank for an intertrial interval with a duration of between 750 and 1,250 ms (value drawn randomly from a uniform distribution).

In addition to model identities and distractor conditions, target location and orientation were counterbalanced across trials, resulting in 12 Models × 3 Distractor Conditions × 2 Target Locations × 2 Target Orientations = 144 trials per block. Each trial type (neutral/neutral, angry/neutral and neutral/angry) was presented an equal number of times, as such there were 48 trials of each type per block. An exemplary trial sequence is shown in Figure 1.

Participants were assigned to one of three experimental groups (control, implicit, explicit). Those in the control group received a fixed reward of 5 ct for a correct response within the time limit. In the implicit group, the reward amount was contingent on the configuration of the distractor faces that preceded the target. If both faces were neutral, participants received a reward of 5 ct. If the face presented on the side of the target was angry (i.e., the opposing face was neutral), an amount of 2 ct was rewarded. In the converse case (i.e., a neutral face preceding the target with an angry face contralateral to the target) participants received 8 ct (given, in either case, that the reaction to the target was correct and sufficiently fast). These contingencies were designed to direct attention away from the negative faces toward the neutral ones by giving higher rewards in reaction to the latter, especially in cases where both expressions were present (i.e., participants had the choice of focusing on either). The explicit group received the same manipulation as the implicit group, with the only difference being an additional sentence in the instruction that alluded to the reward contingency but did not state it, with the aim of exploring whether this instruction (and consequently participants' awareness of the contingency) affected the training's effectiveness. Alluding to the presence of the contingency was intended to facilitate its subconscious perception and acquisition in accordance with the original idea of ABM, whereas an outright statement of the contingency might have rather engaged deliberate top-down control processes. The additional sentence translated to "The reward depends on the expression of the faces shown before." Figure 2 summarizes the differences between the groups.

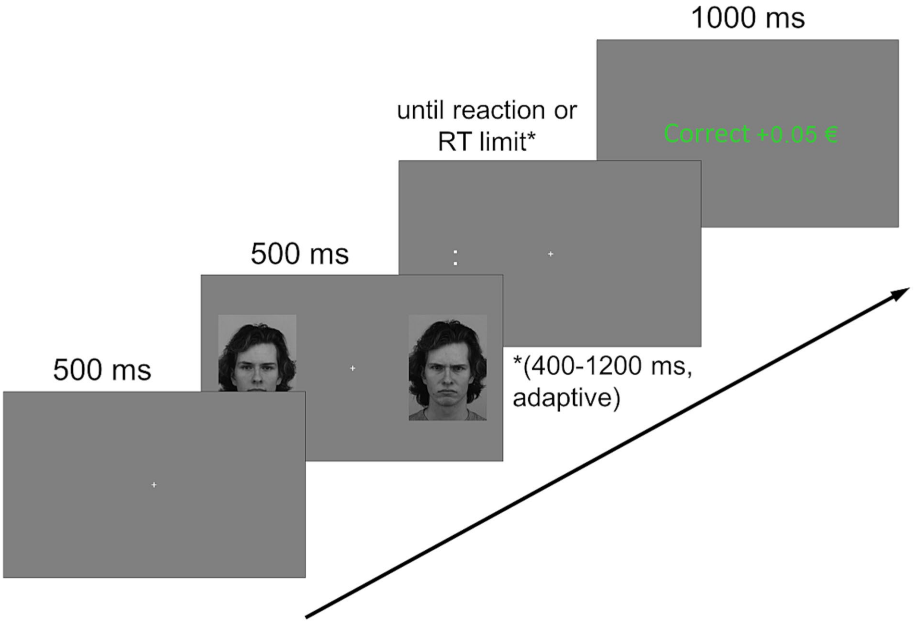
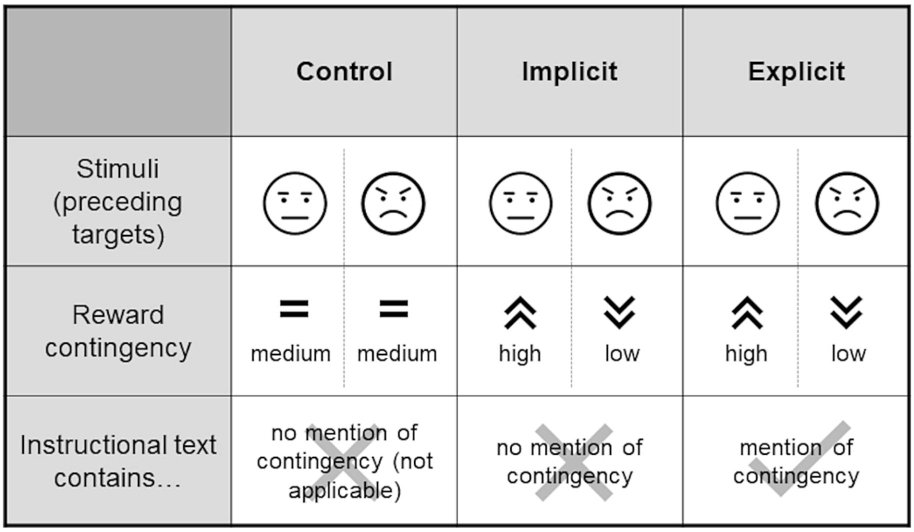


FIGURE 1
Exemplary trial sequence. A fixation cross, displayed for 500 ms, was followed by two distractors (faces of the same person with varying expressions) on either side of it, again displayed for 500 ms. A target stimulus replaced either of the distractors and stayed on screen until reaction or until an adaptive time limit (between 400 and 1,200 ms) was reached. Feedback depending on the (non-)reaction was then displayed for 1,000 ms, followed by an intertrial interval of 750 to 1,250 ms during which the screen was uniformly gray (not pictured) Facial stimuli shown here are image IDs AM14NES and AM14ANS, adapted with permission from the Karolinska Directed Emotional Faces database (Lundqvist et al., 1998).



	Control		Implicit		Explicit	
Stimuli (preceding targets)	😑	😠	😑	😠	😑	😠
Reward contingency	= medium	= medium	⇑ high	⇓ low	⇑ high	⇓ low
Instructional text contains…	✗ no mention of contingency (not applicable)		✗ no mention of contingency		✓ mention of contingency	

FIGURE 2
Experimental groups. The stimuli presented to each of the groups were identical, however, the groups differed with respect to whether or not there was a contingency in the amount of the reward that could possibly be collected when reacting quickly and correctly to the target following the stimulus (see Figure 1). Such a contingency (higher rewards for neutral faces and lower rewards for angry faces) was present for the training groups but not the control group. The training groups again differed within the instructional texts that were displayed prior to the task. In the "implicit" group, the contingency was not mentioned, however the "explicit" group made a reference to it. Schematic representations of angry and neutral stimuli are used in this figure, for an example of actual stimuli used see Figure 1.

Prior to the experiment, participants completed questionnaires on their general demographic information, their trait social anxiety [Social Interaction Anxiety Scale/SIAS; Mattick and Clarke, 1998; German version by Stangier et al. (1999)] and reward sensitivity [Reinforcement Sensitivity Theory-Personality Questionnaire/RST-PQ; Corr and Cooper, 2016; German version by Pugnaghi et al. (2018); with only the items pertaining to the factor Reward Reactivity being included], in this order. The SIAS consists of 20 items such as

"When mixing socially, I am uncomfortable." that are rated on a 5-point scale ranging from "Not at all characteristic or true of me" to "Extremely characteristic or true of me" and has high internal consistency and retest reliability (Rabung et al., 2006). The RST-PQ is a 65-item questionnaire using a 4-point rating scale ranging from "Not at all" to "Highly" and has been demonstrated to be a reliable and valid measure (Pugnaghi et al., 2018). As mentioned before, from several scales included in the RST-PQ, only the Reward Reactivity scale was used here, which consists of ten items such as "I find myself reacting strongly to pleasurable things in life."

Before the start of the recording, participants were allowed to practice the task in a training block that consisted of 10 random non-rewarded trials (using distractors that were not present in the actual experiment) until they performed at least 7 of these correctly. Following this, participants completed three blocks of the aforementioned 144 trials for a total of 432 trials, during which behavioral and EEG data were recorded. Trials were presented in random order within each block. There were self-paced breaks between and in the middle of all blocks. At the end of the experiment, participants filled out a post-test questionnaire containing some qualitative questions about the procedure.

2.3 Behavioral data processing

Erroneous trials (13.8%) and trials without reaction (18.6%) were excluded from the analysis for a total of 32.4% of removed trials. From the remaining correctly answered 67.6% of trials, outliers (reaction time exceeding $2 \times SD$) were removed separately for participants and conditions (i.e., group, block, distractor valence). Another 2.6% of the overall trials were removed in this step. The amount of remaining trials did not differ significantly between groups as shown by a one-way between-subjects ANOVA [$F(2,57) = 1.38$, $p = 0.26$, $\eta_p^2 = 0.05$].

The average reaction time for each cell was calculated from the remaining trials. These averages consisted of a minimum amount of 24 individual trials (mean = 31.23; max = 40). A bias score for angry faces was calculated separately for each participant and block by subtracting the average reaction time (RT) for neutral faces (i.e., trials, in which an angry and a neutral face were present and the target appeared behind the neutral face) from the average RT for angry faces (such that more negative values indicate a larger attentional bias for angry faces). This entails that the reaction times from the neutral/neutral conditions were not used in this calculation and are therefore not further included in the analysis of the behavioral data.

2.4 EEG recording and processing

The EEG was recorded using a 32-channel EEG system (Brain Products GmbH, Gilching, Germany) consisting of actiCap active electrode caps and a BrainAmp MR plus amplifier. The recording was performed using BrainVision Recorder v1.21.0303 software at a sampling rate of 500 Hz, with a band pass filter of 0.016 to 250 Hz and impedances that were kept below 20 kΩ. The 32 recording sites (Fp1, Fp2, F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, C3, C4, Cz, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, TP9, TP10, T7, T8, PO9, PO10, O1, O2, Oz, according to the international 10–20 system) were referenced to FCz online, with the ground electrode placed at AFz.

Data were preprocessed offline using BrainVision Analyzer 2 (v2.2.1.8266) software. 0.1 Hz high-pass and 30 Hz low-pass Zero Phase Shift IIR Butterworth filters (24 dB/octave roll-off) were applied. For correction of ocular artifacts, an Ocular Correction ICA (extended biased infomax algorithm) was performed for all EEG channels. Components for which the sum of squared correlations with HEOG/VEOG exceeded 15% were excluded. HEOG and VEOG were operationalized as the difference between electrodes F7 and F8 and the mean of electrodes Fp1 and Fp2, respectively. Data were rereferenced to the average of all electrodes, with FCz being reinstated as an additional channel. For each block, data were segmented into epochs from-200 to 800 ms around distractor onset. Epochs that contained a voltage step of over 50 µV/ms were rejected, as were those with a maximum difference larger than 100 µV within 100 ms or those that reached an amplitude below or above −70/70 µV at any point. Similarly, epochs with a voltage difference exceeding 80 µV within 600 ms in the HEOG channel (to which the ICA had not been applied) were rejected to ensure that only trials without eye movements remained. Baseline correction was performed by subtracting the average signal in the time window from −200 to 0 ms before averaging the waveforms separately for each participant, block and distractor condition (i.e., neutral/neutral, angry/neutral and neutral/angry). These averages were calculated from a minimum of 20 trials each (of a maximum of 48 trials), with the mean being 43.99 (SD = 6.08). The case of a cell containing less than the 20 necessary trials occurred for less than 4% of cells overall, however, six participants were excluded from further analysis due to this. After the preprocessing, 19/19/16 participants remained in the control/implicit/explicit groups, respectively.

The N2pc component, which was chosen as the primary outcome measure due to its property of accurately reflecting selective spatial attention, was calculated in accordance with standards protocols. It was defined *a priori* as the difference in mean amplitudes at electrodes P7/P8 contralateral minus ipsilateral to the angry stimulus position 180–300 ms after distractor stimulus presentation. The choices of time and electrodes of interest were based on existing literature (*cf.* Eimer, 1996; Eimer and Kiss, 2007; Reutter et al., 2017). The N2pc was calculated in this way separately for each participant and block.

In an additional, exploratory analysis, we also used a novel operationalization of the N2pc. This was motivated by a strong lateralization effect present in previous data collected in our group. In those data, angry faces presented in the left visual hemifield caused overall much larger deflections within their contralateral electrode (P8) than those presented in the right visual hemifield caused within P7. These lateralization effects were several times larger than the N2pc itself. This causes difference-based submeasures calculated from the two electrodes to be of opposite polarity depending on the order of subtraction (P8-P7 vs. P7-P8, *cf.* Figure 3).

To prevent this lateralization effect from masking actual experimental effects, we also calculated the N2pc not across hemispheres but within, utilizing the trials with neutral/neutral distractor configuration for that purpose. For instance, for the trials with angry/neutral distractor configuration, the mean amplitude at electrode P8 (i.e., contralateral to the angry face) was calculated as typical. However, the average amplitude at the same electrode (P8) during presentation of neutral/neutral distractors was subtracted from this, thus yielding the difference in activation between angry and neutral stimuli within the electrode contralateral to the angry distractor (note that accordingly, the ipsilateral stimulus was neutral in both cases).

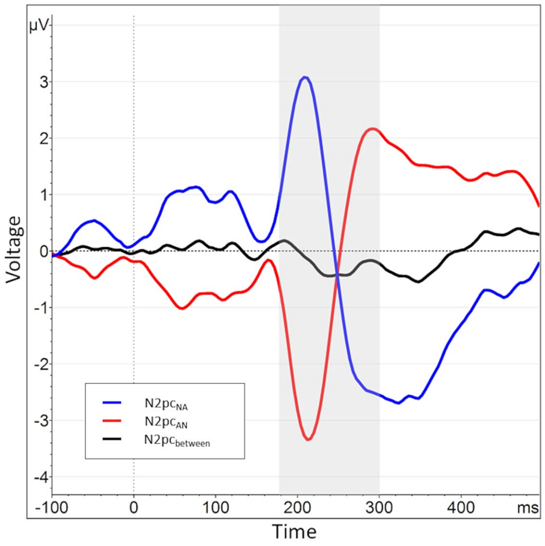


FIGURE 3
When splitting the $N2pc_{between}$ into submeasures based on hemisphere, a pattern of near symmetry around the *x*-axis emerges, indicating a strong lateralization effect. The N2pc for angry faces presented in the right visual hemifield, i.e., processed in the left hemisphere, is shown in blue ($P7_{NA}$ - $P8_{NA}$). The N2pc for angry faces presented in the left visual hemifield, i.e., processed in the right hemisphere, is shown in red ($P8_{AN}$ - $P7_{AN}$). The $N2pc_{between}$, the mean of these two submeasures, is shown again in black and manifests only as a small deviation from the symmetry.

This novel way of calculating the N2pc within single electrodes over different trials will subsequently be referred to by the label $N2pc_{within}$, while the N2pc that was conventionally calculated as the difference between electrodes in a single trial will be called $N2pc_{between}$.

To summarize the above, the two variants of the N2pc were calculated according to the following formulae, where the subscripts refer to the stimulus configurations of the trials included (A = angry, N = neutral):

$$N2pc_{between} = \frac{N2pc_{NA} + N2pc_{AN}}{2},$$

where $N2pc_{NA} = P7_{NA} - P8_{NA}$, i.e., electrode contralateral minus ipsilateral to angry stimulus for all trials with neutral/angry distractor configuration and.

$N2pc_{AN} = P8_{AN} - P7_{AN}$, i.e., electrode contralateral minus ipsilateral to angry stimulus for all trials with angry/neutral distractor configuration.

and

$$N2pc_{within} = \frac{N2pc_{P7} + N2pc_{P8}}{2},$$

where $N2pc_{P7} = P7_{NA} - P7_{NN}$, i.e., electrode P7 with an angry stimulus in the contralateral position minus electrode P7 with a neutral stimulus in the contralateral position and.

$N2pc_{P8} = P8_{AN} - P8_{NN}$, i.e., electrode P8 with an angry stimulus in the contralateral position minus electrode P8 with a neutral stimulus in the contralateral position.

As described, all values indicated above refer to the mean activity at the respective electrode locations 180–300 ms after stimulus onset.

2.5 Statistical analysis

As indicated above, the main outcome measures used in our analyses were the N2pc (both variants), with reaction time bias toward angry faces being a secondary measure. The internal consistency of these measures was examined with a Monte Carlo-based split-half approach (Williams and Kaufmann, 2012) as performed by the *splithalfr* package (Pronk et al., 2022) with 5,000 repetitions, using data from the control group only (as per the study design, stability of effects over time could not be assumed for the other groups). Monte Carlo splitting involves the construction of two full-length data sets for each original data set based on random sampling with replacement (stratified by target category in our case), scoring the task and calculating the intercorrelation of the two series of scores across participants. This process is then repeated multiple times (i.e. 5,000 in our study) and the resulting Spearman-Brown corrected correlation coefficients averaged [see Parsons et al. (2019) for a discussion of the technique]. To assess the overall presence of attentional biases during the dot probe task, we performed one-sample, one-sided t-tests on all three measures, testing against zero. Mixed 3 × 3 factorial ANOVAs on all three measures with the between-subjects factor Group (control, implicit, explicit) and the within-subjects factor Block (1, 2, 3) were performed to assess group differences and potential changes in AB over the course of the experimental session. We also separately entered z-transformed SIAS and RST-PQ scores as covariates to account for the influence of the respective personality traits.

3 Results

3.1 Questionnaires

1.05% of questionnaire items were missing and thus interpolated by the mean of the other items. Sum scores in the SIAS questionnaire indicated a wide range of social anxiety levels from very low to high, with the majority showing low to moderate scores. Five participants had a score above 34 [cut-off value for social anxiety as suggested by Heimberg et al. (1992)]. Participants showed moderate to very high reward reactivity as specified by the RST-PQ sum scores. Descriptive statistics for both questionnaires are presented in Table 1.

3.2 Behavioral measures

The average winnings earned by participants amounted to 14.61€ (*SD* = 0.30€) and did not differ between experimental groups as indicated by a one-way between-subjects ANOVA [$F(2, 57) = 0.44$, $p = 0.65$, $\eta_p^2 = 0.02$]. The overall reaction time average for correct trials was 450.54 ms (*SD* = 66.49).

The average overall reaction time bias for angry faces was 0.6 ms (with a *SD* of 8.28 ms and a split-half reliability estimate of 0.72 (*SD* = 0.12) with a bootstrapped 95% confidence interval of [0.54, 0.86]). Lower values indicate speeded responses for angry faces, and thus the descriptive direction of the effect was in fact opposite to the

TABLE 1 Descriptive statistics for the sum scores from SIAS and RST-PQ questionnaires.

