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Anxiety and threat magnification in subjective and physiological responses of fear of heights induced by virtual reality

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ABSTRACT

Fear of heights (acrophobia) is a common condition, yet it is not well understood. Immersive virtual reality (VR) offers experimental rigour in safe laboratory settings. Using VR in exploring individual differences in clinically relevant phenotypes is a relatively new methodological approach. This study shows how the field can be advanced by the adoption of this new technology. We examined threat magnification in subjective levels of distress and electrodermal activity (EDA) during fear of heights induced by VR. Moreover, we compared VR and mindfulness techniques in reducing subjective distress. With a sample of 128 (63 males) young people (mean age = 22.85, SD = 3.97), results showed that subjective levels of distress increased and EDA decreased during induced fear of heights. Furthermore, the results indicate that threat magnification mediated the relationship between anxiety and (a) physiological arousal and (b) subjective distress. Finally, moderated regression analysis showed that VR and mindfulness techniques were successful in reducing subjective levels of distress in highly aroused individuals after fear induction. This study provides evidence for usefulness of avoidance based models of personality in explaining human defensive reactions.

Picture yourself bending over the balcony on the top floor of skyscraper and looking down on streets below. Many people would feel tension in their muscles, body trembling, and even dizziness. Some sensation seekers may enjoy such an activity, whereas more anxious and panic-prone individuals are more likely to experience fear in much less intense situations (e.g., in an elevator). In this paper, we examine the role of threat magnification in experiencing physiological and subjective levels of distress related to fear of heights (acrophobia) in anxious individuals. In addition, we examine the efficiency of two relaxation strategies.

There is a sharp differentiation between anxiety and fear. This distinction reflects the theoretical framework of this study - reinforcement sensitivity theory (RST) of personality. RST postulates existence of two avoidance related brain-behavioural systems: Behavioural Inhibition System (BIS) and Fight/Flight/Freezing System (FFFS). Anxiety presents the affective output of the BIS, which is activated in the situations of conflict between (but not only) approach and avoidance motivation. Fear represents the affective reaction of the FFFS to immediate threat. Anxiety typically occurs when approaching the threat, while fear occurs in presence of threat (Corr & McNaughton, 2012) where the primary motivation is to avoid/escape. Moreover, fear and anxiety are associated with different brain-behavioural circuits (McNaughton & Corr, 2008) and they are treated with different psychopharmacological agents (Gray & McNaughton, 2003), both of which imply different psychological mechanisms. Corr and McNaughton (2012) defined two psychological mechanisms in explaining fear and anxiety: perceived distance and defensive orientation. According to this perspective, temporally and spatially closer perceived threats evoke fearful reactions, while more distant threats result in anxiety.

Some individuals are prone to threat magnification, that is, they tend to overemphasise the dangerousness and closeness of the threat, which may trigger a defensive response (see also McNaughton & Corr, 2004). Risk analysis is the behavioural output of the BIS (McNaughton & Corr, 2018) and a form of approaching the source of threat with caution. On the other hand, FFFS-mediated fear moves an individual away from the source of the threat. RST recognises three main defensive behaviours that are activated by the FFFS: fight, flight and freezing. According to the hierarchical organization of defensive behaviours (Gray & McNaughton, 2003), flight will occur if the source of threat is distant and escape is an option. If escape is not possible, the second line of defence is hiding or pretending to be dead, which reflects

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in tonic immobility or freezing (Schmidt, Richey, Zvolensky & Maner, 2008). If both strategies are not achievable, the only behaviour left is to attack the source of threat in order to create a possibility of escaping (i.e. defensive fight; Krupić & Dinić, 2017).

