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

Dino Krupić[1*], Barbara Žuro[1], Philip J. Corr[2]

[1] Faculty of Humanities and Social Science, University of Osijek

[2] City, University of London, UK

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*Corresponding author: Dino Krupić, University of Osijek, Faculty of Humanities and Social Science, Department of psychology, Lorenza Jagera 9, 31000 Osijek, Croatia

Abstract

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

Key words: Freezing, threat magnification, reinforcement sensitivity theory, virtual reality

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Picture yourself bending over the balcony on the top floor of skyscraper and looking down on street below. Many people would feel tension in their muscles, body trembling, and some would experience dizziness. People would react differently to this and related situations. Some sensation seekers enjoy risky activities, such as paragliding (Guszkowska & Bołdak, 2010), whereas more anxious and panic-prone individuals are much more likely to experience fear, even in less intense situations (e.g., on the mention of an elevator). In this paper, we examine mechanisms underlying the individual differences in physiological and subjective levels of distress related to fear of heights (acrophobia). In addition, we examine the efficiency of two relaxation strategies.

There is a sharp differentiation between anxiety and fear, despite their high comorbidity. This distinction reflects the theoretical framework of this study, namely the reinforcement sensitivity theory (RST) of personality which is the most prominent theory explaining the distinction between fear and anxiety. RST postulates the 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 activates in the situations of conflict between (but not only) approach and avoidance motivation, while fear represents the affective reaction of the FFFS to immediate threat. Anxiety typically occurs while approaching the threat, whereas fear occurs in presence of threat (Corr & McNaughton, 2012). Also, fear and anxiety are associated with different brain-behavioural circuits (McNaughton & Corr, 2008), can be treated by different psychopharmacological drugs (Gray & McNaughton, 2003), and imply different psychological mechanisms. Regarding the later, Corr and McNaughton (2012) defined two psychological mechanisms in explaining fear and anxiety: perceived distance and defensive

orientation. According to them, temporally and spatially closer perceived threats evoke fearful reactions, while for the anxiety, threats are perceived as more distant. Some individuals, while perceiving distance, have a problem with threat magnification (i.e., they tend to overemphasize the dangerousness – closeness - of the threat, which may trigger a defensive response). Risk analysis is the behavioural output of BIS activation (McNaughton & Corr, 2018), which is a form of approaching the source of the threat with caution, whereas FFFS-mediated fear moves an individual away from the threat. RST recognises three main defensive behaviours that are activated by the FFFS: fight, flight and freezing – this depends on perceived defensive distance. According to hierarchical organization of defensive behaviours (Gray & McNaughton, 2003), flight will occur if the source of threat is distant and the escaping from the danger is available option. If the escape is not possible, the second line of defence is to hide from the predator or pretend to be dead, which reflects in tonic immobility (Schmidt, Richey, Zvolensky, & Maner, 2008) or freezing. If the both previous strategies do not apply, the only possible behaviour is to attack the source of threat in order to minimise the threat and to escape (i.e. defensive fight; Krupić & Dinić, 2017).

Mindfulness and virtual reality (VR) have recently 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). Mindfulness encourages perceiving and accepting every thought, feeling and sensation the way they are experienced (Kabat-Zinn, 2003). Increasingly, researchers are emphasizing importance of mindfulness as a possible protective factor and moderator of negative stress effects (Rau, 2016). Most mindfulness programs last several weeks, but research showed 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 had shown that virtual reality (VR) can be used as a distraction in such

situations (e.g. Wiederhold, Gao, Sulea, & Wiederhold, 2014). Advances in technology have allowed the development of virtual environments designed specifically for relaxation, such as natural environments that in several studies have proven to be effective in reducing stress (Annerstedt et al., 2013).