Questionnaire	Mean	Min (Abs. Min)	Max (Abs. Max)	SD	Skewness	Kurtosis
SIAS	21.53	4 (0)	51 (80)	9.9	0.83	0.75
RST-PQ	29.72	22 (10)	38 (40)	3.91	0.16	−0.48

Missing items (1.05%) were interpolated by the mean of the respective participant's other answers. Absolute min/max indicate the lowest/highest possible sum scores for the questionnaire.

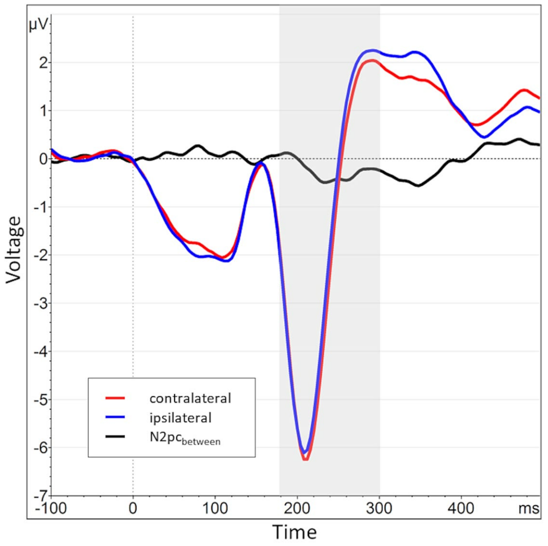


FIGURE 4
Grand average waveform of the N2pc$_{between}$ waveform and its constituents across all participants and blocks at electrode positions P7 and P8. The time window of interest (180 to 300 ms post stimulus onset) is marked in gray. The average activity contralateral to angry face stimuli (e.g., at P8 for angry/neutral distractor configuration) is shown in red (mean of P8$_{AN}$, P7$_{NA}$), while the corresponding ipsilateral activity is shown in blue (mean of P8$_{NA}$, P7$_{AN}$). The N2pc$_{between}$ (black) is the difference between contra- and ipsilateral activations.

predicted direction, albeit negligible (i.e., reactions to targets following angry faces were slower on average by less than one millisecond). This effect did not significantly differ from zero as shown by a one-sample two-sided t-test [t (59) = 0.56, p = 0.58, d = 0.07]. The mixed two-way ANOVA produced non-significant results, indicating that neither experimental condition [Group, F (2, 57) = 0.15, p = 0.86, $\eta_p^2 = 0.02$] nor time points [Block, F (2,114) = 0.10, p = 0.91, $\eta_p^2 < 0.01$] nor their interaction [F (4,114) = 0.56, p = 0.69, $\eta_p^2 = 0.02$] affected RT bias scores. Adding the SIAS and RST-PQ scores as covariates did not reveal a significant influence of these variables (all "p"s > 0.06).

3.3 N2pc

Across all participants and blocks, we found an average N2pc$_{between}$ amplitude of −0.24 μV (SD = 0.37 μV), which indicated a generally stronger negative deflection in the hemisphere contralateral to the angry face stimulus compared to the ipsilateral hemisphere (see Figures 4, 5 shows the topology plot of this effect). This difference proved to be statistically significant as indicated by a one-sample one-sided t-test [t (59) = −4.9, p < 0.01, d = 0.64], suggesting the presence of a general attentional bias toward angry faces. Considering the average amplitudes separately by block and condition, the N2pc descriptively decreased in size (i.e., approached zero) over the course of the entire experiment in both the implicit and explicit training conditions. This decrease was continuous in the implicit condition, but not so in the explicit condition, where it is interrupted by a temporary shift into the opposite direction in block 2. In the control condition, the N2pc showed a steady descriptive increase in size (i.e., more negative values) with each block (see Figure 6). However, when performing the mixed two-way ANOVA with the factors Group and Block, the critical interaction of Group × Block did not reach significance [F (4,102) = 1.92, p = 0.11, $\eta_p^2 = 0.07$]. Neither of the two main effects were significant (Group [F (2,51) = 0.02, p = 0.99, $\eta_p^2 < 0.01$], Block [F (2,102) = 0.78, p = 0.46, $\eta_p^2 = 0.02$]). Adding the SIAS and RST-PQ into the model again did not yield significant results (all 'p's > 0.07).

The split-half reliability of the N2pc$_{between}$ was estimated to be 0.82 (SD = 0.08, 95% CI [0.71, 0.89]). However, when considering the hemispheres separately (i.e., calculating the N2pc separately for trials with a left-sided vs. a right-sided angry face), these sub-measures displayed Spearman-Brown corrected reliability estimates of 0.98 (SD = 0.01, 95% CI [0.97, 0.99]) and 0.98 (SD = 0.01, 95% CI [0.96, 0.99]), respectively.

Regarding these sub-measures, we found the same hemispheric lateralization effect known from previous data (see section 2.4). That is, when plotted together, the two waveforms almost perfectly mirrored each other on the x-axis, with the collapsed N2pc merely representing a comparably minor deviation from this pattern (see Figure 3). This is reflected in a significant negative correlation of the two sub-measures, r (160) = −0.92, p < 0.01. Therefore, it seems that the side of data recording has *per se* a considerably larger influence on the variable of interest than the actual manipulation of stimulus position, possibly masking experimental effects.

The N2pc$_{within}$ that was calculated to circumvent this lateralization effect (see section 2.4) had an average amplitude of −0.32 μV (SD = 0.4) across all blocks and conditions (see Figures 7, 8 for the topography). This difference was again shown to significantly differ from zero by a one-sample one-sided t-test [t (55) = −6.06, p < 0.01, d = 0.81], again reflecting the presence of a general attentional bias toward angry faces. The split-half reliability of the N2pc$_{within}$ was estimated to be 0.64 (SD = 0.17), with a 95% CI of [0.52, 0.74]. Comparing submeasures of the N2pc$_{within}$ based on hemisphere to each other (see Figure 9) showed that, as intended, these were not affected by the lateralization effect found for the N2pc$_{between}$, with a significant positive correlation between the submeasures of r (160) = 0.21, p < 0.01. The reliability estimates for the submeasures were 0.7 (SD = 0.16, 95% CI [0.44, 0.84]) and 0.68 (SD = 0.13, 95% CI [0.56, 0.81]) for the left and right hemisphere (P7 and P8), respectively.

Inspecting the average amplitudes separately by block and condition, the revealed pattern (see Figure 10) differed from that described above for the N2pc$_{between}$. Again, the N2pc descriptively

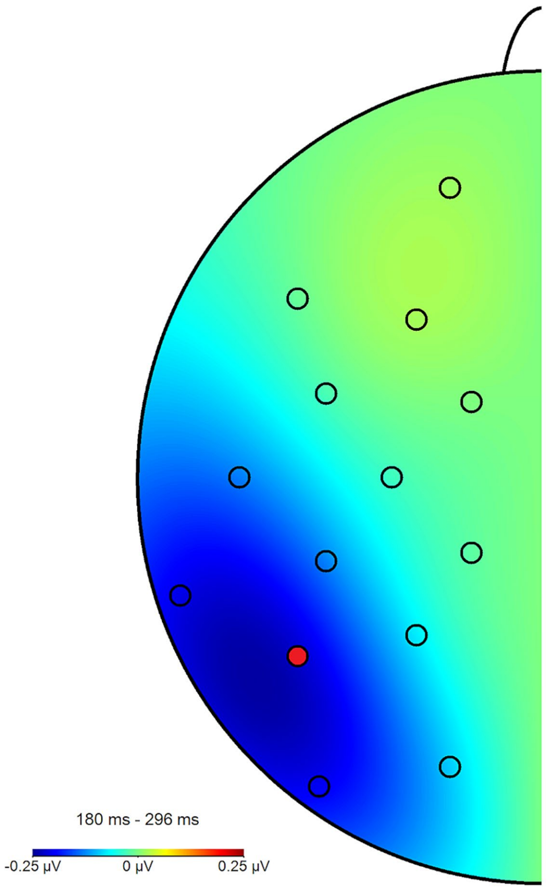


FIGURE 5
Topography plot of the $N2pc_{between}$ effect across all participants and blocks. The electrode of interest (P7) is marked in red (P8 not pictured). For the purpose of this figure, difference waves from the angry/neutral and neutral/angry stimulus configurations were collapsed and mapped to the left side of the skull, such as if all angry faces had been shown in the right hemifield, when this was in fact counterbalanced.

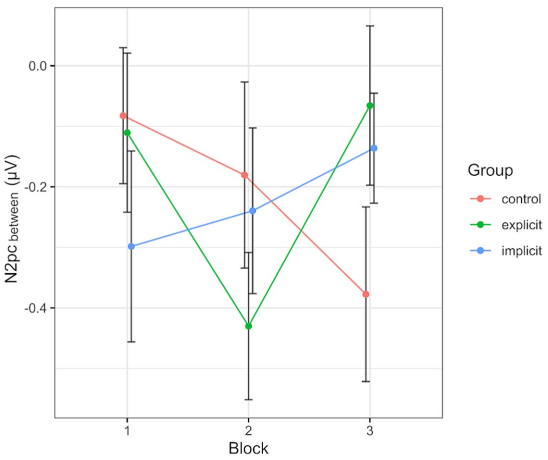


FIGURE 6
Progression of the $N2pc_{between}$ over the three blocks, split by group. Each data point corresponds to the mean of the segment marked in gray in Figure 4 (regarding the black line). Error bars indicate SEM.

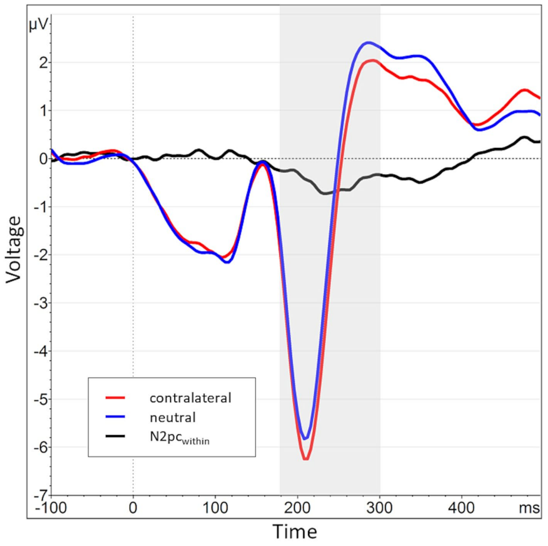


FIGURE 7
Grand average waveform of the $N2pc_{within}$ waveform and its constituents across all participants and blocks at electrode positions P7 and P8. The time window of interest (180 to 300 ms post stimulus onset) is marked in gray. The average activity contralateral to angry face stimuli is shown in red (mean of $P8_{AN}$, $P7_{NA}$, identical to the red line from Figure 4), while the corresponding activity when both faces (i.e., also the contralateral one) were neutral is shown in blue (mean of $P8_{NN}$, $P7_{NN}$). The $N2pc_{within}$ (black) is the difference between contralateral and neutral activations.

increased in size in block 2 in the explicit condition, but was diminished in block 3, even reaching a positive value (indicating attention away from negative faces). The control group showed an inverted progression, decreasing in block 2 but again ending up at a more negative value in block 3 than at the beginning of the training session. The values in the implicit group stayed more or less the same across all three blocks. When performing the mixed two-way ANOVA with the factors Group and Block, there was a significant interaction of Group × Block [$F\,(4, 102) = 4.07$, $p < 0.01$, $\eta_p^2 = 0.14$]. The two main effects again did not reach significance (Group [$F\,(2, 51) = 0.59$, $p = 0.56$, $\eta_p^2 = 0.02$], Block [$F\,(2,102) = 0.38$, $p = 0.69$, $\eta_p^2 = 0.01$]. Adding the SIAS and RST-PQ into the model did not change the previous results and there was no significant interaction or main effect of either questionnaire (all "p"s > 0.14). Following up on the significant interaction by performing separate one-way ANOVAs with the within-subject factor Block for each group, the main effect Block reached significance in the explicit group [$F\,(2, 30) = 6.08$, $p = 0.02$, $\eta_p^2 = 0.28$], but not so in the implicit group [$F\,(2, 36) = 0.05$, $p = 0.96$, $\eta_p^2 < 0.01$] or the control group [$F\,(2, 36) = 2.46$, $p = 0.1$, $\eta_p^2 = 0.12$]. *Post hoc* pairwise comparisons between group means using Bonferroni correction showed a significant difference (reduction) in $N2pc_{within}$ amplitude between blocks 2 and 3 within the explicit group ($p < 0.01$).

4 Discussion

We evaluated the effectiveness of reward-based attentional bias modification within a single training session using electrophysiological measures. Measuring the conventional N2pc as an index of selective

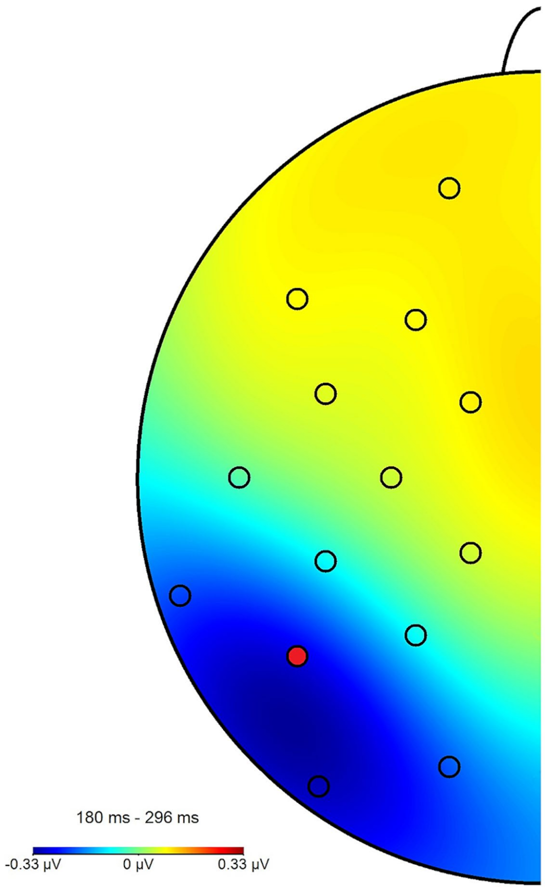


FIGURE 8
Topography plot of the N2pc$_{within}$ effect across all participants and blocks. The electrode of interest (P7) is marked in red (P8 not pictured). For the purpose of this figure, difference waves from the angry/neutral and neutral/angry stimulus configurations were collapsed and mapped to the left side of the skull, such as if all angry faces had been shown in the right hemifield, when this was in fact counterbalanced.

attention toward angry face stimuli, we were able to identify a general attentional bias over all groups and blocks. However, for this conventional N2pc quantification we did not observe any substantive effects of the ABM training. Furthermore, the electrocortical activation seemed to be strongly characterized by lateralization effects as has previously also been reported by Reutter et al. (2019). This prompted us to explore an alternative calculation of the N2pc, combining values from within hemispheres rather than across. Over the course of the training session, we found a significant reduction of this measure during the second half of the training period, however only within the group whose instruction contained an explicit reference to the contingency between distractor valence and the level of reward associated with it.

Some of our findings are consistent with previous results. Specifically, the overall presence of an attentional bias toward angry faces as marked by (both variants of) the N2pc corroborates earlier studies (Eimer and Kiss, 2007; Feldmann-Wüstefeld et al., 2011; Kappenman et al., 2014; Osinsky et al., 2014; Reutter et al., 2017). Similarly, the absence of an attentional bias within reaction time data as well as their mediocre reliability has been shown repeatedly in recent research (Schmukle, 2005; Staugaard, 2009; Kappenman et al., 2014; Rodebaugh et al., 2016; Kruijt et al., 2019). It is worth noting that unlike the study sample in Reutter et al. (2017, 2019) and consistent with Osinsky et al. (2014), our sample was not preselected for high social anxiety scores, reinforcing the view that a certain level of attentional bias toward threat is found in the general population (e.g., Öhman et al., 2001; Schupp et al., 2004), not only within clinical or subclinical samples.

However, the main findings of this study raise several discussion points. Firstly, we must acknowledge that our manipulation did not have a significant impact on our main dependent variable, the conventional N2pc, but only on its exploratory variant instead. As previously discussed, this alternative quantification of the N2pc was calculated within hemispheres to increase sensitivity to possible experimental effects. To the best of our knowledge, there is no pre-existing literature examining this calculation method. Thus, it remains conjecture if both variants represent the same underlying neurocognitive mechanisms and can be interpreted equivalently. The basic logic behind both is consistent: a difference value based on posterior contralateral electrodes, with the minuend being the electrode involved in the processing of an angry stimulus and the subtrahend being the homolog (N2pc$_{between}$) or identical (N2pc$_{within}$) electrode during the processing of a neutral stimulus. However, it should be noted that for the conventional calculation method, every trial that entered the calculation contained both an angry and a neutral stimulus, whereas for the alternative method, the trials that constituted the subtrahend contained neutral stimuli only. Thus, the two methods differ on the very basis of the physical conditions involved. This may entail an interesting advantage of the exploratory method, in that, contrary to the conventional method, it allows for a comparison between the activity caused by an angry stimulus and a truly neutral condition.

Taken together, we believe that these considerations form the basis for interpreting the similarities and differences in results between the two variants: On the merit of following the same principle, the exploratory variant may be assumed to indicate selective spatial attention in the same way as the conventional N2pc does; as such both were able to showcase the general attentional bias present across all participants and blocks. Assuming the training effect found for the exploratory N2pc to be genuine, the most obvious explanation for why this did not manifest for the conventional variant (although exhibiting the same tendency) is the influence of the lateralized processes that prompted the alternative calculation in the first place. It is of note that hemispheric asymmetries have previously been reported in the context of the N2pc, having been speculated to reflect language-related lateralized processes due to the use of stimulus material with linguistic components (Eimer, 1996; Liu et al., 2009). Accordingly, in the present study, the lateralization effects might have been a consequence of the right-hemispheric dominance known for facial processing (Hay, 1981; Kanwisher et al., 1997; Prete and Tommasi, 2018).

Taking a closer look at the pattern of results obtained for the exploratory N2pc$_{within}$, its disappearance at the end of the training session in the explicit group indicates that the reward-based training was effective insofar as that threatening faces were no longer processed preferentially at this point. The fact that we found this significant reduction only within the explicit training condition might be taken to indicate that conscious knowledge of the reward contingencies is

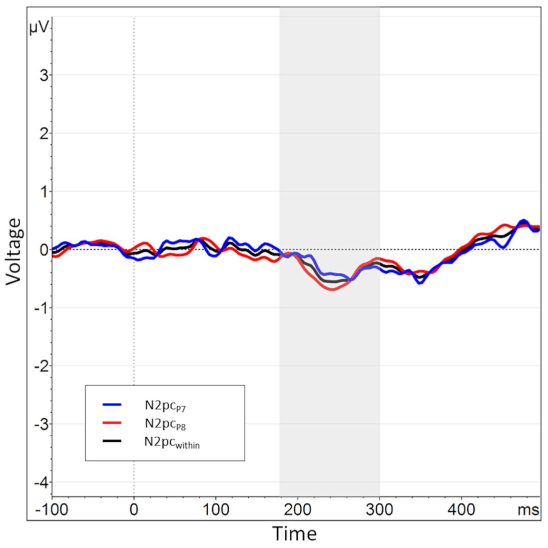


FIGURE 9
When splitting the $N2pc_{within}$ into submeasures based on hemisphere, the submeasures show a high degree of similarity (as opposed to the submeasures of the $N2pc_{between}$). The N2pc based completely in the left hemisphere, i.e., the difference in activation when an angry vs. a neutral face is shown in the right visual hemifield, is shown in blue ($P7_{NA} - P7_{NN}$). The N2pc for the right hemisphere is shown in red ($P8_{AN} - P8_{NN}$). The $N2pc_{within}$, the mean of these two submeasures, is shown again in black.