People cope with anxiety and fear in numerous ways. Mindfulness and virtual reality (VR) have been growing in popularity as stress coping strategies. Mindfulness can be defined as increased attention of present experiences in a non-judging and accepting way (Linehan, 1993). Researchers are emphasizing the importance of mindfulness as a possible protective factor and moderator of negative stress effects (Tomlinson, Yousaf, Vittersø & Jones, 2018). Most mindfulness programs last several weeks, but research has shown that even one mindfulness intervention can reduce stress (Durocher, Marti, Morin & Wakeham, 2018). On the other hand, diverting attention from stressors can be helpful in achieving relaxation. Research has shown that VR can be used in such situations (e.g. Wiederhold, Gao, Sulea & Wiederhold, 2014). Advances in technology have allowed the development of virtual environments designed for relaxation, such as natural environments, which in several studies have proven to be effective in reducing stress (Annerstedt et al., 2013).

1.1. The present study

In previous research, fear has typically been induced by affective pictures (Lang, Greenwald, Bradley & Hamm, 1993), videos (Jansen & Frijda, 1994), threat scenarios (Blanchard, Hynd, Minke, Minemoto & Blanchard, 2001) or by using shocks in a typical Pavlovian contextual fear conditioning, usually in studies conducted on experimental animals (Landeira-Fernandez, DeCola, Kim & Fanselow, 2006). However, usage of VR technology is growing rapidly (e.g. Carl et al., 2019) since it offers the possibility of increasing the ecological validity of experimental studies with minimal risks to participants. The main advantage of VR over traditional emotion-induction strategies is the interactive property of its animation. This property can significantly increase the sense of the presence and reality of the experimental situation (Slater, Lotto, Arnold & Sánchez-Vives, 2009).

VR has been found effective in provoking and in the treatment of fear of heights (for earlier studies see Opdyke, Williford & North, 1995). Recent developments suggest that VR can be effective in reducing anxiety problems even without the presence of trained therapist (Freeman et al., 2018), which might increase treatment provision for mental health disorders. More relevant to this study, the efficiency of self-guided VR based treatment has been found effective in reducing fear of heights (Donker et al., 2019).

The aim of this study is to examine the role of threat magnification as an underlying mechanism, which might help explaining the relationship between avoidance-related personality traits and physiological and the subjective manifestation of fear of heights (acrophobia). We hypothesise that anxious individuals are prone to threat magnification, which then elevates psychological and physiological reactions during the laboratory induced fear of heights. The model representing our hypothesis is displayed on Fig. 1. The main hypothesis is the existence of an indirect effect of anxiety on physiological reactions and subjective levels of distress through the threat magnification (path a), which subsequently elevates the levels of state anxiety (path b), which finally results in elevated physiological and subjective levels of distress (path c).

Since threat magnification does not have standard measure, we will use the Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pivik, 1995). This scale assesses the tendency to “magnify or exaggerate the threat value or seriousness of the pain sensations”. We argue that this instrument is a useful proxy measure of general threat magnification tendency. First, pain lies at the heart of the theoretical underpinnings of avoidance motivation (Corr & Krupić, 2019). Second, pain catastrophizing is a type of relatively stable coping strategy that is strongly related to anxiety and fear (Slater et al., 2009). In addition, Jackson, Minbashian and Criado-Perez (2019) distinguish two levels of personality. Level 1 stands for the trait-like constructs that represent average or typical affect, behaviour, cognition and desires of an individual. Level 2 represents the state-level of personality that is less stable and more dependent on situational cues. For self-report measure of arousal in inducing fear of heights on the level 2, the Physiological Arousal Questionnaire (PAQ; Kallen, 2002) is used. Finally, as the measure of stable individual differences in anxiety, we use the Questionnaire of Approach and Avoidance Motivation (QAAM; Krupić, Krupić, & Corr, 2020).

2. Method

2.1. Participants

Community sample was recruited by advertising on social networks. We had 133 participants, but 11 of them were excluded due to problems of recording their physiological reactions. The final sample consisted of 60 female (49.18%) and 62 male (50.82%) participants in the age range of 19 to 45 years (M = 22.86, SD = 4.04).