The present study

In past research, fear has typically been induced by affective pictures (Lang, Greenwald, Bradley, & Hamm, 1993), videos (Jansen & Frijda, 1994), and threat scenarios (Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001). However, the emergence of the use of immersive VR technology is growing rapidly (e.g. Carl et al., 2019). VR offers the possibility to increase the ecological validity of experimental studies at the minimal risks to participants. Studies using VR technology have been directed at, for example, the study of fear of spiders (Miloff et al., 2016), open spaces (Malbos, Rapee, & Kavakli, 2013), combat related PTSD (Gonçalves, Pedrozo, Coutinho, Figueira, & Ventura, 2012). In this study, we will use VR to induce the fear of heights and then to reduce this fear.

We aim to examine the mechanism underlying anxiety in fear of heights (acrophobia). We hypothesize that anxious individuals are prone to threat magnification, which can subsequently elevate psychological and physiological reactions during the laboratory induced fear of height. The model representing our hypothesis is displayed on Figure 1. The main hypothesis is the existence of an indirect effect of anxiety on physiological reactions and subjective level of distress through the threat magnification (path a) which subsequently elevates the level of state anxiety (path b), which finally results in elevated physiological and subjective level of distress (path c).

- Figure 1 -

Since threat magnification does not have standard measure, we use the Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pivik, 1995), which assesses the tendency to "magnify or exaggerate the threat value or seriousness of the pain sensations" (Sullivan, 2009). We argue that this instrument is useful as a proxy measure of general threat magnification tendency since pain lies at the heart of the theoretical underpinnings of avoidance motivation (Corr & Krupić, 2019). In addition, Jackson, Minbashian and Criado-Perez (2019) recently distinguished two levels of personality. Level 1 represents the trait-like constructs that represents average or typical affect, behaviour, cognition and desires of an individual. Level 2 represents the state-level of personality functioning that is less stable and more dependent on situational cues. For the self-report measure of physiological arousal in inducing fear of heights on the level 2, we will use Physiological Arousal Questionnaire (PAQ; Kallen, 2002).

Analytical approach

To examine the overall effects of inducing fear of height, we will use repeated ANOVA, while for the model depicted on Figure 1, we will use model 6 of Hayes' Process macro (Hayes, 2017) for IBM SPSS 21. The efficiency of relaxing methods we will assess by moderated regression analysis (model 1). All regression models will be tested by 5000 of bootstrap samples for 95 percentile bootstrap confidence intervals, whereas the reported coefficients in this program are unstandardized ordinary least square (OLS) coefficients.

Method

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 females (49.18%) and 62 males (50.82%) participants in the age range of 19 to 45 years (M = 22.86, SD = 4.04).

Instruments

Immersive virtual reality HTC Vive headset was used to induce two emotional states. After the fear of height was induced by commercially available application, Richie's plank experience, Nature TreksVR was used for the relaxation. In Richie's plank experience, VR application participants enter the elevator that leads them to the top of the skyscraper. Once they would arrive at the top, the door opens and they would see a two meter long wooden plank at the exit of the elevator, looking over an urban environment. In order to enhance the immersiveness, we calibrated real wood plank with the plank from the application, so that participants had even more realistic feeling of walking on the plank. The VR application used for the purpose of relaxing participants showed naturalistic landscape in quiet and peaceful environment.

Moodmetric ring (MM; Torniainen, Cowley, Henelius, Lukander, & Pakarinen, 2015) is an instrument specialized 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 indicating higher arousal that can be either positive (e.g. excitement) or negative valence (e.g. stress). Approximatively, the MM scores in range from 1 - 20 are correspondent to deep relaxation (e.g. meditational state), from 21 - 40 to regular relaxation (e.g. the state during reading or walking), 41 – 60 are correspondent to states during mild activities (e.g. talking), 61-80 reflects arousal during elevated activity (e.g. working under mild pressure), and 81 – 100 reflects high arousal reflecting strong emotions.

Tape of mindfulness technique for stressful events is a 4:29 minutes 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 and close their eyes" 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.

Questionnaire of approach and avoidance motivation (QAAM; *authors names - hidden due to double blind policy of review process since the paper is submitted*) is 27-items questionnaire containing four approach-related scales (wanting, seeking, getting and liking) and two avoidance scale of anxiety and fear. In this study. only avoidance type 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 the each of statement described 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 were .85 and .82, respectively.