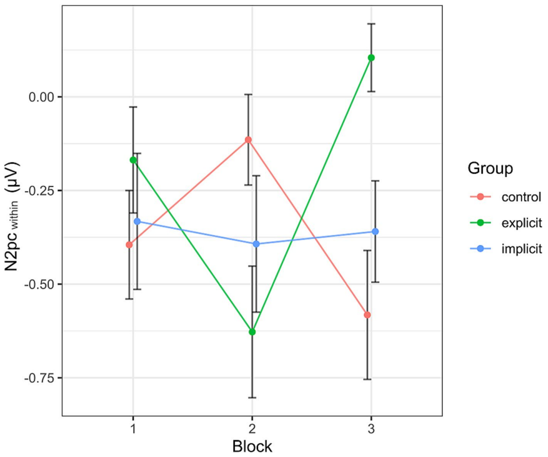


FIGURE 10
Progression of the $N2pc_{within}$ over the three blocks, split by group. Each data point corresponds to the mean of the segment marked in gray in Figure 7 (regarding the black line). Error bars indicate SEM.

necessary to achieve the desired training effect. Yet, in the post-test questionnaire, the vast majority of participants in the explicit as well as the implicit condition stated not having been aware of any contingency during the experiment (there were only two to three exceptions in either group). Thus, it cannot be concluded that the reason for the significant effect within the explicit group lies within explicit awareness of the training contingency. It might however be the case that the allusion toward the contingency primed participants in the explicit group and facilitated their subconscious perception of it. Indeed, in order to address attentional biases which are subconscious processes themselves, ABM has been designed to operate on the subconscious level in its original conception, with the use of implicit instruction being the standard especially in its early stages (see, e.g., Hakamata et al., 2010). On the other hand, this approach has been challenged by several studies who found an advantage for explicit training methods (Krebs et al., 2010; Nishiguchi et al., 2015). Note that regardless of the outcome of this debate in the traditional ABM literature, in the context of *reward-based* ABM, the question of which method is superior remains up for debate, as the same results do not necessarily hold for value-driven attention (it's not unreasonable to assume that awareness of reward contingencies in this context might make them more effective). An alternative to the previously attempted explanation, i.e., facilitation of subconscious perception, for the differential outcome between implicit and explicit training groups might be that participants in the explicit training group were in fact consciously aware of the reward contingencies as a result of the instruction, yet failed to mention so in the post-test questionnaire for whatever reasons. In conclusion, while the present results do imply an advantage for an explicit over an implicit instruction, the uncertainty with respect to the participants' actual levels of contingency awareness as well as the exploratory nature of the dependent variable prevent a conclusive explanation of this effect.

Another point that should be addressed are the reliability estimates associated with the various dependent variables. The low reliabilities of reaction time biases in previous research have generally drawn criticism and been a major reason for the attempt to switch to other modalities. In the present data set, this has been met with partial success. While the two subcomponents of the conventional N2pc displayed nearly perfect reliabilities by themselves, the collapsed measure scores lower, while still being in a viable range. The exploratory N2pc measures had even lower reliabilities, both the collapsed as well as the intrahemispheric submeasures, being of overall questionable reliability. Interestingly, the RT bias displayed higher reliabilities than the exploratory N2pc measures, in fact being overall acceptable. To interpret these patterns, it helps to take a look at the underlying properties of the reliability assessment. The fact that reliabilities are estimated by correlating (subsets of) a dataset with itself means that high scores are contingent on the presence of stable between-subjects variability. That is, even if a task itself produces robust effects, if these effects are too similar between participants, reliability estimates will be low. While low between-subjects variability is usually coveted, leading to stable and replicable effects, it paradoxically also means that it causes problems for the use in a correlational context (Hedge et al., 2018). Furthermore, the systematic and stable variance between participants that leads to high reliability scores can be introduced both by effects of interest and by other factors that are not relevant to the study question. Conversely, they are impacted by the introduction of unsystematic variance or noise. In the context of the present study, the lateralization effect caused by face processing is an example for a factor of no interest. Its presence, however, results in large and stable between-subjects variability. This explains why the conventional N2pc submeasures display such high reliabilities, as they include the lateralization effect which even gets exacerbated by the subtractions involved in the calculation. The collapsed conventional N2pc on the other hand displays lower reliability because the systematic variance introduced by the lateralization effect is canceled out. This however may actually be seen as an advantage, since the remaining reliability is more likely to truly reflect that of the effect of interest. Finally, the exploratory N2pc circumvents the influence of lateralization effects as it was intended to do, thereby losing systematic variance (of no interest). At the same time, and as mentioned above, it uses physically different trials, while for the conventional N2pc, the difference is taken between electrodes within the same trial, meaning that random inferences in the signal are largely subtracted away. The latter does not work for the calculation of differences across trials, thus introducing a higher level of random noise. These two considerations may explain why the exploratory N2pc has the overall lowest reliability. Taken together, the assumed pattern is as follows: submeasures of the conventional N2pc include high systematic variation of interest, high systematic variation of no interest and low noise and therefore display excellent reliability. The collapsed conventional N2pc includes high systematic variation of interest, low systematic variation of no interest and low noise and therefore exhibits good reliability. The exploratory N2pc and its submeasures include high systematic variation of interest, low systematic variation of no interest and high noise and thus show questionable reliability. As a final comparison between the two variants of the N2pc, the exploratory variant may be described as more sensitive but less reliable (but see the reliability paradox mentioned above).

The current study aimed to find evidence for a reward-based ABM training's effectiveness under the simplest and most general conditions, that may have acted as limitations at the same time (a single training session, no preselection of participants and limited sample size), in the hope that if successful, these findings could be extrapolated to the other cases as well (with the inverse not necessarily being the case). In our case, due to the partially exploratory nature of the analyses as well as the inconclusive pattern of the results and reliability measures, the presented finding of a significant attentional bias reduction in the explicit training condition should be treated as preliminary. Further studies could take the inverse approach and maximize each of the parameters (i.e., a high number of training sessions in a large, preselected sample) to provide conclusive evidence for or against the potential efficacy of reward-based ABM under the most facilitative conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Board of the University of Osnabrück. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SK: Formal analysis, Investigation, Project administration, Writing – original draft, Software. RO: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Human emotional evaluation of ancestral and modern threats: fear, disgust, and anger

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Introduction: Animal and human ancestors developed complex physiological and behavioral response systems to cope with two types of threats: immediate physical harm from predators or conspecifics, triggering fear, and the risk of infections from parasites and pathogens leading to the evolution of the behavioral immune system with disgust as the key emotion. Integration of the evolutionary concepts of the fear module and behavioral immune systems has been infrequent, despite the significant survival advantages of disgust in various contexts. Studies comparing attention to ancestral and modern threats accompanied by fear have yielded ambiguous results and what qualifies as salient modern disgusting stimuli remains unclear. We do not know whether disgust or the behavioral immune system, as inherent aspects of human psychology, have adapted to safeguard us from pandemic risks or poisoning by modern toxic substances.

Methods: To test these effects, we have developed a survey comprised of 60 short vignettes describing threats evoking fear and disgust belonging to one of the three main categories of threats: (1) ancestral (phylogenetic), (2) modern (ontogenetic), and (3) pandemics of airborne disease. Each vignette was evaluated on a 7-point Likert scale based on fear, disgust, and anger. In total, 660 respondents completed the survey. The data were analysed using a factor analysis and general linear model with the respondent as a random factor.

Results: The results show that the strongest fear is triggered by modern threats (electricity, car accidents), while the highest disgust is evoked by ancient threats (body waste products, worms, etc.). Interestingly, disgust does not respond to modern threat stimuli such as toxic substances or radioactivity as these evoke mainly fear and anger. Finally, a distinct response pattern was found for pandemic threats, in which both fear (e.g., of disease and death) and disgust (e.g., of used face masks) are employed.

Discussion: Our study offers valuable insights into the emotional responses to ancestral and modern threats and their adaptation to pandemic challenges. Ancestral threats are not always more powerful stimuli than adequate threats of the modern type, but they function specifically. Thus, snakes and heights as fear-inducing ancestral threats form separate factors in a multivariate analysis, whereas all ancestral disgust stimuli group together. The threat of a pandemic forms a specific category and people process it emotionally and cognitively. These insights contribute to our understanding of human psychology and behavior in an ever-changing world.

KEYWORDS

anger, COVID-19, fear of heights, fear of snakes, ontogenetic threat, oral disgust, pandemic of airborne disease, phylogenetic threat

1 Introduction

Throughout human evolution, the survival of our animal and human ancestors was perpetually challenged by diverse environmental threats (Öhman, 2007). These encompassed immediate physical dangers from predators and conspecifics belonging to other tribes (Barrett, 2015), as well as insidious risks posed by parasites and pathogens (Perry, 2014). Research in evolutionary psychology suggests that such threats that were likely to cause injury or even death have shaped the human brain's fear response, resulting in the development of cognitive mechanisms that prioritized survival (Öhman and Mineka, 2001).

The amygdala as a key component of the brain's fear circuitry played a primordial role in the detection of phylogenetic threats (LeDoux, 2003; Öhman, 2005) and the initiation of a rapid and instinctual "fight-or-flight" response (LeDoux, 2012). Furthermore, the ancestral environment fostered the development of fear-learning mechanisms (Öhman and Mineka, 2001; Mineka and Zinbarg, 2006; Zsido et al., 2023), enhancing the acquisition of threat-related information for adaptive decision-making. Interestingly, the distribution of fears is non-random as some objects or situations tend to be feared by humans much more often than others (especially animals such as snakes or spiders and natural/physical elements such as heights, storms, dark, enclosed spaces etc.; Curtis et al., 1998). Therefore, Seligman (1971) proposed an influential theoretical model of biological preparedness arguing that phobic reactions reflect our evolutionary past and are associated with stimuli posing a real threat to the survival of human pre-technological ancestors (see also Bracha, 2006).

However, others have challenged the view of the amygdala being a fear module responding specifically to fear-related stimuli and argued that research has already shown a variety of triggers of the amygdala activation including positive stimuli. Therefore, Sander et al. (2003) proposed an alternative theory that the amygdala processes objects or situations that might be relevant to the organism no matter its emotional valence.

Apart from the fear-inducing predators and conspecifics, another critical danger has existed throughout our evolutionary history, representing an even more substantial threat - the risk of infection from parasites, bacteria, and viruses (Curtis, 2014). However, given the qualitative distinction between imminent physical attacks and pathogen exposure, the emotion of fear might not have been the only appropriate response (Oaten et al., 2009). Instead, our ancestors, even as early mammals, evolved a specialized mechanism known as the behavioral immune system, with disgust as its key emotion (Curtis and Biran, 2001; Schaller and Park, 2011). Whether disgust evolved from a simple response to bad taste (distaste), which can indicate spoiled and potentially dangerous food (Chapman et al., 2009; Rozin et al., 2009), or whether it was designed from the beginning to respond to a wider range of stimuli associated with disease and infection (Curtis, 2014), the authors agree that the category of triggers has been further expanded throughout biological and cultural evolution, including even immoral acts (moral disgust; Tybur et al., 2013).

Disgust in any case serves as a powerful signal to avoid potential sources of infection, supporting the survival of our ancestors in pathogen-rich environments. Behavioral responses to disgust include withdrawal, distancing, or dropping of the potentially infectious object (Curtis et al., 2011). Universal disgust elicitors are bodily wastes and fluids (faeces, urine, vomit, blood, saliva, mucous), organs, sick or unhygienic individuals, spoiled or unfamiliar food, and certain animals acting as disease vectors (Tybur et al., 2013).

Functionally, both fear and disgust serve to protect the biological integrity of an organism (Nesse, 1990) but are principally different as to the characteristics of impending danger (Keltner and Gross, 1999). Disgust, in contrast to fear, activates at different levels a neural network involving the anterior insular cortex, basal ganglia, ventrolateral and medial prefrontal cortex, anterior temporal cortex, and visual cortex (Wicker et al., 2003; Chapman and Anderson, 2012; Koenigs, 2013; Becker et al., 2016). As for the physiological response, disgust is usually associated with activation of the parasympathetic nervous system, including heart rate deceleration (Cisler et al., 2009), however, the results of physiological studies are not always consistent. Kreibig (2010) in her review suggests a second, partially overlapping, pattern characterized by sympathetic-parasympathetic co-activation with heart rate acceleration, faster breathing, and decreased inspiration (in relation to contamination stimuli, in contrast to blood and injury). In conclusion, there is an ongoing debate about parasympathetic activation in disgust reaction, but it is clearly not as strong a sympathetic activator as fear (Rozin et al., 2016).

While much research has focused on disgust in humans, studies in non-human primates have also provided valuable insights into the evolutionary origins and function of disgust and the behavioral immune system (Rottman, 2014). In primates, the facial expression of disgust is characterized by distinct features, such as a raised upper lip, exposing teeth, a wrinkled nose, and narrowed eyes (Preuschoft and van Hooff, 1995). These facial movements serve as important communicative signals within primate social groups. It has been shown that a group of mandrills exhibits a reduced tendency to remain in close proximity (<1 m) to a highly parasitized faecal sample (Poirotte et al., 2017). Given that the divergence time between Cercopithecoidea (Old World monkeys, a superfamily containing mandrills) and Hominoidea was estimated to be the Oligocene period (33.9–23 MYA; Springer et al., 2012), the disgust must have emerged even earlier in primate evolution.

In a series of experiments with bonobos, researchers observed that these primates exhibited avoidance behaviors and contamination-risk sensitivity in response to food items along a gradient of contamination probabilities. These responses appeared to require multisensory cues to associate contamination events with specific food items, aligning with the parasite avoidance theory of disgust. Surprisingly, there was no observed sex-based bias in contamination-risk aversion, and the study suggests that physiological responses to contaminants may have evolved alongside behavioral avoidance mechanisms in primates (Sarabian et al., 2018). Similarly, the feeding behavior of chimpanzees (*Pan troglodytes troglodytes*) is influenced by potential contaminants, primarily conspecific faeces. When food was associated with the odour of faeces, these animals were less inclined to feed and often vacated the area. Conversely, there was no discernible difference in their feeding behavior when exposed to the odours of blood or semen, which are not necessarily linked to pathogen avoidance but could be related to antipredator behavior or reactions to conspecific aggression (Sarabian et al., 2017; see a review by Schwambergová et al., 2023).

Over time, the nature of threats has evolved, ranging from ancestral challenges that early humans faced to the modern complexities of the contemporary world. Only a few studies compared the evaluation of ancestral and modern threats. Shapouri et al. (2023) have recently demonstrated that the evolutionary age of disasters is one of the factors that affect emotional experiences evoked by these threats and can impact our evaluations of catastrophes. Technological (modern, manmade) disasters were rated as slightly less arousing but significantly more unpleasant than natural (ancient) disasters. In another study, people were more concerned about the negative consequences of human hazards compared with natural hazards. The same negative outcome (e.g., number of birds killed by an oil spill) was more negatively evaluated when caused by humans than when caused by nature. Furthermore, when identical risk information was provided, participants evaluated nuclear power more negatively compared with solar power (Siegrist and Sütterlin, 2014).

While ancestral life-threatening stimuli are strong attention-catchers (Öhman et al., 2001; Blanchette, 2006; Rudolfová et al., 2022; Štolhoferová et al., 2023), the impact of modern threats on attention remains equivocal (*cf.* Zsido et al., 2019; Abado et al., 2023). Despite the differences in cognitive processing, both ancestral and modern threats involve the activation of stress-responsive systems. The hypothalamic–pituitary–adrenal (HPA) axis releases cortisol, facilitating adaptive physiological responses to threats (McEwen and Gianaros, 2011). Additionally, the role of the amygdala in detecting threat-related stimuli remains relevant across both contexts, emphasizing its evolutionary significance (Phelps and LeDoux, 2005). However, the distinct cognitive evaluation and processing of modern threats may modulate the extent to which these shared neural and physiological pathways are engaged (Öhman and Mineka, 2001).

The coexistence of ancestral and modern threats in the contemporary world has also implications for mental health and well-being (Katsampouris et al., 2022). An overactive fear response such as specific phobias, initially adaptive for ancestral threats, may contribute to anxiety disorders when chronically activated in response to modern stressors (Nesse, 1999). The adaptation of ancestral fear mechanisms to modern threats may exacerbate the experience of chronic stress and anxiety (McEwen and Gianaros, 2011). Furthermore, the ubiquity of modern threats in media may amplify fear responses and contribute to heightened levels of anxiety and stress-related disorders (Vasterman et al., 2005).

To the best of our knowledge, no similar research comparing a response pattern to ancestral and modern disgust elicitors exists. Moreover, it is not even known whether there are any contemporary threats (except moral code violations) with the potential to trigger disgust. Only recently, a study by Hacquin et al. (2022) showed that nuclear energy might be a modern disgust elicitor activating the behavioral immune system. One of the main goals of our study was to support that finding and test, whether other modern disgusting stimuli could be identified. We aimed to create "mirror" stimuli similar to fear studies, which compare, for example, fear of snakes and fear of guns (for a review, see for example Shapouri and Martin, 2022), i.e., fear of injury or death, which might however be caused by stimuli of different evolutionary age. Thus, in the case of disgust, we aimed to create situations in which poisoning might occur using stimuli such as spoiled food (ancestral) versus toxic chemical substances (modern; see below).

Another possible candidate is the threat of a pandemic of infectious disease. In the past and even in modern times, infectious diseases have remained a significant cause of mortality, especially in lower-middle-income countries. Pandemics have been a recurring phenomenon throughout human history, shaping societies, economies, and healthcare systems and adherence to avoidance behavior and good hygiene practices, driven by disgust, can mitigate the risk of infection (Tybur et al., 2013).