2.2. Instruments

2.2.1. Immersive virtual reality

HTC Vive headset was used to induce two emotional states. Application Richie's plank experience was used to induce fear of height and Nature TreksVR for relaxation. In Richie's plank experience participants entered an elevator that led them to the top of the skyscraper. When they arrive at the top, the door would open and they could see a two-metre-long wooden plank at the exit of the elevator, looking over an urban environment. The VR application used for the purpose of relaxing participants showed a naturalistic landscape in a quiet and peaceful environment.

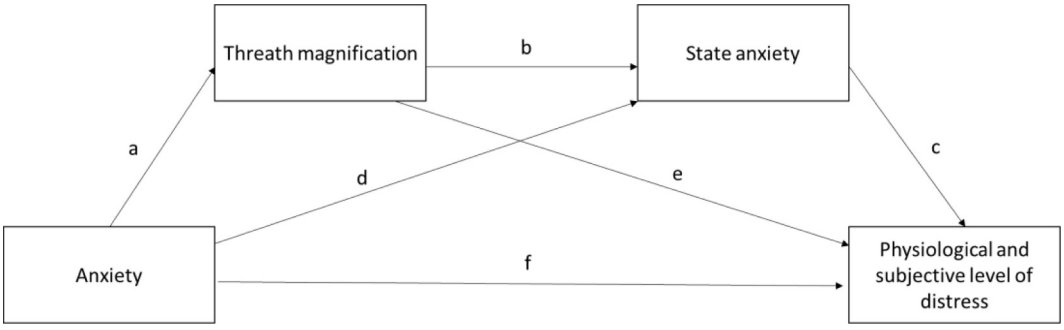

Fig. 1. Hypothetical serial mediational model.

2.2.2. Electrodermal activity

Moodmetric ring (MM; Torniainen, Cowley, Henelius, Lukander & Pakarinen, 2015) is an instrument specialised for measuring electrodermal activity (EDA). The MM ring collects skin conductance levels and transform the signals into MM scale ranging from 1 to 100, where higher values indicate higher arousal that can be either positive (e.g. excitement) or negative valence (e.g. stress). Approximately, the MM scores in range from 1–20 reflect state of deep relaxation (e.g. meditational state); from 21–40, regular relaxation (e.g. reading or walking); 41–60, states during mild activities (e.g. talking); 61–80, arousal during elevated activity (e.g. working under mild pressure); and 81–100, high arousal such as strong emotions. The MM ring has a small data storage capacity, so the data are transferred by Bluetooth connection to computer for permanent storage.

2.2.3. Mindfulness technique for stressful events

Tape of mindfulness technique for stressful events is a 4:29 min long auditory tape of female voice giving verbal instructions based on the work of Segal, Williams and Teasdale (2002) and Kabat-Zinn (2003). In the first part of the tape, participants are instructed on how to make themselves comfortable with their eyes closed. In the second part, participants are instructed to pay attention to their current thoughts, emotions and physical sensations in body and to became fully aware of them.

2.2.4. Questionnaire of Approach and Avoidance Motivation

Questionnaire of Approach and Avoidance Motivation (QAAM; Krupić, Krupić, & Corr, 2020) is 27-item questionnaire containing four approach-related scales (wanting, seeking, getting and liking) and two avoidance scales of anxiety and fear. In this study, only avoidance scales were used. Anxiety scale consists of seven items reflecting physiological reactions before important or stressful events (e.g. "*I sweat a lot in unpleasant situations*"). Fear scale contains four items reflecting symptoms of panic attacks (e.g. "*I have had thoughts that I will die during the panic attack*"). Participants rate how well each of the statement describes them on a 6-point Likert scale, ranging from 1 - Completely disagree to 6 - Completely agree. Cronbach's alpha reliability coefficients for Anxiety and Fear scales in this study were .85 and .82, respectively.

2.2.5. Pain Catastrophizing Scale

Pain Catastrophizing Scale **(PCS**; Sullivan, 2009) contains 13 items reflecting thoughts and feelings associated to pain (e.g. "*I wonder whether something serious may happen*"). Participants estimate the degree to which they experience these thoughts and feelings on the 5-point Likert scale, ranging from 0 - Not at all to 4 - All the time. Cronbach's alpha reliability coefficient was .93.