The types of diseases more prevalent in human evolutionary history, which shaped our disgust response, might differ from those that pose a threat today. Since for most of their evolutionary history humans lived in relatively small groups and with only limited inter-group contacts (Weisdorf, 2005), one should expect only epidemics with local character. Mainly the transmission of airborne diseases via respiratory droplets and aerosols depends heavily on human mobility and contact frequency within and between populations (Kucharski et al., 2020). Human ancestors, living in relatively small groups with limited inter-group contacts, were more susceptible to local epidemics rather than global pandemics caused by airborne diseases (Weisdorf, 2005; Troisi, 2020). However, approximately 10,000 years ago, with the formation of cities and extensive trade networks, the landscape of disease transmission changed (Weisdorf, 2005). During Antiquity, we know of several large pandemics, e.g., the Antonine plague (suspected smallpox pandemic; Duncan-Jones, 1996) or the Plague of Justinian (bubonic plague pandemic; Frith, 2012). Since the Middle Ages well into the 19th century, repeated outbreaks of bubonic plague and smallpox were the cause of hundreds of millions of deaths worldwide (Frith, 2012). One of the most devastating pandemics in history, the Black Death, caused by the bacterium *Yersinia pestis*, decimated Europe's population between 1,347 and 1,351. The rapid spread of the disease through fleas on rats led to millions of deaths, profoundly affecting medieval societies (Cohn Jr, 2002). The second largest pandemic yet is considered the so-called Spanish flu of 1918–1920 (Trilla et al., 2008). Caused by the H1N1 influenza virus, the Spanish Flu is often cited as a benchmark for pandemic severity. With an estimated 50 million deaths worldwide, its impact was magnified by the context of World War I and the global movement of troops (Barry, 2009). Interestingly, all these historically deadly pandemics were of airborne diseases.

However, it remains a topic of inquiry as to how disgust may reduce the risk of infections transmitted through the respiratory route, such as tuberculosis or viral influenzas (Schwambergová et al., 2023). Yet, sudden outbreaks of bacterial or viral diseases with the potential to rapidly spread globally present one of the biggest health challenges humans will need to face in the future. This is especially the case of airborne pathogens as we witnessed recently with the pandemic of COVID-19 (Wu et al., 2020). In conclusion, the threat of a pandemic can be considered as a modern threat against which both emotions of fear and disgust could protect. This has also become one of our main research interests here.

Fear and disgust are not the only emotions triggered by certain types of threats. The COVID-19 pandemic, as mentioned above, has brought unprecedented challenges and disruptions to societies worldwide (Cash and Patel, 2020). While much attention has been focused on the physical health consequences of the virus, there is growing recognition of the impact of the pandemic on mental health (Cullen et al., 2020). The COVID-19 pandemic has engendered a profound sense of uncertainty and fear due to its rapid spread, high mortality rates, and the lack of a definitive treatment or vaccine during the initial phases (Taylor, 2019; Coelho et al., 2020). This has been further accentuated by multiple psychosocial stressors associated with the pandemic such as economic instability, job loss, and financial strains, creating fertile ground for increased anger to manifest (Pfefferbaum and North, 2020). Finally, social isolation, disrupted routines, and concerns about loved ones' health have added to the emotional burden (Brooks et al., 2020). These stressors can amplify frustration and irritation, leading to anger as an emotional outlet. Thus, anger has emerged as a significant and complex emotion during this crisis (Smith et al., 2021) and needs to be incorporated into psychobehavioral studies of pandemic threats.

However, anger is not only an emotional response to various stressors like restraint from many "normal" goal-directed activities caused by the pandemic situation, but it is one of the basic emotions that informs and guides many aspects of human behavior (Scarantino and Griffiths, 2011). There is neuroscientific evidence that points to the phylogenetic origins of two circuits underlying anger that have had an evolutionary role in promoting the survival of human ancestors (reviewed in Williams, 2017). This emotion is tightly connected with approach-avoidance motivation and serves as an internal signal helping to overcome different types of obstacles and aversive situations. External displays of anger can be cross-culturally stable (Matsumoto et al., 2010) and are a communication signal that plays an important role in dealing with conflicts in interpersonal relationships and emotional attachments (Williams, 2017). Anger motivates humans mostly to approach the threat and deal with it, whereas fear and disgust are linked more with an avoidance response (Harmon-Jones et al., 2013). From an evolutionary point of view, we can see the ancestral function of anger for confronting various threats, and thus this emotion can easily supplement an evasive function of fear whenever human ancestors had to face the imminent danger of predation or attacks from conspecifics.

There is research on the theory of biological preparedness when scientists use angry faces as ancestral stimuli (similarly to snakes or spiders used in research on the evolution of fear) to trigger anger and show how it works in the context of conditioning. It is predicted that evolutionarily prepared stimuli should be conditioned faster, and their extinction should be slower. Moreover, the psychophysiological response to them should be stronger compared to neutral stimuli (Öhman and Dimberg, 1978; McNally, 1987; Ney et al., 2022).

Interestingly, humans generalize anger also to moral indignation over a violation of morality that is caused by the wrongness of one's actions and especially by the intent to harm (Hechler and Kessler, 2018). Surprisingly, the same moral violation of the rules is experienced by some people more as anger, while other people report feeling disgusted. Feeling disgusted at moral violations is more likely to occur whenever others break the rules and is more likely to be associated with indirect aggression. Feelings of anger are typical when the respondent himself violates the moral code (Molho et al., 2017). Moreover, moral anger and moral disgust appear to have a surprisingly similar pattern of activation in fMRI (Oaten et al., 2018). Anger for its evolutionary importance as well as for its generalization to dealing with moral violations is an important emotion that should accompany or complement our emotional reaction to ancestral as well as modern threats.

1.1 Aims

While fear and disgust have been extensively studied separately, there is a need to explore them simultaneously. It is necessary as well to compare ancestral and modern threats to understand the intensity of emotional and behavioral responses they trigger and their adaptability in the context of modern challenges like pandemics. Integration of the evolutionary concepts of the fear module and behavioral immune system has been infrequent, despite the significant survival advantages of disgust in various contexts. Studies comparing attention to ancestral and modern threats accompanied by fear yielded ambiguous results and what qualifies as salient modern disgusting stimuli remains unclear. We do not know whether disgust or the behavioral immune system, as inherent aspects of human psychology, have adapted to protect us from pandemic risks or poisoning by modern toxic substances. This paper explores the foundations of fear and disgust in the context of both ancestral and modern threats, elucidating their emotional manifestations and potential relevance to modern challenges.

The specific aims of the study were to find out whether:

1 There is a difference between ancestral and modern threats within each emotion, in other words, if the ancestral machinery can be effectively applied to new types of current threats or which threats, either phylogenetic or ontogenetic, are more salient in triggering fear, disgust, or anger.
2 There are specific triggers (types of threats) of each emotion or it is rather the current level of threat relevance that is primordial. Or, what stimuli are the best triggers of fear, disgust, or anger?
3 The psychobehavioral circuits for processing fear and disgust have been adapted to respond to threats of pandemics of various diseases and whether these elicit more fear, disgust, or anger.

2 Materials and methods

2.1 Respondents

In total, 660 respondents completed the whole survey (484 women, 176 men). The participants were of Central European origin and spoke Czech. We recruited them mainly from the staff and students at several universities (including a University of the Third Age) and their relatives, so that we could obtain respondents of different age groups but with the same socioeconomic background (age 18–88, mean 39.98 ± 18.47). Out of these, 295 participants have had a biological education (*sensu lato*, including medicine, or agriculture), while the remaining 365 participants have been educated in a different field (mainly technical or social sciences).

Biological education is a process usually involving dealing with various animals (vertebrate and invertebrate) and using various methods from microscopy to handling living organisms or dissecting the dead ones. For biological students, all these activities are initially more or less disgusting like for other people. However, the disgust sensitivity is lower for university students with more interest and higher competencies (Randler et al., 2013). However, increased interest and decreased disgust sensitivity are also measurable for similar activities with 10 to 12-year-old children (Prokop and Fančovičová, 2017). Eventually, all students become accustomed to various animal-related practices during the educational process, not only with respect to reducing disgust but also fear of unpopular animals, both of which are significantly reduced (Randler et al., 2012). Among biologically educated respondents (biologists, biology teachers, physicians, nurses, and people with agricultural education at high school or college degree), we repeatedly found a lower disgust propensity and lower fear of fear-inducing animals such as snakes (fear: Rádlová et al., 2020; fear and disgust: Polák et al., 2020a, 2022; Staňková et al., 2021).

In our previous studies, we have often detected the effect of gender on fear and disgust (women experiencing higher fear of snakes: Polák et al., 2016 and spiders: Polák et al., 2020b; or higher disgust propensity: Polák et al., 2019). The effect of age (decreasing emotional sensitivity with age) on the subjective experience of fear and disgust when evaluating animal stimuli or completing assessments is less pronounced than the effect of gender but should still be considered (Landová et al., 2018; Polák et al., 2020a, 2022). As a significant proportion of vignettes simulating ancestral threats focus on snakes or invertebrates, we find it necessary to include the effect of biological education, sex, and age in the statistical models.

2.2 Stimuli and procedure

During a pilot study, we developed 77 short vignettes describing potentially dangerous situations that might evoke strong fear or disgust. We did not include vignettes on anger for several reasons. First, it is not clear what stimuli should be ancestral and modern concerning anger. Second, we see anger rather as a complementary emotion to fear and tightly attached to the moral aspect of disgust. Finally, one of the main objectives of this study was to see if the pandemics of airborne disease would be more similar to ancestral or modern threats based on fear and disgust – both emotions are linked to avoidance behavior, which may be also useful during the pandemic threat. As anger often leads to the opposite behavior, i.e., approach and attack, it would be complicated to think about its evolutionary advantage in the context of pandemic threats.

When creating the vignettes, we took inspiration from several established questionnaires, e.g., the Snake Questionnaire (Klorman et al., 1974, Czech translation by Polák et al., 2016) and the Disgust Scale - Revised (Haidt et al., 1994, modified by Olatunji et al., 2007, Czech translation by Polák et al., 2019), however, we modified the questions to be more relevant for Czech respondents, local environment, and their everyday lives. Most of the vignettes were newly created.

Each vignette belonged to one of the three main categories of threats: (1) ancestral (phylogenetic; snakes, heights, spoiled food, or other contamination disgust, e.g., "I go to the basement to get something and suddenly I hear a snake hissing."), (2) modern (ontogenetic; electricity, car accidents, toxic chemical substances visible and invisible, e.g., "I'm riding as a passenger in a car when suddenly the driver loses consciousness."), and (3) pandemics of an airborne pathogen (COVID-19 or another unspecified disease, e.g., "I feel someone sneeze on my face."). In total, 112 participants rated each vignette on a 7-point Likert scale by fear, disgust and anger during the pilot study. Based on these ratings, we selected only those vignettes that strongly elicited exclusively one of the two main negative emotions (high fear and low disgust and vice versa; here, we consider anger to be rather a secondary emotion). 17 vignettes evoking weak emotions or vignettes with ratings that did not correspond well to the predefined category were excluded from the main study.

Thus, 60 vignettes have been retained for further testing, 20 for each threat category (for the stimuli examples, see Table 1, and for the full list of vignettes, including the excluded ones, see Supplementary Table S1). The data collection took place between October 2022 and June 2023.

As the extent of the study did not allow to cover all possible situations that people may be afraid of, we included two open-ended questions at the very end of the experiment, where we asked what they currently feared the most or what they found the most disgusting. The participants were instructed to write their answers down if these stimuli were not represented in the questionnaire (no maximum stimuli limit was given and the respondents could also leave the question unanswered).

The testing procedure was conducted both online and as pen-and-paper. While younger participants usually prefer the online format, older people are easier to recruit in person, we were thus able to obtain a more age-balanced sample. The respondents were first asked a series of sociodemographic questions. Each vignette was then evaluated on a 7-point Likert scale based on fear, disgust, and anger (1 = not at all, 7 = extremely strong). The participants were asked to rate all the vignettes according to all three emotions, no time limit was set for the task.

2.3 Ethical note

This study was carried out following the approval of the Ethical Committees of Charles University, Faculty of Science (approval no.

TABLE 1 Examples of the vignettes used in the experiment.

Vignette category	Expected predominant emotion	Vignette example
Ancestral	Fear	I'm camping in nature and see a snake slithering near my tent.
	Disgust	I urgently need to use the toilet on the train, but it is very dirty.
Modern	Fear	I'm driving a car in the winter, and I feel that I am losing control of the vehicle on an icy road.
	Disgust	While swimming in a river, I find that there is an iridescent oil coating on the surface that has an unpleasant chemical smell.
Pandemic	Fear	A close family member is in the ICU with a severe case of respiratory disease.
	Disgust	A person with obvious symptoms of respiratory disease sits down next to me on public transport.

2021/02, granted on 14 April 2021) and National Institute of Mental Health (no. 91/21, granted 31 March 2021) and in accordance with the Declaration of Helsinki. All subjects provided their informed consent with participation in the study and personal data processing.

2.4 Statistical analysis

Raw scores for each question were used where possible, as we attempted not to transform the data to maintain as much variability as possible in the ratings of individual respondents. Agreement in the emotional evaluation among the respondents was quantified using the Kendall's coefficient of concordance (performed in SPSS 22; IBM Corp, 2013). Cumulative link mixed models for ordinal data (CLMM as implemented in R package ordinal; Christensen, 2022) were computed to examine the effect of respondents' characteristics (gender, age, education) and stimuli categories on the evaluation of vignettes on a Likert-like scale; respondents' identity was introduced as a random factor. To test the significance of differences in emotional evaluation between different stimuli categories, we performed a *post hoc* Tukey test (using the R package lsmeans; Lenth, 2016). Subsequently, a factor structure in the vignette ratings was examined using a factor analysis (principal component extraction and varimax normalized rotation method were used). A parallel analysis was used to determine the number of factors. We then visualized the data structure using a cluster analysis (the distance matrix was calculated using Pearson correlations among ratings, and tree diagrams were built using the Ward's method). We also applied the item response theory (IRT) approach to the vignettes' ratings, specifically a graded response model to check for the discrimination parameter. This was performed in Stata 18 (Stata Corp, 2023). Unless otherwise stated, the calculations were performed in R Statistical Software (v. 3.6.1; R Core Team, 2019) and Statistica 10 (Stat Soft, Inc., 2011).

3 Results

3.1 Emotional salience of stimuli

Six hundred and sixty respondents rated 60 vignettes describing a potential threat on a 7-point scale according to three negative emotions: fear, disgust, and anger. One hundred and twelve of these respondents participated in the pilot study evaluation, where they evaluated a larger number (77) of vignettes. However, because the ratings of the final set of vignettes obtained from these two experiments are highly correlated (Spearman's correlations for fear $R = 0.962$, disgust $R = 0.923$ and anger $R = 0.965$, all $p < 0.0001$), we pooled the two samples of respondents for all subsequent analyses.

Mean fear and disgust scores were negatively correlated (Kendall's $\tau = -0.497$, $p < 0.0001$), while the mean disgust and anger scores were correlated positively (Kendall's $\tau = 0.311$, $p = 0.0004$). Correlations between the fear and anger scores were not significant but there was a trend for a negative relationship suggesting the dichotomy between a fight or flight response. For mean emotional ratings in each vignette category, see Table 2, and for a graphical representation, see Figure 1.

For most stimuli, the predominant emotion (highest score) corresponded to the pre-defined category, i.e., fear vignettes elicited high fear and low disgust and vice versa. The only exception was for the modern disgust category, where fear was stronger than disgust and the highest scores were found in the anger evaluation.

While comparing ancestral versus modern stimuli, our results do not suggest that ancestral threats should universally be more powerful than adequate threats of modern type. While the highest disgust is evoked by ancient threats (body waste products, worms, etc.), the strongest fear is triggered by modern threats (electricity, car accidents).

3.2 Agreement among respondents

Despite high variability in stimuli and respondents, the evaluation agreement was significant and quite high: Kendall's coefficient of concordance for fear $W = 0.408$, disgust 0.378, and anger 0.346 (all $p < 0.0001$). Interestingly, there was a higher agreement for ancestral vignettes (ranging from 0.478 to 0.409) for all emotions compared to both modern (0.319 to 0.300) and pandemic threats (0.382 to 0.245) when computed separately (all $p < 0.0001$).

3.3 Variability among respondents

Next, we performed generalized linear models (GEEGLM) to analyse the effect of respondents' characteristics (gender, age, biological education) and stimuli threat categories on the emotional evaluation of vignettes. Raw scores of individual respondents were used as a response variable, and respondents' identity was introduced as a random factor. The results showed that all explanatory variables had a significant effect on the evaluation of fear (gender and category $p < 0.0001$, age $p = 0.0078$, education $p = 0.0028$) and disgust (gender, education and category $p < 0.0001$, age $p = 0.0042$). For anger evaluation, the effect of gender, education,

TABLE 2 Mean ratings of fear, disgust, and anger for individual categories of threats as described by short vignettes (7-point scale, 1 = not at all, 7 = extremely strong).

Category	Mean fear	Fear SD	Mean disgust	Disgust SD	Mean anger	Anger SD
Ancestral fear	**4.330**	2.13	2.103	1.78	2.119	1.80
Modern fear	**4.820**	2.02	1.886	1.62	3.095	2.14
Pandemic fear	**3.930**	2.08	1.916	1.59	2.659	2.03
Ancestral disgust	2.002	1.67	**4.407**	2.03	3.503	2.17
Modern disgust	3.900	2.16	3.167	2.07	**4.432**	2.15
Pandemic disgust	2.497	1.89	**3.749**	2.06	3.456	2.12

The strongest emotion in each category is indicated in bold, standard deviations (SD) are also provided.

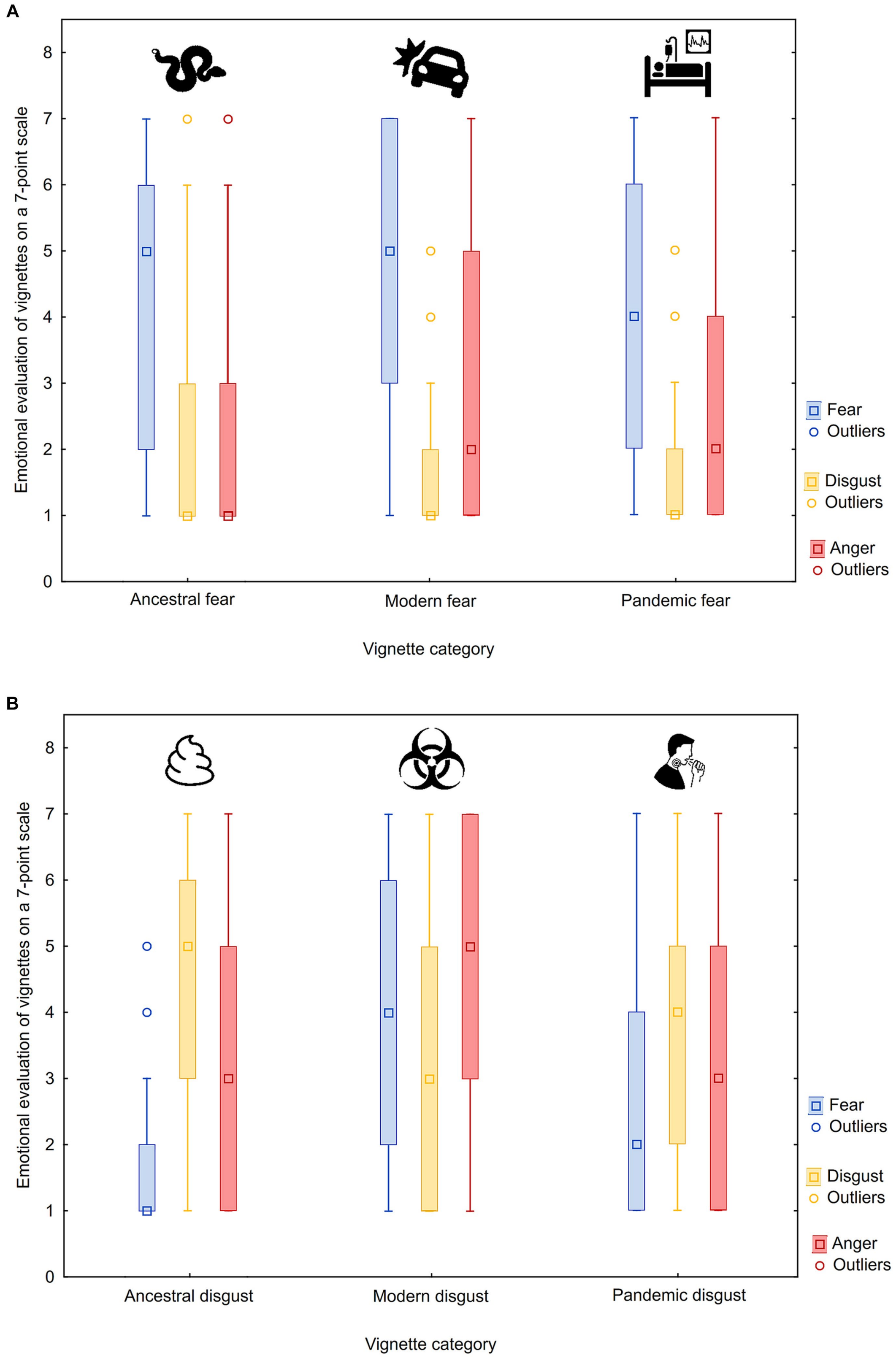

FIGURE 1
Graphical representation of fear, disgust, and anger ratings of vignettes representing potential threat for humans (using raw scores). Six vignette categories are divided into two graphs for a better clarity: fear vignettes **(A)** and disgust vignettes **(B)** according to the expected predominant negative emotion. Median (middle point), lower and upper quartiles (box range) and non-outlier minimum and maximum values (whiskers) are provided together with outlier points.

and category (except one case of pandemic disgust category) was significant (all significant $p < 0.0001$), while the effect of age was not significant. Thus, there was a slight tendency for higher scores in women and respondents with non-biological education for all three emotions and higher scores in older people for fear evaluation and lower scores in older people for disgust evaluation. However, these effects of respondents' characteristics were rather subtle compared to the effect of stimulus belonging to a category (for complete results, see Supplementary Table S2).

3.4 Factor analysis and item response theory

Since the threat category effect was the strongest of all explanatory variables examined for all emotions, we looked at this variable in more detail. At first, we performed a *post hoc* Tukey test for the differences between all six pre-defined stimuli categories (pairwise comparisons). All of the comparisons were significant (on the $p < 0.0001$ level) except for one pair in each emotional evaluation: there was no difference in fear scores between modern disgust and pandemic fear vignettes, no difference in disgust ratings between modern fear and pandemic fear and no difference in anger ratings between ancestral disgust and pandemic disgust.

Subsequently, a factor structure in the vignette ratings was examined using a factor analysis, number of factors was determined by a parallel analysis. As for fear, five separate factors were recognized and together explained 36.58 of the total variability. The first factor consisted of most of the disgust-related vignettes (i.e., low fear group), the second one grouped together most of the fear vignettes except for snake fear (separate factor 3) and the majority of pandemic fears (factor 4). For disgust, six factors explained 35.52% of the total variability and the grouping of vignettes corresponded quite well to the pre-defined categories, except for the ancestral fear category – snakes once again formed a distinct cluster (factor 4), while fear of heights grouped with pandemic fear or modern fear vignettes. Although the modern disgust category elicited some level of fear, it did not group with other fear-related vignettes. And for anger, four factors explained 31.04% of the total variance. Pandemic disgust and most of modern disgust vignettes formed their respective distinct factors (factor 3 and 4), the remaining factors consisted of the rest of the disgust-related (factor 1) and fear-related (factor 2) vignettes (for all factor loadings, see Supplementary Table S3, and for the visualization, see Supplementary Figure S1).

Finally, we applied the item response theory (IRT) approach to the vignettes' ratings, specifically a graded response model to check for the discrimination parameter. The higher the coefficient, the more the item discriminates between respondents. On the other hand, a low discrimination coefficient might also be interpreted as high agreement between respondents. Thus, both results might be relevant in our experiment. To further examine the results, we then computed Spearman's correlations between the discrimination coefficient and mean emotional ratings of each item in each vignette category. Here, we briefly describe the most important results (please see Supplementary Table S4 for complete results). For fear, most correlations were negative (higher fear rating, lower discrimination) except for the modern fear category. For disgust, none of the correlations was significant (on the $p < 0.05$ level). For anger, the correlations within fear categories were also negative, and disgust categories were not significant. This pattern might indicate some differences between fear and disgust evaluation which will be further discussed below.

3.5 Open-ended questions

As the extent of the study did not allow to cover all possible situations that people might be afraid of, the respondents had the opportunity to express themselves in optional open-ended questions at the very end of the experiment. Due to the nature of this optional questions, the responses have not been statistically processed in depth, but we present some interesting findings. The three most frequently mentioned fears were: fear of war (including specifically the war in Ukraine, Russian aggression, or the threat of nuclear war; 112 respondents), fear for the life and health of family or loved ones (110 respondents), and fear for one's future (most often fear of not finishing school, exams, not being able to find a job, etc.; 81 respondents). While the first two categories were rather evenly represented across all ages, fear of the future was more prevalent among younger respondents. Considering the age factor and frequency of the answer "war," these responses could be taken as a reflection of what is currently happening in the respondents' lives, i.e., they would represent a currently relevant threat.

For disgust, there were generally fewer stimuli not covered by the main questionnaire. Immoral behavior (e.g., lying, recklessness, or selfishness; 77 respondents) was the most frequently mentioned, followed by poor hygiene (e.g., bad human smell; 62 respondents), and spiders (52 respondents) came in third; thus, rather ancestral stimuli appeared. There was no obvious age pattern, but poor hygiene and spiders were strongly prevalent among women (men were more likely to leave the question unanswered). The difference in responses regarding fear and disgust in the open-ended questions reflects the main results from the vignette assessment.

4 Discussion

Understanding the complex interplay between ancestral and modern threats and their impact on human emotional responses is crucial for unraveling the intricacies of human psychology. This section focuses on three key points derived from our research, which will be discussed in detail in an order corresponding to the aims of the study: the difference between ancestral and modern threats within each emotion, stimulus specificity and triggering of individual emotions, and the adaptation of psychobehavioral circuits to pandemic threats.

4.1 Emotional evaluation of ancestral and modern threats

The complexity of human emotional responses to various threats is a central theme that emerges from this study. While the evolutionary perspective suggests that ancestral threats should elicit more intense emotional reactions due to their historical relevance, or conversely, modern threats could be considered more pertinent in today's world, this research reveals a nuanced interplay of emotions (Öhman, 2007). Surprisingly, our findings indicated that the emotional salience of threats did not always align with their categorization as ancestral or modern.

The rather unexpected dominance of fear in response to modern threats, such as car crashes and electricity, challenges conventional wisdom (LeDoux, 2003) and the expectation that ancestral threats should universally elicit stronger emotions (Seligman, 1971; Öhman, 2007). It suggests that the immediacy and potential for physical harm associated with these threats can trigger a powerful fear response, overriding other emotional considerations. In today's fast-paced and technology-driven world, where these modern threats are ever-present, our evolved fear response may be adapting to prioritize immediate physical safety (LeDoux, 2012), i.e., prioritize currently relevant threats over the evolutionary older ones. This fits well into the neuropsychological 'relevance theory' first proposed by Sander et al. (2003). These authors hypothesize that although the amygdala might have been originally shaped to respond exclusively to various threats via a fear psychophysiological reaction and defensive behavior, it has then evolved into a less specialized system processing and labelling all stimuli relevant to the goals and needs of an organism.

Nevertheless, snakes and heights, representing ancestral fears (Seligman, 1971; Nesse, 1994), ranked as the second most feared stimuli in our experiment, underscoring the enduring impact of these threats on human psychology. It is worth noting that 1.3 million people die each year because of road traffic crashes compared to 80 to 140 thousand of people dying because of snake bites (according to World Health Organization, 2022; World Health Organization, 2023), while snake phobia is more prevalent (2.6%; Polák et al., 2016) than phobic fear of driving (1.1%; Becker et al., 2007). Phobias of various animal species also do not always correspond to the fear of people in the general population, nor the actual danger of the feared animals (see for example Polák et al., 2020a; Staňková et al., 2021). This further highlights the complexity of human fears and the importance of experimental design when comparing different stimuli.

Pandemic threats (connected with fear of severe course of illness, suffering, and death) ranked third in terms of fear, with still high ratings, thus reflecting their relevance in contemporary times. Although there are studies that have addressed the fear emotion induced by COVID-19 (e.g., Ahorsu et al., 2020; Coelho et al., 2020), to the best of our knowledge, this is the only study to date that compares emotions evoked by the risk or health consequences of a pandemic with other types of threats. Finally, disgust-related stimuli in general scored as low fear-evoking (as expected), except for some modern threats depicting toxic chemical substances etc. (see below). However, it could be argued that previous research comparing old and new threats has typically not focused on specific emotions and their intensity, but rather on other parameters such as attention, stimulus detection, or conditioning (for a review, see Shapouri and Martin, 2022). Thus, it would not be so surprising that different experimental designs may yield different results.

In the case of disgust, ancestral threats, including body waste products and worms, provoked the greatest disgust responses in our experiment, as we expected according to the literature (Curtis et al., 2011). These findings align with the theory of the behavioral immune system, suggesting that disgust may have evolved as a response to stimuli posing a real threat to the survival of our pre-technological ancestors, as they are associated with potential sources of infection (Curtis and Biran, 2001; Schaller and Park, 2011). However, what was particularly intriguing was that some modern threats, which we anticipated would elicit disgust, instead triggered quite strong fear (and anger) responses. For example, toxic chemical substances and radioactivity, although invisible in the environment, evoked fear rather than disgust. This highlights the complexity of emotional responses to modern threats and suggests that the relevance of threats, as well as cognitive factors, play a significant role in shaping emotional reactions.

These findings challenge the idea that ancestral and modern threats lead to distinct emotional outcomes. Instead, they suggest that the human emotional landscape is highly adaptable and capable of responding to a wide range of threats, whether ancient or modern, with fear, disgust, or even anger.

As the extent of the study did not allow to cover all possible situations that people might be afraid of, the respondents had the opportunity to express themselves in open-ended questions at the very end of the experiment. These responses have not been statistically processed, but we present some interesting findings. The three most frequently mentioned fears were: fear of war (including specifically the war in Ukraine, Russian aggression, or the threat of nuclear war; 112 mentions), fear for the life and health of family or loved ones (110 mentions), and fear for one's future (most often fear of not finishing school, exams, not being able to find a job, etc.; 81 mentions). While the first two categories were rather evenly represented across all ages, fear of the future was more prevalent among younger respondents. Considering the age factor and frequency of the answer "war," these responses could be taken as a reflection of what is currently happening in the respondents' lives, i.e., they would represent a currently relevant threat.

For disgust, there were generally fewer stimuli not covered by the main questionnaire. Immoral behavior (e.g., lying, recklessness, or selfishness; 77 mentions) was the most frequently mentioned, followed by poor hygiene (e.g., bad human smell; 62 times), and spiders (52 times) came in third; thus, rather ancestral stimuli appeared. There was no obvious age pattern, but poor hygiene and spiders were strongly prevalent among women (men were more likely to leave the question unanswered). The difference in responses regarding fear and disgust in the open-ended questions reflects the main results from the vignette assessment.

We considered the emotion of anger to be rather secondary in situations described in this research, yet high anger scores were found in some of the vignettes. By far the highest mean anger ratings were for modern threats concerning toxic chemicals and pollution and, in general, a positive correlation between disgust and anger ratings was found. A similar interactive effect of anger and disgust (that are still viewed as separate emotions) on moral judgements and decision-making was also previously reported (Salerno and Peter-Hagene, 2013; Giner-Sorolla et al., 2018).

In conclusion, our results showed stronger saliency in ancestral stimuli when rating disgust, but not for fear and anger, where currently relevant threats predominated.

4.2 Stimulus specificity

Our research also delved into the concept of stimulus specificity and the triggers for individual emotions, including fear, disgust, and anger. To see the pattern in emotional response to different stimuli, we employed an exploratory factor analysis (see Supplementary Table S3).

For fear, ancestral threats, such as snakes, emerged as the most specific triggers, distinct from other threats. Snake stimulus specificity was previously demonstrated many times (there is even a specific fear-evoking snake morphotype – a venomous viperid snake; Rádlová et al., 2019; Landová et al., 2020; even cross-culturally; Frynta et al., 2023). This result aligns with the concept of evolutionary preparedness, suggesting that specific stimuli associated with ancestral dangers remain potent elicitors of fear. In contrast, pandemic threats also demonstrated a high level of specificity with two rather distinct subcategories – eliciting predominantly fear or disgust (see also Troisi, 2020), indicating that the threat relevance is a critical factor in triggering different emotions. This fact might be associated with the concept of localized parasite–host co-evolutionary races claiming that humans are more vulnerable to distant pathogens coming from outsiders rather than locals, because they have had only a limited chance to develop immunity against them (Fincher and Thornhill, 2008). Thus, the global spread of unfamiliar pathogens presents a great health risk where distinctive fear and disgust responses may compensate for the non-adapted immune system.

The complexity of disgust responses became apparent when examining fear-related stimuli. Low disgust-scoring stimuli would be predicted to group together according to disgust scores. However, modern disgust stimuli, such as chemical pollution and radioactivity, did not group with other fear-related vignettes, although the disgust ratings were not very high (lower than fear scores). This suggests that the emotional responses to modern disgust threats are multifaceted, involving both fear and disgust.

Disgust results did not show such levels of specificity as no subcategories of stimuli remained separate in the analyses (as opposed to, for example, the above-mentioned snakes). It was also demonstrated in previous research, that disgust might be more prone to generalization, e.g., in harmless stimuli visually resembling primary disgust elicitors (e.g., slimy worm-like animals; Davey, 2011; Staňková et al., 2021).

Anger, an emotion often associated with frustration and irritation, demonstrated its unique patterns of specificity. Modern disgust stimuli, such as chemical pollution and radioactivity, triggered distinct anger responses, suggesting that these threats carry a moral dimension (Salerno and Peter-Hagene, 2013; Giner-Sorolla et al., 2018). Additionally, pandemic threats connected with disgust elicitors were also specific triggers of anger, highlighting the multifaceted nature of emotional reactions to global health crises (Mota et al., 2020; Pfefferbaum and North, 2020; Schwambergová et al., 2023).

4.3 Adaptation of psychobehavioral circuits to pandemic threats

The adaptability of psychobehavioral circuits for processing fear and disgust to pandemic threats was one of the major aims of our study. While we did not calculate the effect of pandemic threats separately, we analysed their emotional impact in comparison to other types of threats. The results demonstrated that pandemic threats elicited a range of rather high-intensity emotional responses (even after the first wave of COVID-19), including fear, disgust, and anger, yet it remains a specific category of threats. This suggests that the psychobehavioral circuits responsible for processing fear and disgust may have adapted to respond to the unique challenges posed by global health crises (McEwen and Gianaros, 2011).

Pandemic threats, particularly relevant in the context of our contemporary world, elicit a complex array of emotions (Taylor, 2019). The rapid spread and high mortality rates of infectious diseases can engender fear, as evidenced by their rankings in the fear category, they also trigger strong feelings of disgust and, notably, anger (Pfefferbaum and North, 2020), leading to behavioral changes aimed at reducing the risk of infection. Additionally, the moral dimension of pandemics, involving issues of responsibility and social behavior, can trigger anger and frustration in response to non-compliance with public health measures (Barry, 2020). This multifaceted emotional response can be attributed to several factors.

First, the immediacy and unpredictability of pandemics, as seen in events like the COVID-19 pandemic, can induce fear on a global scale. The fear of infection and the potential consequences for one's health and well-being are palpable, leading to heightened anxiety and stress (Coelho et al., 2020; review in Salari et al., 2020). Second, the moral dimension of pandemics cannot be overlooked. The study suggests that pandemic threats, often associated with issues of public health and societal responsibility, may evoke anger (Coelho et al., 2020; Trnka and Lorencová, 2020). Factors such as government responses, misinformation, and social behavior can contribute to a sense of moral outrage. This complex interplay of emotions reflects the broader societal impact of pandemics and the ethical dilemmas they pose.

4.4 Implications for risk perception and decision-making

Understanding the complexity of emotional responses to threats has significant implications for risk perception and decision-making. Individuals may weigh emotional responses differently when assessing risks, and this can influence their choices and behaviors. For instance, an immediate fear response to a modern threat may lead to a heightened sense of danger, potentially affecting risk-taking behaviors. This has been previously shown in the study by Siegrist and Sütterlin (2014). The affect associated with natural or human-caused hazards influenced how people interpreted new information and mediated the evaluation o of negative outcomes associated with the hazard. In other words, equally negative outcomes are differently evaluated depending on the cause when people are more concerned with human than natural hazards. Such a cognitive-affective bias may finally lead to riskier decisions.

Recognizing the emotional dimensions of pandemic threats, including fear, disgust, and anger, can inform public health interventions and messaging. Strategies to mitigate the spread of diseases may benefit from a nuanced understanding of how people emotionally respond to pandemic-related information and directives. Our results may also indicate that humans in modern times can adequately assess current risks, even when dealing with newly emerging threats. It cannot be said that modern behavior and decision-making are entirely dependent on evolutionary processes, although in some cases the influence of evolution may still be strong - for example, in some specific phobias (e.g., snake phobia), where there is a relatively conserved intense response to ancestral danger that may be maladaptive or at least exaggerated in modern times.

4.5 Future directions

This study offers a thought-provoking exploration of human emotional responses to a diverse array of threats. However, it also raises numerous questions that warrant further investigation. Future research could delve deeper into the interplay of emotions in response to specific threat scenarios and explore how individual differences, cultural factors, and personal experiences shape emotional responses.