2.2.6. Physiological Arousal Questionnaire

Physiological arousal questionnaire (PAQ; Kallen, 2002) is a 7-item self-report questionnaire assessing the perceived current state of physiological arousal (e.g. "*Do you feel your heart beating?*"). Participants estimate to what extent they felt aroused on a 9-point scale, ranging from 0 - Not at all to 8 - Very much. Cronbach's alpha reliability coefficient was .83.

2.3. Procedure

Prior the experimental part of study, participants completed the QAAM and PCS. Next, EDA (in three minutes) and subjective level of distress, on the scale from 1 to 10 (higher number indicates higher distress), were collected as the baseline measures before the inducement of fear of heights. Baseline measurement point was followed by the fear induction procedure. In this phase, participants wore a VR headset and were placed in the VR application in front of an open elevator. Once they had reached the top floor of the skyscraper, they were instructed to walk until the end of the plank and return back in the elevator. During that time, EDA was recorded. Immediately after returning to the elevator, they were asked to rate their subjective level of distress, complete PAQ and to estimate how real the application was on the scale from 1 to 10 (higher number indicates higher immersiveness). In the final sequence of the study, participants were asked to enter another room where they were placed in one of three possible experimental conditions. Soon as they got in the room, we started to measure their EDA. The control group waited in silence, the second group listened to the mindfulness tape, and the third group watched Nature TreksVR. All three conditions lasted approximately four and a half minutes. In eleven cases the Bluetooth connections failed to store the data from the MM Ring onto computer, which reduced our sample size. We decided to remove all data for participants if physiological recording in any measurement point was missing. Finally, we obtained subjective levels of distress at the end of the relaxing condition. All participants were fully debriefed and the topic of the study was shortly discussed. Ethical committee of Faculty of Humanities and Social Sciences, University of Osijek gave the approval for this study.

3. Results

On the scale from 1 to 10, participants rated fear inducing VR application as very realistic ($M = 8.44$, $SD = 1.51$). The results of ANOVA (Table 1) indicated that VR produced a strong effect on both physiological and subjective levels of distress (Fig. 2).

Serial mediation regression model, tested by model 6 of Hayes' Process macro (Hayes, 2017) for IBM SPSS 21, confirmed the hypothetical model (Fig. 1). The QAAM Anxiety was directly related to the subjective levels of distress ($r = .27$, $p < .01$) and EDA ($r = .23$, $p < .05$), and both relationships were completely explained by the PCS, PAQ and two serial mediators (Tables 2 and 3). The model can be explained by two indirect effects (Table 4). First, QAAM Anxiety scale is positively associated with subjective levels of distress by experiencing higher levels of physiological arousal (PAQ). The second indirect effect implies that anxious individuals (QAAM Anxiety) are prone to catastrophizing (PCS), which increases perceived physiological arousal (PAQ), which then leads to a higher subjective levels of distress. The same indirect effects were significant in the model where EDA was

Table 1
Descriptive statistics and the results of two repeated ANOVAs for the EDA and subjective level of distress in all three measurement points.

	M	SD	F	Partial eta square	Bonferroni post-hoc test
EDA MoodMetrics (N = 115)					
Baseline (B)	49.93	20.83			
Fear of heights (VR)	31.65	19.20	49.323	.30	B > VR & R
Relaxation (R)	29.57	22.36			
Subjective level of distress (N = 123)					
Baseline (B)	2.77	3.92			
Fear of heights (VR)	5.14	2.65	83.569	.43	VR > B & R
Relaxation (R)	2.42	2.04			

*Note: In both repeated ANOVA, Mauchly's W test of spheresticity was significant at the level of 1%, thus we reported F values with Greenhouse-Geisser's correction of degrees of freedom; For EDA degrees of freedom were 1.69 and 192.57, whereas for the EDA were 1.89 and 213.99.

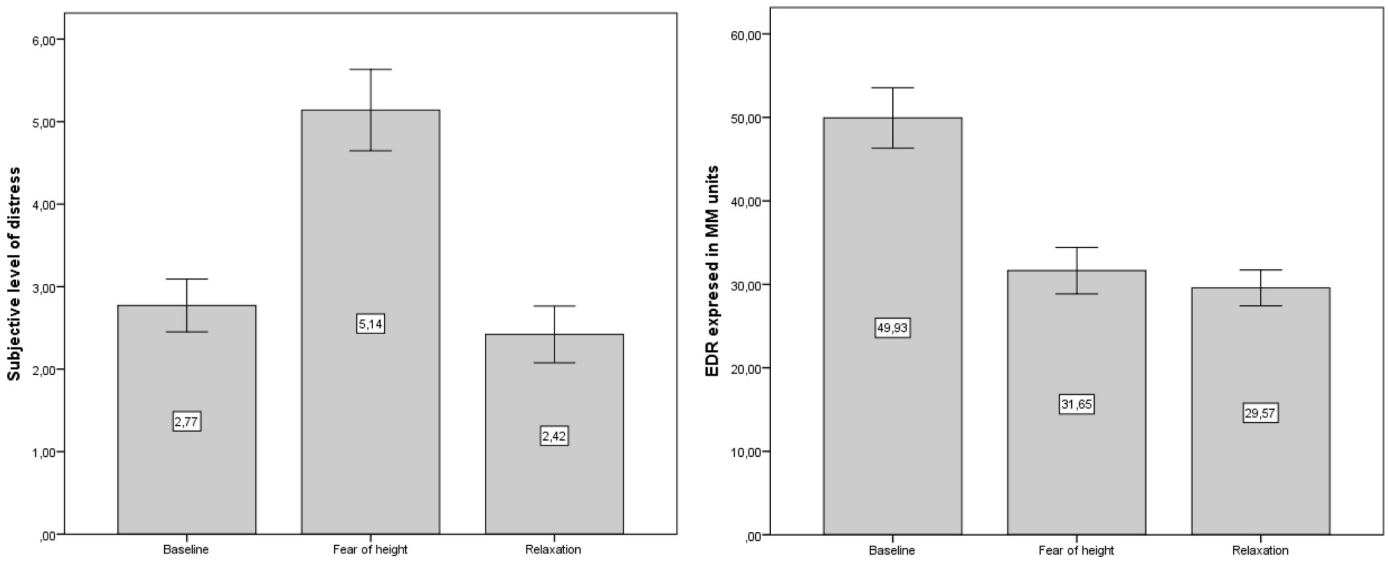

Fig. 2. Graphical presentation of arithmetical means and error bars (95% CI) for EDA and subjective level of distress reported in baseline, experimental induction by the VR and relaxation condition.

entered as outcome variable (Table 4).

The effectiveness of relaxing methods was examined by moderated regression analysis (model 1 in Hayes' Process macro) (Table 5). As it can be seen in Fig. 3, individuals with higher levels of PAQ benefited the most in the VR group, while the level of distress increased significantly for individuals high on PAQ in the control group. The hierarchical moderated regression model where subjective level of distress was replaced by EDA was not significant ($R^2 = 0.08, F(5, 108) = 2.09, p = .07$).

4. Discussion

The main aim of our study was to examine the role of individual differences in experiencing subjective distress and physiological reactions during VR induced fear of heights, and the efficiency of the VR and mindfulness techniques in relaxing participants with different levels of distress.

The EDA (expressed in MM units) was strongly reduced in fear of height condition in comparison to the baseline level. In passive

Table 2
Serial mediation model of the underlying mechanisms of anxiety in explaining subjective level of distress.