There is an opportunity for more elaboration of research on modern disgust stimuli; similar works to those on fear (except for moral disgust) are still lacking. Although in our study modern stimuli tended to elicit more of a fear response, perhaps a different design would have reached different results. Among other things, it also depends on the type of stimulation - modality: e.g., use of picture stimuli, possibly olfactory (irritating chemical smell) or even auditory (coughing), etc.

In our study, we mostly gave space to the conscious response; it would be useful to design an experiment with a greater automatic unconscious component (e.g., psychophysiology) that could, among other things, reveal more about whether the pandemic can be considered more of an ancestral or modern threat.

This paper did not show a large effect of respondents' characteristics, but it would be useful to do further analyses if we had more data on respondents - for example, information on their sensitivity to specific threats or their emotional response in general (e.g., questionnaires measuring disgust sensitivity or trait anxiety), or to elaborate more on the effect of age for different types of threats. Finally, it would also be worth studying the effect of other than biological education on emotional evaluation of ancestral and modern threats.

5 Conclusion

The primary goal of this project was to gain a deeper understanding of the evolution of emotions and how evolutionarily ancestral systems of perception can function in a modern world with newly emerging threats. The threat of a pandemic forms a specific category and people process it emotionally and cognitively. Ancestral threats may not be stronger in general, there is often an effect of the current relevance of the threat, but ancestral stimuli may have a specific pattern of response. Disgust appears to be an emotion where ancestral stimuli are as strong or stronger than other tested stimuli, and the influence of disgust-inducing stimuli on the perception of pandemics cannot be rejected. We confirmed the need to consider moral aspects and anger, especially when evaluating pandemics and modern threats.

In conclusion, our study offers valuable insights into the emotional responses to ancestral and modern threats and their adaptation to pandemic challenges. The interplay between ancestral and modern threats, stimulus specificity, and the adaptability of psychobehavioral circuits highlight the complexity of human emotional responses. Our findings contribute to a deeper understanding of human psychology, shedding light on how the human brain navigates the complexities of a rapidly changing world. As we continue to encounter novel threats, our emotional responses evolve, providing valuable insights into the adaptability and resilience of the human mind. As we move forward, further exploration of emotional responses to contemporary challenges will be essential for informing fields such as psychology, evolutionary biology, and public health. This research challenges the preconceived notions about which threats should provoke the strongest emotional responses and highlights the adaptability and specificity of our emotional reactions. By embracing the complexity of human emotions, we can better navigate the ever-evolving landscape of threats and continue to adapt and thrive in the face of adversity. These insights contribute to our understanding of human psychology and behavior in an ever-changing world.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethics Committee of Charles University, Faculty of Science (approval no. 2021/02, granted on 14 April 2021) and National Institute of Mental Health (no. 91/21, granted 31 March 2021). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

ŠP: Data curation, Formal analysis, Investigation, Software, Visualization, Writing – original draft, Writing – review & editing. JP: Conceptualization, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. MJ: Data curation, Investigation, Writing – review & editing. AC: Investigation, Writing – review & editing. KS: Investigation, Writing – review & editing. DF: Conceptualization, Formal analysis, Methodology, Software, Supervision, Validation, Writing – review & editing. EL: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1321053/full#supplementary-material

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Do first responders and populations perceive risks similarly? A comparative study of seven countries

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Introduction: Risk perception illustrates the subjective evaluation of individuals concerning the characteristics, severity, and capacity to cope with potential hazards. Risk perception influences attitudes and actions individuals take to protect themselves from future threats. Risk perceptions might change among different stakeholder groups such as society and first responders. Identifying risk perceptions of stakeholders is essential to establish effective protective measures.

Method: This study investigated the commonalities and diversities in risk perception among first responders and the public, within and between seven European and beyond countries. A self-administered questionnaire was used to gather data from both first responders and civilians. They were asked to assess their risk perception level for five categories of risks (Extreme weather-related events, nature-related events, social disruptions, critical services dependencies, and pandemics).

Results: Using Univariate Analysis of Variance showed disparity concerning both the levels of risk perception between the public and first responders, as well as their relative ranking. For example, concerning extreme weather-related and nature-related events, risk perception levels of the first responders is higher than that of the population in six out of the seven studied countries. In contrast, the population's risk perception is higher compared to the first responders in six out of the seven countries, concerning critical infrastructure dependencies and pandemics.

Discussion: The relative gaps between the first responders versus the population, within each country, vary considerably. Norway for example presents significant differences between the two internal populations concerning all risks (except for extreme weather), while in Sweden, no significant gaps were identified, concerning all five risks.

KEYWORDS

risk perception, resilience, pandemics, nature-related events, extreme weather, critical services dependencies, social disruptions

Introduction

All societies are exposed to numerous risks that pose a threat to the well-being of their population, due to natural or human-made occurrences. Pandemics, floods, earthquakes, wars, industrial collapses, and more, frequently occur worldwide, impacting the safety and security of many communities. Preparing for, coping with, and overcoming such risks are highly dependent on the resilience of societies, which is determined, as shown by Bodas et al. (2022), by levels of trust, individual resilience, individual preparedness, and risk awareness, among other factors. In this article, we examine the gaps in risk perceptions of emergency professionals and first responders compared to those of the general population. Gaps, which as we present in the article, can affect essential factors of societal resilience, and thus may impact on the capacity of societies to react to such risks.

Risk perception is the subjective judgment that individuals make concerning the attributes, severity, and means of coping with various hazards (Grima et al., 2021). It reflects the appraisal of people concerning the likelihood of the danger and its potential adverse consequences (Bubeck and Botzen, 2013; Lechowska, 2018). Risk perceptions pertain to both the perceived severity of the situation (the potential damage that may incur), as well as the perceived vulnerability (probability of being negatively impacted) of oneself or that of loved ones (Kollmann et al., 2022).

Risk perception significantly influences various aspects of public preparedness for and function during emergencies. Risk perception was found to be associated with knowledge and information about appropriate actions in different emergency situations, adherence to recommendations and instructions, and communication with official emergency authorities (Bodas et al., 2022). Simultaneously, risk perception plays a critical role in the context of emergency professionals and first responders responsible for managing emergencies and disasters and was found to be correlated with factors such as motivation (Elkady et al., 2022). Consequently, discrepancies in risk perceptions concerning various hazards between first responders and the general population may undermine societal resilience. For instance, such gaps may diminish trust levels if the public feels that their concerns about perceived risks are not adequately addressed by first responders. Additionally, these gaps may reduce individual and public preparedness for threats that are perceived as less risky by the general population compared to first responders. Subsequently, this article aims to identify these disparities and emphasize similarities that may bolster societal resilience. Diverse behavioral models explain the variability in risk perceptions of different populations (Turner et al., 2006; Rudisill, 2013). For example, the psychometric model focuses mainly on the psychological management of human thoughts, decision-making, and subsequently – implementation of actions (Kiani et al., 2022), while the cultural model centers on the cognitive processes that impact thoughts and beliefs that lead to any measures that are adopted (Rippl, 2002). The Health Belief Model (Kamran et al., 2021) and the Protection Motivation Theory (Gumasing et al., 2022) posit that people will be more highly inclined to adopt both beliefs and behaviors when they consider a situation to be more severe (potentially detrimental) and themselves more vulnerable to its effects (Trifiletti et al., 2022).

Different risk perceptions may stem from varied factors including demographic characteristics (such as age, gender, and socio-economic status) (Brown et al., 2021; Kollmann et al., 2022; Shah et al., 2022); personality traits (such as ways of coping with stressful situations, views concerning fate versus control of events; leadership qualities) (Al-Dahash et al., 2022); cultural and social contexts (for example, local values and norms, or trust in data and in the authorities) (Renn and Rohrmann, 2000; Cori et al., 2022); assorted beliefs (such as religion, level of religiosity, fears, political or other attitudes) (Grima et al., 2021; Siegrist et al., 2021); as well as familiarity or knowledge about the hazard (Al-Dahash et al., 2022). The Social Amplification of Risk Framework (SARF) suggests that the interaction between psychological, cultural, social, and contextual factors, and the characteristics of the adversities, impact the risk perception and consequently, also influence protective behavior (Knuth et al., 2014).

Risk perceptions must be taken into consideration by risk managers, as they affect both attitudes and actions of the population (Lechowska, 2018). Risk perceptions have been found as significant predictors of health-related protective behaviors (Floyd et al., 2000; Scovell et al., 2022), though there is controversy concerning their relative impact. Several studies have shown that risk perceptions are only weakly or not at all associated with personal behavior that aims to protect the individual from adversity (Bubeck and Botzen, 2013; Lindell, 2013). In contrast, other studies have shown that risk perceptions positively impact protective behavior and contribute toward the adoption of measures that are vital to increasing the safety and resilience of populations (Scovell et al., 2022). It has been claimed that people tend to adopt protective (and preventive) measures when they believe that either they or others close to them may be negatively impacted by the different hazards (Kahlor et al., 2006; Dryhurst et al., 2020; Harper et al., 2020). Several studies have presented that people with higher risk perceptions expressed higher levels of compliance with protective behavior that was recommended (Barr et al., 2008; Jacobs et al., 2010). It should though be noted that there may be discrepancies between the intention to comply with recommended protective behavior and the actual adherence to such behavioral measures, otherwise known as the intention-behavior gap (Park et al., 2021; Kollmann et al., 2022).

Emerging from the classic theory of risk perceptions, scholars introduced the risk perception paradox, a phenomenon that challenges the conventional understanding of how individuals respond to perceived risks. While it's commonly believed that a high risk perception would naturally lead to personal preparedness and subsequent risk mitigation behaviors, the reality is more complex. Studies have shown that even when individuals possess a high awareness of risks, they might not necessarily take appropriate preparedness actions (Shapira et al., 2018). This paradoxical behavior can be attributed to various factors. Firstly, individuals might recognize the risk but choose to accept it, especially if the perceived benefits, such as residing near a river, outweigh the potential hazards. Secondly, while individuals might understand the risk, they may not feel empowered to act, often transferring the responsibility to others. Lastly, there are instances where individuals, despite understanding the risk, might lack the resources, both economic and personal, to make meaningful changes. This intricate relationship between risk perception and actual preparedness actions underscores the need for a nuanced approach in risk governance and communication (Wachinger et al., 2013).

In response to any adversity, authorities and first responders must communicate with the population, to encourage the adoption of protective behavior by all individuals, to ensure their safety and survivability. The risk perception of both sectors (authorities/first responders versus the civil society) is vital to enhance effective preparedness and response to the situation. Nonetheless, it cannot be assumed that these two different groups in society similarly perceive the risk. Authorities and first responders need to recognize the similarities and differences that may prevail in their risk perceptions compared to that of the population. Many studies have been conducted among either first responders or varied populations (Lachlan et al., 2021; Spett, 2021; Cuesta et al., 2022). Furthermore, Elkady et al. (2022) identified the needs of first responders from the public to better manage any adversity. In contrast, despite an extensive literature review, no studies were found that compared the risk perceptions of first responders with those of civil society members.

Risk perceptions have also been found to differ among varied societies, even when they face similar threats. For example, despite the comparable risk for terror events among European countries, a relatively higher level of risk perception was identified over time in specific countries, such as England, Spain, and Turkey (Drakos and Müller, 2014), while concerning nuclear threat, French people perceived the risk as highest, compared to British, Spanish, and Swedish individuals (Viklund, 2003). Knuth et al. (2014) identified different levels of risk perception concerning earthquakes as well as other hazards (such as fires, floods, or terror events) in seven European countries (Germany, the Czech Republic, Italy, Turkey, Spain, Sweden, and Poland). Similarly, significant variability in risk perception, distress levels, and perceived readiness was reported during the COVID−19 pandemic among medical responders, such as among physicians from Spain, Belgium, and France (Guerrisi et al., 2022). Similar variability was identified concerning risk perceptions of local populations among eight different European countries, in a study that was conducted during the COVID−19 pandemic; although the individual respondents from the eight societies all ranked the pandemic as being the highest risk (out of five potential risks, including social disruptions, extreme weather, pandemic, critical services dependencies, and, nature-related events), the relative severity and probability of the risks varied among the respective societies (Bodas et al., 2022). The same dataset of that study is used in the current study.

Considering the importance of better understanding the realm of risk perceptions, the aim of the study was to identify commonalities and diversities in risk perceptions between first responders and civil populations among and between seven countries, within and beyond Europe.

Methods

The study was cross-sectional, whence the data collection was conducted simultaneously in seven countries, within and beyond Europe. The primary method used for data collection was a self-administered questionnaire. Questionnaires are an effective technique to gather data from large samples as they provide a standardized set of questions that are easily interpretable by all the responders (Saunders et al., 2009). The uniform set of responses allows for a robust quantitative analysis of the results.

Study population and sampling

The study investigated the risk perceptions of two different types of populations: the emergency responders and authorities (Group 1), and the civilians (Group 2) in seven countries: France, Israel, Italy, Norway, Romania, Spain, and Sweden. These countries differ in the characteristics of their populations as they cover both Western and Eastern European countries as well as one country outside of Europe. The study was conducted in January and February 2021, amid the COVID−19 pandemic.

For Population number 1 we targeted first responders from organizations such as the civil defense, firefighters, police, medical staff, NGOs, or governmental authorities who are experienced in dealing with emergencies. Regarding Population number 2, we targeted civilians over the age of 18. At least 500 respondents, representing the various groups of the population in each country, were recruited. Stratified sampling was used to ensure the inclusion of the varied groups, based on the Central Bureau of Statistics in the respective countries, considering age, gender, and geographic location.

Study tools

The study tools were quantitative, internet-based questionnaires that were used to assess the risk perceptions of emergency responders and authorities (Population no. 1) and civilians (Population no. 2) for five different categories of risks as defined by UNESCO as follows (Rohit et al., 2010):

- Extreme weather-related events (e.g., cyclones, flooding, snow, droughts, wildfires),
- Nature-related events (e.g., geophysical events, earthquakes, tsunamis, landslides, volcanoes),
- Social disruptions (e.g., technological events, cyber-attacks, terrorist attacks, protests, riots, massive human displacements),
- Critical services dependencies (e.g., transportation networks, water, and energy.),
- Pandemics (e.g., biological events, contagious diseases).

For Population number 1, the questionnaire was based on a Likert scale ranging from 1 (not at all aware) to 5 (extremely aware) to assess the risk perceptions of the members of the emergency services. For Population number 2, we used a designated tool which is the digital version of the Pictorial Representation of Illness and Self-Measure (iPRISM) tool, developed by Büchi and Sensky (1999). This tool was initially used to graphically assess the perceived possibility of suffering from an illness, but it has since been demonstrated that it can also be used for a wide range of applications (Bodas et al., 2022). In this study, the iPRISM tool, shown in Figure 1, was used to rapidly assess the perceived level of risk for each type of risk. The iPRISM tool showed the participants a digital white rectangular board with a fixed yellow disk at the bottom right corner. The participants were instructed that the yellow disk represented themselves and the whiteboard represented their life at that moment. Moreover, the tool provided five colored disks, each representing a different type of risk. Participants were asked to place the colored disks on the whiteboard, relative to the yellow disk, based on their risk perception, meaning that if the colored disk is placed far from the yellow disk, the perceived risk is low, and vice versa. The results obtained from iPRISM are the distance, in centimeters, between the colored disks and the yellow disk. Distance measures ranged between 0 and 26 cm, with smaller values representing higher risk perception levels. The main advantage of this tool is that it enables us to assess the risk perception visually, in a universal language, facilitating its understanding across different cultures.

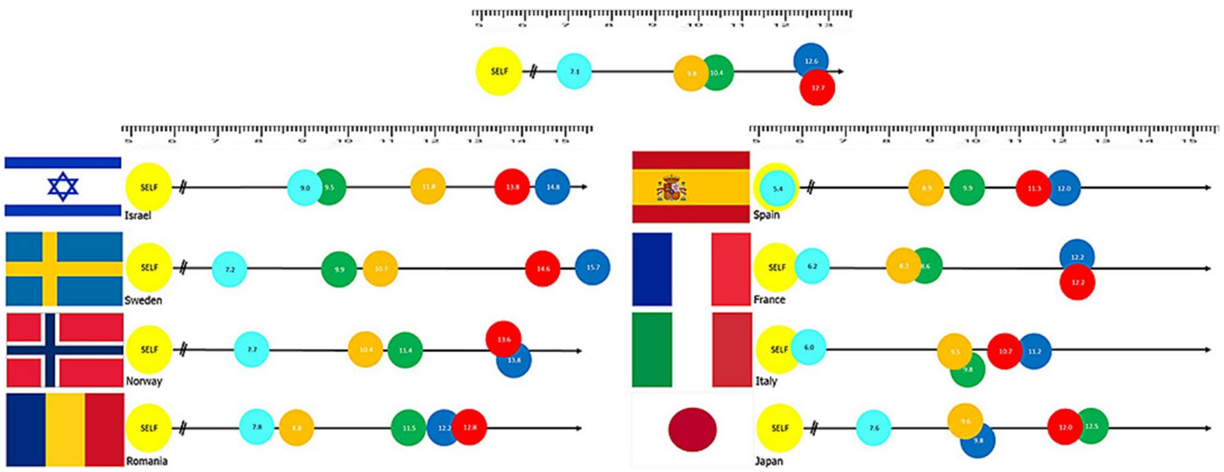

FIGURE 1
The iPrism tool. Results of the iPRISM tool assessing risk awareness through distances assigned by participants between themselves (yellow "SELF" disk) and specific risk objects [Light blue: Panldemics, Orange: Critical infrastructure fail (water, energy), Green: Social disruption (e.g., war), Blue: Natural Hazard (e.g., earthquakes), and Red: Extreme weather]. Taken from Bodas et al. (2022).

The questionnaires were tailored to the specific needs and levels of understanding of the two target populations, and thus the questionnaire for the population was based on visual representation of the five risks, while the first responders and authorities were asked directly to rank the varied risks (the next sub-section includes more details about the used tools).

Data collection

The responses of Population number 1 were collected using the SurveyMonkey[1] web service. We used the Snowball sampling technique to disseminate the survey and to reach the maximal number of responders. Snowball sampling was the most appropriate sampling method considering the specific characteristics of the targeted survey respondents, and thus responders were asked to share the questionnaire with their colleagues. The questionnaire was distributed by the authors of this article and other partners in a consortium through personal and professional connections.

Concerning Population number 2, we contracted the iPanel company for the data collection task. iPanel is an Israeli company that provides online data collection services since 2006. The company subcontracted local vendors in the other participating countries to gather the needed data. Due to the typical characteristics of Population number 2 and the expertise of iPanel company in online polling, utilizing them for this task proved to be efficient. However, due to the specific nature of the respondents in Population number 1, it was not possible to use an internet panel company, and thus a direct approach to those respondents was required.