	Pain Catastrophizing Scale		Physiological Arousal Questionnaire		Subjective level of distress	
	Coeff	SE	Coeff	SE	Coeff	SE
QAAM Anxiety	**0.59****	0.11	**0.52****	0.14	0.00	0.03
Pain Catastrophizing Scale	–	–	**0.28****	0.10	0.02	0.02
Physiological Arousal Questionnaire	–	–	–	–	**0.12****	0.02
Constant	17.52**	3.11	8.40*	3.97	0.79	0.77
	$R^2 = .18$		$R^2 = .23$		$R^2 = .37$	
	$F(1, 116) = 97.15$**		$F(2, 115) = 17.06$**		$F(3, 114) = 22.70$**	

** $p < .01$.

Table 3
Serial mediation model of the underlying mechanisms of anxiety in explaining the EDA during fear of heights.

	Pain Catastrophizing Scale		Physiological Arousal Questionnaire		EDA of distress	
	Coeff	SE	Coeff	SE	Coeff	SE
QAAM Anxiety	**0.59****	0.11	**0.52****	0.14	0.21	0.26
Pain Catastrophizing Scale	–	–	**0.28****	0.10	0.18	0.18
Physiological Arousal Questionnaire	–	–	–	–	**0.37***	0.16
Constant	17.52**	3.11	8.40*	3.97	11.70	6.87
	$R^2 = .18$		$R^2 = .23$		$R^2 = .11$	
	$F(1, 116) = 97.15$**		$F(2, 115) = 17.06$ **		$F(3, 114) = 4.93$**	

** $p < .01$.

Table 4
Indirect effects of anxiety on subjective level of distress and EDA during fear of heights.

	Estimate	SE	Lower bound	Higher bound
Subjective level of distress during fear of heights				
Anxiety -> PCS -> Subj. distress	.0109	.0124	−.0121	.0371
Anxiety -> PAQ -> Subj. distress	**.0622**	**.0204**	**.0270**	**.1064**
Anxiety -> PCS -> PAQ -> Subj. distress	**.0201**	**.0096**	**.0043**	**.0419**
EDA during fear of heights				
Anxiety -> PCS -> EDA	.1077	.1250	−.1242	.3817
Anxiety -> PAQ -> EDA	**.1920**	**.1096**	**.0215**	**.4454**
Anxiety -> PCS -> PAQ -> EDA	**.0620**	**.0436**	**.0033**	**.1713**

Note: Indirect effects in **bold** are significant 95% confidence level. PAQ – Physiological Arousal Scale; PCS – Pain Catastrophizing Scale; EDA – Electrodermal activation.

Table 5
Moderated regression analysis estimating the level of subjective distress in three relaxing conditions.

	Subjective level of distress	
	Coeff	SE
Physical Arousal Questionnaire	0.02	0.02
W1	−0.57	0.38
W2	**2.01****	0.38
Physical Arousal Questionnaire X W1	−0.02	0.03
Physical Arousal Questionnaire X W2	**−0.09****	0.03
Constant	1.77**	0.26
R^2	*0.35*	
F(5, 115)	*12.11***	

Note: *$p < .01$; Experimental conditions were treated as multi-categorical variable were W1 stands for comparison of the mindfulness in contrast to control and the VR group, whereas W2 is the comparison of the VR in contrast to control and the mindfulness conditions. The interaction has explained additional 5.66% of variance ($\Delta F(2, 115) = 4.97$, $p < .01$).

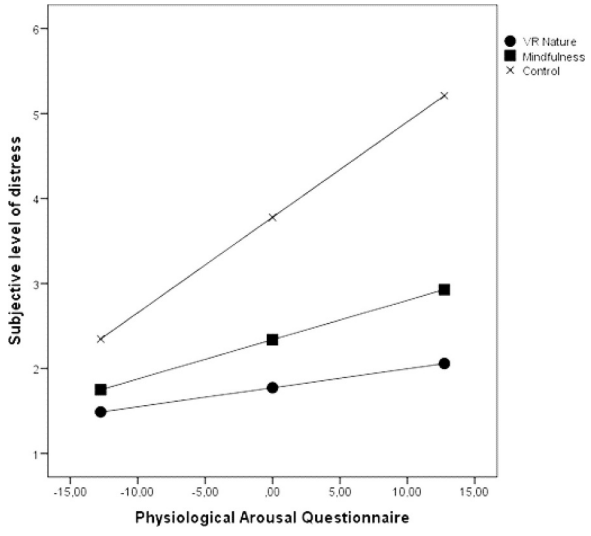

Fig. 3. Effectiveness of three relaxing strategies on subjective level of distress in dependence of the (mean-centred) PAQ.

defensive reactions, such as in the case of freezing when threat is immediately present and unavoidable, parasympathetic system activity dominates over that of the sympathetic system (Roelofs, 2017). This is reflected in reduced heart beats (Walker & Carrive, 2003), reduced mobility (Fanselow, 1994), changes of body temperature (Hagenaars, Oitzl & Roelofs, 2014), and reduced electrodermal activity (Collet, Petit, Priez & Dittmar, 2005). In our VR animation, participants were placed on the top of a very high building, where the most appropriate defensive response would be slowing body movements (i.e. tonic immobility) accompanied by increased attention to the cues in the environment. Thus, the decrease of EDA with accompanied increase of subjective levels of distress observed in our study can be best described as freezing reaction (see Hagenaars et al., 2014). This leads to conclusion that fear of height is most likely to produce freezing defensive reaction.

Although EDA was reduced at the group level, analysis on the level of individual differences showed that anxious individuals had higher levels of EDA during fear of heights, which confirmed the model depicted in Fig. 1. The indirect effect indicates that anxious individuals are prone to threat magnification (measured by PCS) that subsequently leads to the detection of physiological arousal (measured by Physiological Arousal Questionnaire; PAQ), which can explain both subjective levels of distress and elevation of EDA. To our knowledge, this is the first experimental study exploring the role of threat magnification as an underlying mechanism of avoidance motivation postulated by McNaughton and Corr (2004), and the first to show that the PCS can be meaningfully used as a proxy measure of threat magnification. There are many studies showing the effectiveness of psychological interventions on decreasing catastrophizing thinking (for a review see Sullivan, 2009), and our experimental results indicate that such intervention may be beneficial for anxious individuals.

The results of moderated regression analysis revealed that participants calmed down more in VR and mindfulness group than in the control group. These findings correspond with a number of studies that have highlighted the benefits of mindfulness interventions in stress reduction (for a review, see Chiesa & Serretti, 2009). There are several explanations why the mindfulness tape resulted in lower subjective stress levels. Firstly, focusing on one's breath usually slows and deepens breathing (Western & Patrick, 1988) and results in a sense of calm (Kabat-Zinn, 1994). Furthermore, participants were instructed to accept unpleasant emotions, thoughts or other physical sensations, which also has been found efficient in reducing stress levels (Wolgast, Lundh & Viborg, 2011). However, the lowest subjective levels of distress in highly aroused individuals were found in VR group. We argue that VR acted as a positive distraction causing pleasant emotions that served as a safety signal (Fredrickson, 1998) in highly aroused participants, which overall contributes to the empirical evidence on effectiveness of distraction as relaxation strategy immediately after exposure to stress (e.g. Sheppes & Gross, 2011).

These findings have implications for immediate interventions in stressful situations. It seems that both distractions using relaxing VR animations and short mindfulness interventions can be used in highly aroused individuals to reduce subjective levels of distress. Since the highest subjective levels of distress were found in participants with higher self-reported physiological reactions in control group, it seems particularly important to apply relaxation techniques in such individuals.

4.1. Limitations

Although VR is very useful in realistic inducement of emotional states, the results of this study should be interpreted with caution. The most relevant one reflects the fact that it was not conducted on a clinical sample, which should be attempted in the future in order to confirm the clinical relevance of our findings.

To conclude, we found that EDA decreases during the experience of fear of heights at the group level, but anxious individuals tend to experience higher level of EDA and subjective levels of distress due to their tendency of threat magnification. Although both mindfulness and virtual reality were successful, distracting with pleasant virtual stimuli turned out to be most beneficial in comparison to other methods, especially for individuals with higher self-reported physiological reactions.

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