Both surveys were available in seven languages corresponding to the official language of the participants' countries, namely: French, Hebrew, Italian, Norwegian, Romanian, Spanish, and Swedish. Due to the high scope of the survey, we limited the survey language for the official language in each country, excluding minorities' original languages. While this can create a potential bias in the results. However, as mentioned before, the use of the iPrism tool, as a visual one, narrowed this potential bias.

Statistical analysis

Descriptive statistics were used to describe the characteristics of the sample for each country. In order to compare the two groups (the first responders versus the population) first, a combination of the two scales was needed. The scale provided to the first responders ranked from 1 to 5 where the higher the number, the higher the risk perception level. Meanwhile, the risk perception of the population was measured by iPRISM. In this case, the scale ranged from 0 to 26 and the direction of the scale was the opposite, i.e., the higher the number, the lower the risk perception level. Therefore, we standardized the two scales through these 3 steps:

1. Transforming the range of answers of First Responders from 1 to 5 to 0–4 (being 1 = 0, 2 = 1, 3 = 2, 4 = 3, 5 = 4).
2. Dividing the scale of Population (Originally scaled from 0 to 26) by 6.5 to be scaled from 0 to 4.
3. Transforming the population scale (After dividing by 6.5) to the opposite direction, using the function (4-x) so that the direction of the scale will be the same as the one of the First Responders: the higher the number, the higher the level of risk perception.

After standardizing the scales, the different perceptions of risks were analyzed using univariate analysis ANOVA with 3 effects: Group effect (i.e., differences between first responders versus the population); Country effect (i.e., differences between the 7 countries); Interaction effect group & country (i.e., we examined whether the two independent variables together [group and country] simultaneously

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[1] https://www.surveymonkey.com/

TABLE 1 Descriptive statistics of the study population.

	Israel (P) (*n* = 731) (FR) (*n* = 224)	Sweden (P) (*n* = 521) (FR) (*n* = 17)	Norway (P) (*n* = 686) (FR) (*n* = 186)	Romania (P) (*n* = 691) (FR) (*n* = 189)	Spain (P) (*n* = 675) (FR) (*n* = 173)	France (P) (*n* = 527) (FR) (*n* = 24)	Italy (P) (*n* = 536) (FR) (*n* = 36)
Group *(%)*							
Population	68.9	96.7	72.9	72.4	74.4	95.4	93.3
First responders*	31.1	3.3	27.1	27.6	25.6	4.6	6.7
Age group *(%)*							
20–35	37.7	39.9	33.1	38.8	33.8	39.0	39.4
36–50	30.4	31.2	30.7	43.3	40.4	34.9	35.4
51–65	26.4	27.6	31.3	17.9	25.6	24.0	22.8
66+	5.3	1.4	4.8	0	0.2	2.2	2.5
Gender *(%)*							
Male	49.8	48.4	44.2	41.8	43.3	47.7	47.2
Female	51.1	51.6	55.8	58.2	56.7	52.3	52.8

*Breakdown of the first responders is delineated in Appendix A.

affected the risk perception to a greater extent than the sum of their parts). The results of the 3 effects are presented with *F* value (the ratio between the two variances) value of p (level of significance) and the effect size by partial eta square (ηp2) below each graph. The Bonferroni test (Bland and Altman, 1995) was used for multiple comparisons between countries. The results of the Bonferroni test are presented below each graph in a matrix table using the value of p. All statistical analyses were performed using SPSS software version 25. *p*-values lower than 0.05 were considered to be statistically significant.

Both surveys controlled for demographic variables, as described in Table 1. Furthermore, in the first responders survey, we also incorporated professional variables, such as the individual's role within the organization and the organizational type. Due to variations in sampling methods and the populations reached by each survey, we did not include these variables in the combined analysis. Nevertheless, separate analyses conducted for each sample, which have been presented in other publications, revealed minimal effects of these control variables (Bodas et al., 2022; Elkady et al., 2022).

Results

The study was conducted among samples of both the population and first responders in six European countries as well as in Israel. The samples in each country included at least 500 respondents from the population, while the samples of the first responders ranged from 227 in Israel to 17 in Sweden (Elkady et al., 2022). In the overall sample (including both first responders and the public) 38% were in the age group 20–35, 35% were in the age group 35–50, 25% were in the age group 51–65, and 2% were at the age group 66 and above. A slightly higher percentage of women compared to men responded to the surveys. See Table 1.

Ranks of the perceived risks

The average scores of the perceived risks were calculated to identify differences in risk perceptions between the population and the first responders in each of the seven countries as well as between the two groups in the varied countries. Based on the average scores, we ranked the risks from 1 to 5, where 1 represents the highest risk perception and 5 represents the lowest. See Table 2.

As can be expected, considering that the data collection was conducted during the COVID−19 pandemic, both groups of respondents in all seven countries ranked pandemics as the highest risk. Social disruptions were ranked as the second highest risk by both the populations and the first responders from Israel and Sweden. Conversely, critical services dependencies were reported as the second highest risk by both the population and the first responders from Norway and France, and by the populations (but not the first responders) from Romania, Spain, and Italy. Extreme weather was reported as the lowest risk by both the population and the first responders from Romania and Israel. In contrast, nature-related events were perceived as the lowest risk by the population and first respondents from (Spain, Norway, and France), and by the population (but not the first responders) from Sweden and Italy. The biggest diversities between population and first responders within the respective countries were identified in Italy (concerning extreme weather and nature-related events), while Norway, Spain, and Israel respectively, presented similar perceptions among the population and the first responders in three out of the five investigated risks.

Risk perceptions concerning extreme weather

The risk perceptions of the population, compared to the first responders, concerning extreme weather were lower in most countries, except for Israel and Norway, though these differences were found to be significant only in Spain, Israel, and Italy. In Norway, the extreme weather was perceived similarly by the population and the first responders, while in Israel, the population perceived this risk as significantly more severe than perceived by the first responders. A comparison of the risk perceptions among the different countries presents that extreme weather is perceived by Spanish, French, and

TABLE 2 Ranks of the five perceived risks, according to the two groups (population vs. first responders in the seven countries), 1 being the most severe risk and 5 being the least severe risk.

Country	Group	Extreme weather	Naturerelated events	Social disruptions	Critical services dependencies	Pandemics
Israel	Population	5	4	2	3	1
	First responders	5	3	2	4	1
	The gap	**0**	**1**	**0**	**−1**	**0**
Sweden	population	4	5	2	3	1
	first responders	2	3	2	4	1
	The gap	**2**	**2**	**0**	**−1**	**0**
Norway	population	4	5	3	2	1
	First responders	3	5	4	2	1
	The gap	**1**	**0**	**−1**	**0**	**0**
Romania	population	5	4	3	2	1
	first responders	5	2	4	3	1
	The gap	**0**	**2**	**−1**	**−1**	**0**
Spain	population	4	5	3	2	1
	first responders	2	5	3	4	1
	The gap	**2**	**0**	**0**	**−2**	**0**
France	population	4	5	3	2	1
	First responders	3	4	1	2	1
	The gap	**1**	**1**	**2**	**0**	**0**
Italy	population	4	5	3	2	1
	First responders	1	2	3	4	1
	The gap	−3	−3	−1	−2	0

Italian respondents as a higher risk compared to Romanian, Swedish, Norwegian, and Israeli respondents. See Figure 2.

Regarding the existing differences between the first responders' and population's risk awareness levels, we can see that the bigger difference exists in Spain and Sweden followed by France and Italy. On the contrary, Norway is the country with a lower difference among the two populations, followed by Romania.

Risk perceptions concerning nature related events

The risk perceptions of the population, compared to the first responders, concerning nature-related events were lower in most countries, except for Norway, where the population perceived these risks as significantly higher than those that were reported by the first responders. Significant differences between the two populations were also identified in both Romania and Italy, where as noted, the first responders perceived these risks as more challenging than the populations.

A comparison of the risk perceptions among the different countries presents no significant differences in risk perceptions concerning nature-related events between responders from Italy, Spain, France, and Romania. The risk perceptions among respondents from these four countries are significantly higher than those of respondents from Norway, Sweden, and Israel. See Figure 3.

Regarding the differences in risk awareness between the two populations, Sweden is the country that presents the highest difference between the first responders and the population, and Italy is the second one. Conversely, Spain is the country where the difference between the two populations is the lowest followed by France.

Risk perceptions concerning social disruptions

The risk perceptions of the population, compared to the first responders, concerning social disruptions were found to be higher in Israel, Sweden, and Norway, though the variance was found to be significant between the two populations only in Israel and Norway. Similar levels of risk perceptions were found among both the population and the first responders in Romania, France, and Italy, whereas the population in Spain perceived the risk of social disruptions as somewhat less severe (significantly) compared to the first responders.

A comparison of the risk perceptions among the different countries shows that French respondents perceived this risk as significantly higher compared to the other six countries. No significant risk perceptions were found among respondents from Italy, Israel, Sweden, and Spain. The levels of risk perceptions among the Romanian respondents differed significantly from all other countries, but Norway and vice versa; the risk perceptions among the Norwegian respondents differed significantly from all other countries, but Romania. See Figure 4.

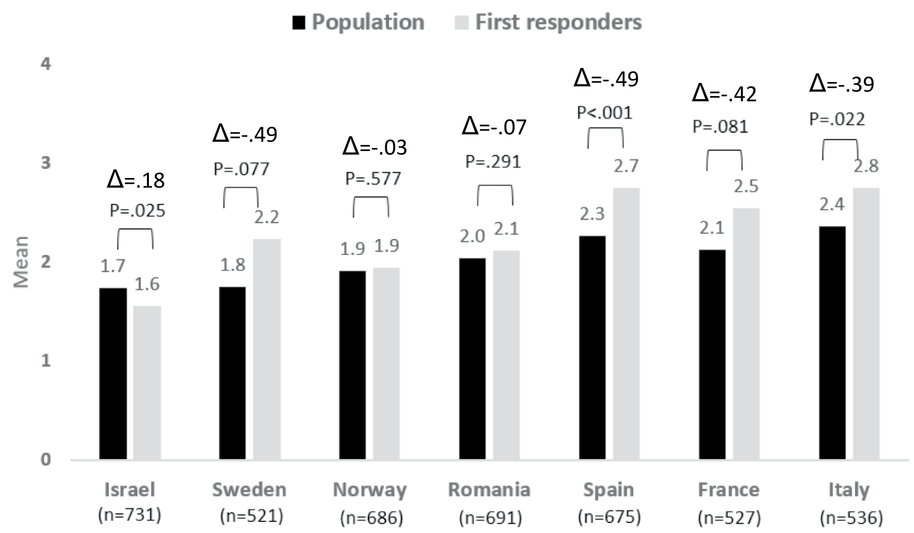

FIGURE 2
Risk perception regarding Extreme Weather — differences between country and group: population vs. first responders.

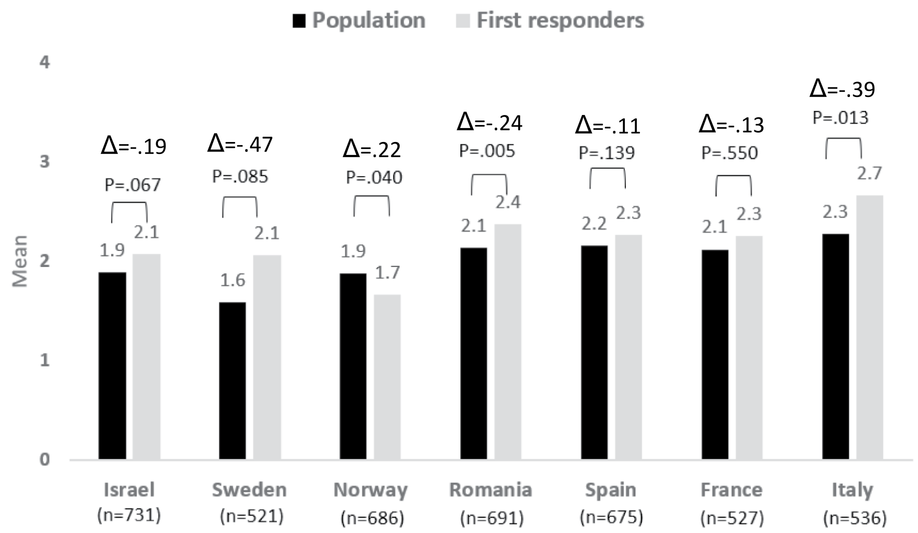

FIGURE 3
Risk perception regarding Nature Related Events — differences between country and group: population vs. first responders.

Risk perceptions concerning critical services dependencies

The risk perceptions of the population, compared to the first responders, concerning critical services dependencies, were found to be higher in all countries, except in France (but the difference between the two groups of population and first responders was significant only in Norway, Romania, and Italy).

Similar to what was found concerning social disruptions, French respondents perceived this risk as higher compared to the other six countries, though the difference was found to be significant only compared to Israel, Italy, Norway, and Sweden. Romania also perceived this threat as more severe compared to all other countries but France, but the differences were found to be significant only in relation to the risk perception of the populations in Israel, Sweden, and Norway. See Figure 5.

In this type of disaster, the differences in risk awareness levels for both populations are quite high, with Italy being the one with the highest difference. Sweden and Norway are the next ones followed by Romania. France is the country that presents the lowest difference in the risk awareness levels of the two populations.

Risk perceptions concerning pandemics

The risk perceptions of the population, compared to the first responders, concerning pandemics, were found to be higher in all countries, except Spain. The differences between the two groups of

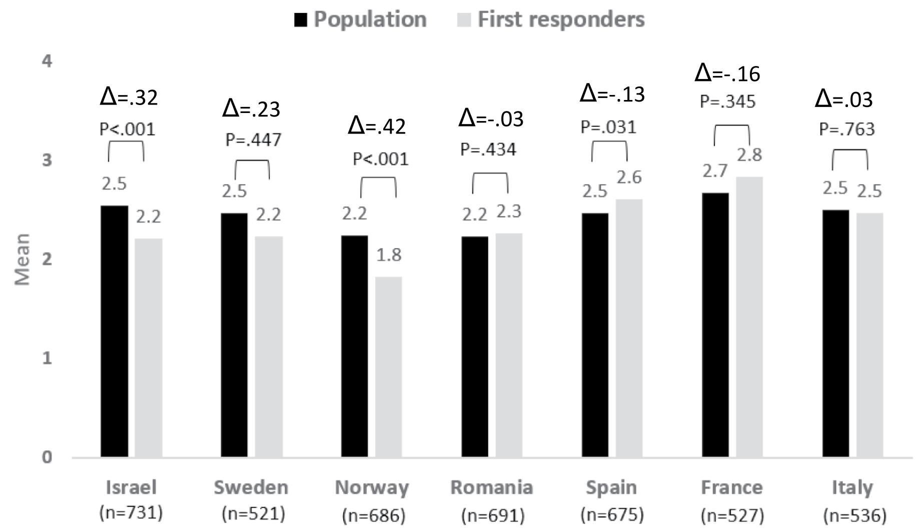

FIGURE 4
Risk perception regarding Social Disruption – differences between country and group: population vs. first responders.

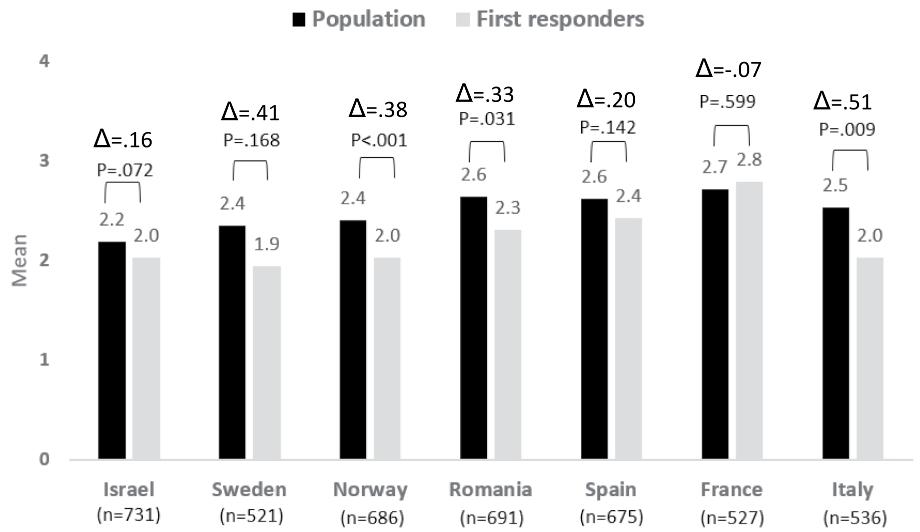

FIGURE 5
Risk perception regarding Critical Services Dependencies – differences between country and group: population vs. first responders.

population and first responders were significant only in Norway, Romania, and Spain. The risk perception of the population in Spain was significantly lower compared to that of the first responders. Sweden is the country that presents the highest difference in the risk awareness level of the two populations. Norway is the second country with the highest difference and Italy the third. In the three cases, the awareness level of the population is higher than that of the first responders. Conversely, Israel is the country with the lowest difference followed by Spain, although in the opposite direction, the first responders' risk awareness level is higher than the population's risk awareness level.

When comparing the risk perceptions of the different countries concerning pandemics, the highest risk perception was found among the sample from Spain, regarding both the first responders and the population. This risk perception was found to be significantly higher than the risk perceptions of the respondents from Israel, Sweden, Norway, and Romania (but not significantly different from France and Italy). The average levels of the perceived risk of pandemics were similar among the first responders from Israel, Sweden, Norway, and Romania, but the risk perceptions of the populations in those countries varied, resulting in significant differences in the overall samples only between Israel and Sweden as well as between Norway and Sweden. See Figure 6.

National differences

Following the results regarding the national differences in risk perceptions of both first responders and the general public, Figure 7 presents the similarities and differences between the countries regarding their risk perceptions.

In this figure, each of the countries is represented as a node or as part of the outer layout of the circle. The arcs between the countries represent the similarity between the countries in risk perception. For example, an edge between Israel and Norway means that Israel and Norway share at least one commonality in one of the categories of risk perceptions. The commonality is defined when there is no significant difference in a risk perception category (e.g., in the case of Israel and Norway, there were no differences between the countries concerning Natural Related Events). The number of categories of risk perceptions with commonalities between the countries defines the thickness of the edges. For example, if there is a commonality in one category then the edge thickness is 1, if there are in two categories, then it is 2, etc. The figure shows that Southern Europe countries such as Spain and Italy, share many commonalities across all risk perception categories. In addition, despite being part of Scandinavia, Norway and Sweden share fewer commonalities than Southern European countries or even compared to their commonalities with Romania. Israel, on the other hand, despite its geographical distance, has some commonalities with Norway and Sweden.

Discussion

As countries are prone to different types of risks, they are expected to present varied risk perceptions. Nonetheless, as some risks are common to a wide range of countries, such as pandemics in general, and COVID−19 in particular, it is essential to understand why they may differ in their risk perceptions of those similar hazards. Furthermore, as displayed in the current study, variabilities may frequently exist within each society when comparing the risk perceptions of first responders with those of the general public. Therefore, we will elaborate on the possible reasons for such differences and their importance.

Our findings resonate with the established concept of the risk perception paradox. While our study highlights varied risk perceptions across different demographics and regions, it's essential to understand that high risk perception does not always translate to proactive preparedness or mitigation actions. As elucidated in the literature, individuals might be fully aware of the risks but might choose to accept them, especially if the perceived benefits overshadow the potential threats (Wachinger et al., 2013). In other instances, the sense of agency might be lacking, leading individuals to transfer the onus of action to others (Shapira et al., 2018). Economic constraints and personal conditions can also hinder individuals from taking preventive measures (Wachinger et al., 2013). This understanding underscores the importance of not just raising awareness but also empowering individuals with the means and motivation to act upon their risk perceptions.

The current study identified commonalities and variabilities in risk perceptions among the general population compared to first responders within and between different countries. The most significant outcome of the study was that the public and first responders in some countries ranked all of the investigated risks (extreme weather, nature-related events, social disruptions, and critical services dependencies) differently except for pandemics, and they also differed in the respective levels of their risk perception. These differences in risk perceptions were found between the two groups both within the investigated countries, as well as between the countries.

As the study occurred during the COVID-19 pandemic, it is not surprising that the only consensus between the public and first responders within and between all the countries was ranking pandemics as their highest concern. Nevertheless, the difference in the perceived risk between the population versus the first responders was relatively (and significantly) high in both Norway and Romania. A potential explanation for this difference within the Romanian society, most especially concerning the civilian population, may be the effect of the strict lockdowns, which led to a sharp increase in the risk perception of the public (Lindner et al., 2022). In contrast, the first

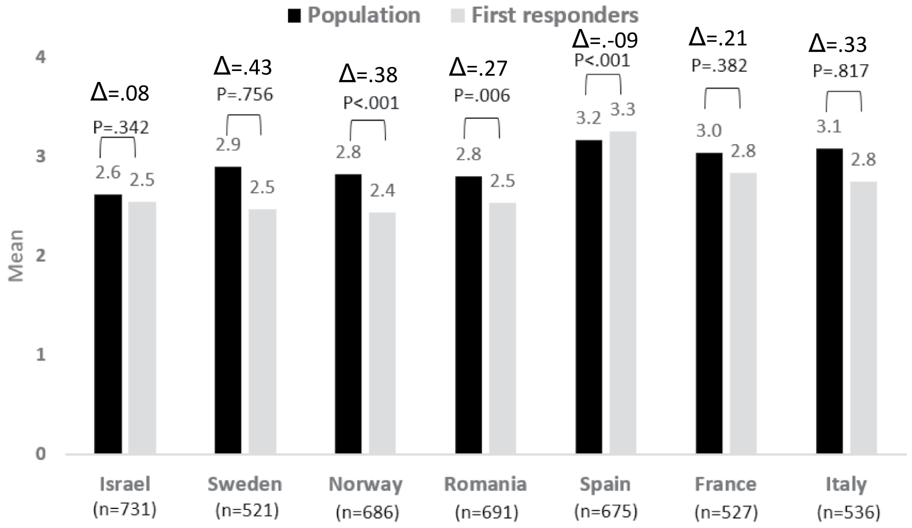

FIGURE 6
Risk perception regarding Pandemics – differences between country and group: population vs. first responders.

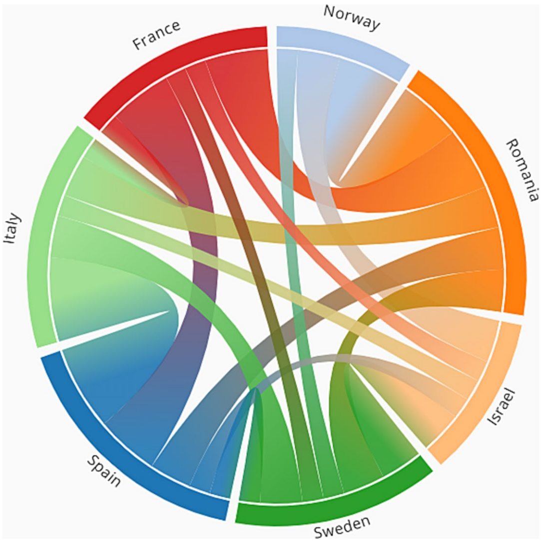

FIGURE 7
The similarities between the countries in terms of risk perceptions.

responders believed that such measures decrease the probability of negative impacts (i.e., limit exposure and spread of the virus), which may have led them to optimism bias (Druică et al., 2020). Similarly, Norway had the second highest rate of confirmed cases *per capita*, after Italy, especially in the earlier stages of the pandemic. Accordingly, this may have affected the risk perception of the public, resulting in their belief that the healthcare system is inexperienced in treating pandemics, leading them to a higher risk perception compared to first responders (Zickfeld et al., 2020).

Regarding Social Disruptions, one possible explanation for the different ranking of risks within France, between the general population and first responders, could be related to the effect of two major social disruption events that occurred in Paris in 2019, highly impacting the society. Substantial criticism was voiced by the public regarding the management by the municipality and emergency organizations of the explosion event in January 2019 (Bürkli, 2020) and the fire in the Notre-Dame cathedral in April, 2019 (Pett, 2019). Previous studies have shown that social disruptions may highly impact first responders over time, even more than they affect the public (Klimley et al., 2018; Motreff et al., 2020). Therefore, it could explain why in the case of France these events led the first responders to rank the social disruptions risk higher than the general population.

The higher risk perception concerning social disruption within the general population in Israel, compared to the first responders, could be a result of the threat of terror attacks. Terror events in Israel are frequent (Hirsch-Hoefler et al., 2016). While first responders are trained to handle and respond to terror attacks, the general population may not have the same level of training and experience (Ashkenazi and Hunt, 2019). Additionally, first responders have a better understanding of the measures that are in place to protect them and the public, which can reduce their perception of the risk (Geiger, 2016). In Norway, the higher risk perceptions that were identified among the general population, compared to the first responders, could be related to the higher media coverage of social disruptions that result from the surge of refugees, echoing such issues in the public's agenda (Hagelund, 2020). In contrast, the higher risk perception among the Spanish first responders, compared to the general public, could be derived from social disruption events such as cyber-terror. The public is not always aware of such attacks, hence perceives the risk as less severe, compared to the first responders that are more exposed to it (Muthuppalaniappan and Stevenson, 2021).

Regarding the ranking of critical services dependencies risks, in all countries but France, the first responders presented lower levels of perceived risks, compared to their respective populations. There are several reasons for this phenomenon. Firstly, emergency responders tend to prioritize addressing risks that pose a direct threat to life and injury over those that disrupt daily societal activities. For instance, they may prioritize extinguishing a fire over addressing disruption in a major road or water network, even though such disruptions can cause hardship for community members. Secondly, many critical infrastructures in Europe are operated by the private sector (Renda and Hammerli, 2010), making companies responsible for handling issues with these systems. Emergency responders may only become involved if the event has a fatal impact. Meanwhile, citizens experience disruptions from the outset. Thirdly, emergency responders often operate in a compartmentalized manner (Loggins et al., 2019), which can affect their priorities. They may prioritize fixing disruptions in the systems for which they are responsible for, without considering the interdependencies between different infrastructures which impact the citizens. More specifically in Spain and Italy this phenomenon aligns with the findings of previous studies in both Spain (Labaka et al., 2016), and Italy (Rehak et al., 2022), which claimed that the implementation of critical infrastructure resilience frameworks is lacking. According to O'Sullivan et al. (2012), a lack of resilience frameworks may imply that the first responders do not appropriately perceive the actual risks, and thus are oblivious to the higher risk perceptions of the public. In Romania, the critical service's dependencies have been a major focus in recent decades, which most probably contributed to the raised awareness of the public (Gheorghiu et al., 2013; Ozunu et al., 2021). Similarly, as this topic was extensively discussed in the Norwegian media, a similar tendency was found in Norway (Hagelund, 2020).

In the category of extreme weather events, the higher rankings of first responders, compared to the general population in Sweden, Spain, and Italy, could be related to the emergency preparedness programs for weather events in those countries. Previous studies already displayed a global trend of elevated risk perceptions of emergency authorities, regarding the effect of extreme weather events, in particular in those countries (Sovacool, et al., 2018; Perera et al., 2020). However, as extreme weather events are less frequent than other types of disasters, the general population's risk perceptions may be less affected than the first responders who are trained for such events (Zhang and Maroulis, 2021).

Similar claims could also be made regarding the higher rankings of nature-related events in Sweden, Romania, and Italy. In the case of Italy, events such as the L'Aquila earthquake can explain the higher risk perception of the first responders, as they are involved as vital bodies in such events (Alexander, 2010). According to Paleari (2018), Italy is exposed to a significant number of natural risks. This may lead the Italian government to earmark financial resources to risk prevention and mitigation, resonating such risks in the eyes of emergency professionals, and among them first responders, more than the public. Similarly, Armaş (2006) portrays a possible explanation regarding

Romania, with cities such as Bucharest (with the highest seismic risks in the world), leading to higher risk perceptions among first responders, but poor education of the population regarding those risks, which, according to Appleby-Arnold et al. (2021), can lead to a low perceived threat among the population, that may be oblivious to the danger. Furthermore, the literature presents high evidence of actions implemented in Romania, by emergency organizations in general and first responders in particular, to study and improve the risk management of such events, including raising the risk awareness of emergency agencies (Mara and Vlad, 2009; Ozunu et al., 2011; Meltzer et al., 2018).

The fact that the general population in Norway had higher risk perceptions regarding nature-related events, compared to first responders, can be explained by their beliefs about the effects of climate change on nature-related disasters. Hanssen-Bauer et al. (2009) previously claimed that climate change could have many positive effects on Norway, compared to other types of adversities. However, while this may lead to lower risk perceptions among first responders, who are trained and more familiar with the risks of climate change, Lujala et al. (2015) showed reverse effects among the public – who tend to be more concerned about climate change. As nature-related disasters may be more complex to understand and to be anticipated by the general population, their risk perceptions may be higher.

Beyond the variabilities that were found in the study between the general population's risk perception and first responders, within each country, this study highlighted differences between the countries. This variability could be derived from diverse social and cultural characteristics that differentiate between the societies, even when they are located in similar geographic locations or have been exposed to comparable types of adversities (Viklund, 2003; Drakos and Müller, 2014).

For example, the higher significant gap (0.38) in Norway, compared to Romania (0.27) concerning pandemics could be a direct result of the effect of COVID-19, that, had a greater effect in Norway (Zickfeld et al., 2020).

Concerning extreme weather events, the difference between Spain and Italy, where first responders had higher risk perceptions, to Israel, where the general population had a slightly higher score of risk perceptions, could be derived from the extreme weather resilience frameworks that operate in those countries, compared to Israel (Green et al., 2013; Hudson et al., 2020; Finzi et al., 2021).

The frequent nature-related disasters and their severity in Italy (Alexander, 2010; Paleari, 2018) could explain the higher gap that was presented between the first responders and the public (0.39), compared to the gap found in Romania (0.24).

The larger gap in Norway, between first responders and the public concerning social disruptions, compared to Israel, could be a result of the varied types of emergencies that explain these gaps within each country. In Israel, the main risk is derived from terror events, which are perceived to pose a greater danger to lives (Hirsch-Hoefler et al., 2016), compared to the complexities that result from the absorption of refugees in Norway (Hagelund, 2020).

Concerning critical services dependencies, the larger gap that was found between the general population and first responders in Italy, compared to Romania and Norway, emphasizes the importance of developing CI resilience emergency frameworks (Labaka et al., 2016). This gap presents how the lack of such frameworks enlarges the difference between the public and first responders' perceptions, compared to countries such as Romania and Norway, in which this topic receives more attention among emergency organizations (Gheorghiu et al., 2013; Hagelund, 2020; Ozunu et al., 2021).

The differences within countries, and the variability in the gaps between the countries, in the risk perceptions of the general population, compared to first responders, support previous studies which claimed that first responders, as a specific professional group, differ from the general public regarding specific demographic characteristics (Brown et al., 2021; Kollmann et al., 2022; Shah et al., 2022) or personality traits (Al-Dahash et al., 2022). The contribution of the discussion made in this study is in connecting these gaps with additional possible explanations, such as different policies in the various countries, the relative focus given for each type of emergency, and the frequency of events.

The differences in risk perceptions between the population and the first responders may lead to challenges in the public's adherence to the directives issued during adversities by the authorities and first responders. Behavioral models, such as the Health Belief Model (Kamran et al., 2021) and Protection Motivation Theory (Gumasing et al., 2022), predict an association between risk perception, compliance, and behavior. Thus, the gaps identified may affect compliance with the authorities' or first responders' instructions concerning the needed protective behavior, in preparation for or during the materialization of hazards (Barr et al., 2008; Jacobs et al., 2010).

Cases in which the public has a higher risk perception may result in two contrasting phenomena. First, the first responders may not be sufficiently sensitive to the risk perceptions level of the public as well as to their needs and expectations concerning those risks, given that they perceive those risks as being less severe (Lohiniva et al., 2020). Second, the overestimation of a particular risk by the general public may lead to a lower preparedness for a more critical risk, that will be ignored (Hengen and Alpers, 2019; Abel et al., 2021). Furthermore, these different perceptions may lead to a growing rift between the public and the first responders, derived from their respective frustration caused by the different levels of risk assessments, as was strongly shown during the COVID-19 pandemic (Bruinen de Bruin et al., 2020; Peleg et al., 2021; Scandurra et al., 2021).

Regarding the first responders, their risk perceptions may affect how they communicate the risk to the population. For example, lower risk perception of the public, compared to risk perceptions of first responders, might result in less compliance with the recommendations – derived from the disbelief of the public that they are necessary (Drury et al., 2019; Cairney and Wellstead, 2021). In contrast, higher risk perception among the public, compared to those of first responders, may create a feeling of being neglected (Simione and Gnagnarella, 2020). For example, make them feel that they are in danger and the official authorities are not providing any assistance, while the first responders perceive this risk as lower than other risks, and thus do not invest wide efforts in protecting the public.

Diversities in the risk perception between countries can result in different adoption of protective measures; for example, that might affect the development of the pandemic's global management. Therefore, another significant contribution of this study is highlighting those worldwide diversities.

Another important contribution of this study is the influence of context on the existing differences between the general population and first responders. This might be due to a lack of trust among the authorities and first responders, different levels of preparedness, different policies regarding risk communication, and more.

Limitations

This study has several limitations. First, this study is based on integrating two surveys with different sampling methods. The general population survey was limited to a sample size of 500 in each country, using random sampling. For some countries, this sample size is adequate, while in others, it may cause difficulties in representing the variety of the population (Bodas et al., 2022). The second study used non-random convenience sampling, resulting in diversities in each country's sample size. Therefore, the conclusions from this study, especially regarding first responders, should be generalized with caution. Second, the national comparison of the study is based on seven specific countries. Factors such as cultural characteristics and geographical environments may complicate the generalization of the commonalities and diversities beyond the sampled countries. It also should be taken into consideration that the data was collected during the COVID-19 pandemic. Therefore, potential limitations or biases can affect the responses of the first responders and the general population, as a result of the pandemic or that their risk perception changed since the availability of COVID-19 vaccinations.

Conclusion

The findings of this study offer significant insights for policymakers and emergency response planners across the countries surveyed. This study shows that although there are some commonalities in risk perceptions among varied countries, there are even more critical diversities both between countries but also among first responders and the general public, within and between countries. Such diversities present challenges in the communication of hazards by authorities and first responders to the public. The observed variations in risk perceptions between the general population and first responders emphasize the need for tailored communication strategies for different groups. Policymakers should consider these differences when designing public awareness campaigns, ensuring that messages resonate with the target audience's unique perspectives.

The differences in the risk perceptions among emergency responders and the populations may impede the implementation of different policies and plans set by the first responders and authorities, as citizens may have different priorities according to their risk perceptions. Furthermore, the ranking of perceived risks can guide resource allocation, prioritizing areas deemed as higher risks by both the public and first responders. The disparities in risk perceptions between countries also suggest the importance of context-specific strategies, taking into account cultural, historical, and socio-economic factors. Such misalignment would require the first responders to be more actively involved in the protection of civilians as they may be unprepared to handle crises due to their lack of awareness. In line with this constraint, future research is needed to investigate how to bridge the gap in the risk perception of both types of populations, to avoid the previously mentioned challenges.

Furthermore, the difference in the risk perceptions among countries reinforces the strategic approach that resilience is contextualized and efforts to enhance it should be tailor-made, considering the specific characteristics of each society, as no one policy 'fits it all'.

Lastly, the study underscores the importance of continuous training for first responders, ensuring they are well-equipped to address the most pressing risks in their respective regions.

Data availability statement

The datasets presented in this article are not readily available because the data collected in this study is not publicly published due to the requirements set by the Ethics Committee that approved the study. Existing analyzed anonymized data will be made available to researchers upon request. Requests to access the datasets should be directed to BA, adini@tauex.tau.ac.il.

Ethics statement

The studies involving humans were approved by Tel Aviv University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BA and LL conceptualized the study. NS and SE collected the data and analyzed the findings, and wrote the first draft. MS conducted the statistical analysis. All authors reviewed the manuscript and modified as needed.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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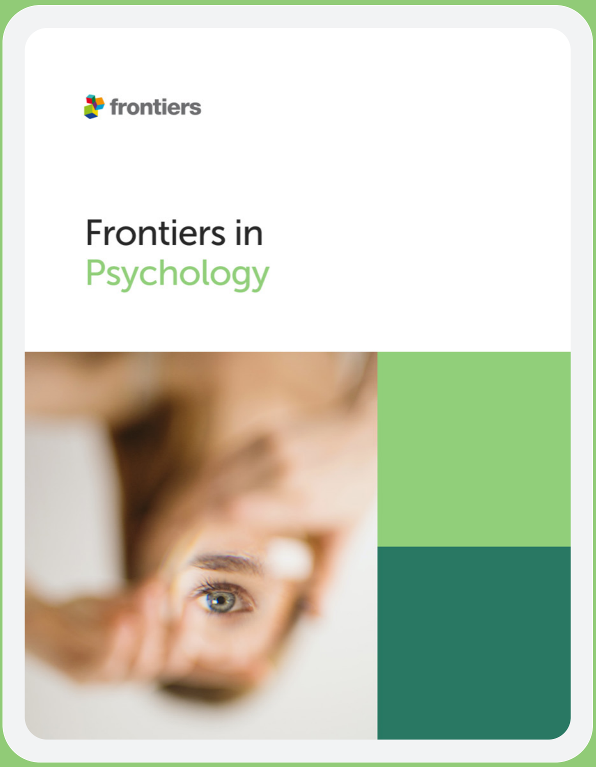

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