Catastrophizing Pain Scale (CPS; Sullivan, et al., 1995) contains 13 items reflecting thoughts and feelings associated to pain (item sample: „*When I'm in pain I feel I can't stand it anymore*"). Participants indicate the degree to which they experienced these thoughts and feelings on the 5-point Likert scale from 0 which reflects "not at all" to 4 "all the time". Cronbach's alpha reliability coefficient was .93.

Physiological Arousal Questionnaire (PAQ; Kallen, 2002) is a 7-item self-report questionnaire assessing the perceived current state of physiological arousal ("*Do you feel your heart beating?*"). The participants indicate on a 9-point scale (0–8) to what extent they felt aroused: 0 = not at all to 8 = very much. Cronbach's alpha reliability coefficient was .83.

Procedure

Prior the experimental part of study, participants completed the QAAM and CPS. Next, EDA (in three minutes) and subjective level of distress, on the scale from 1 to 10 (higher number indicate higher distress), were collected as the baseline measures before the inducement of fear of heights. After the baseline measurement point, we proceeded with the fear induction procedure. The participants wore a VR headset and were placed in the VR application in the front of 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 the EDA was recording. Immediately after the return to the elevator, they were asked to rate their subjective level of distress, the PAQ and to rate how real the application was on the scale from 1 to 10 (higher number indicate higher immersiveness). In the final sequence of the study, participants were asked to enter another room where they were placed into one of three possible experimental condition. Soon as they got in the room, we started to measure their EDA. The control group waited in silence, the second group listened the mindfulness tape, and the third group watched Nature TreksVR. All three conditions lasted approximately three minutes. 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 *XXX* (*name of the institution is hidden due to double blind review policy*) gave the approval for this study.

Results

Before analysing the role of individual differences, we conducted repeated-measures ANOVAs to estimate the effects size of the VR on EDA and subjective level of distress and assessed the reality of the VR application. On the scale from 1 to 10, participants rated the fear inducing VR application as very realistic (M = 8.44, SD = 1.51). This was also confirmed by the results of ANOVA, suggesting that the VR produced a strong effect on both physiological and subjective level of distress. However, in the case of EDA, we obtained the

strong effect but in an unexpected direction, that is, we recorded a strong drop of the EDA during the fear of heights (Figure 2).

- Table 1 -

- Figure 2 -

Serial mediation regression analysis confirmed the hypothetical model. Table 2. The QAAM Anxiety was directly related to the subjective level of distress ($r = .27, p < .01$) and the EDA ($r = .23, p < .05$), but both relationships were completely explained by the CPS and PAQ and two serial mediators (Tables 2 and 3). In Table 4, it can be seen that the model can be explained by two indirect effects. First, Anxiety elevated the subjective level of distress by experiencing higher levels of physiological arousal (PAQ). The second indirect effect implies the other possible interpretation assuming that anxious individuals are prone to catastrophizing which increases perceived physiological arousal, which led to a higher subjective level of distress. The same indirect effects were significant in the model where the EDA was entered as outcome variable (Table 4).

- Table 2 -

- Table 3 -

- Table 4 -

- Table 5 -

The effectiveness of relaxing individuals after induced fear of heights was examined by moderated regression analysis (Table 5). As it can be seen in Figure 3, individuals with higher levels of PAQ during the fear of heights 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 the subjective level of distress was replaced by the EDA was not significant ($R^2 = .08, F(5, 108) = 2.09, p = .07$).

- *Figure 3* -

Discussion

The main aim of this study was to examine the role of individual differences in experiencing subjective distress and physiological reactions during the VR induced fear of heights. The results showed that the EDA was significantly (and very strongly) reduced in the condition of fear of height in comparison to the baseline level. Since we did not expect it, we searched the literature to explain this effect. Bracha (2004) expanded Gray's list of defensive behaviours, so in addition to fight, flight, freeze, he recognises fright and faint reactions on stress. These different reactions are associated with distinctive sympathetic and parasympathetic activations. In the case of freezing, parasympathetic system dominates over sympathetic (Roelofs, 2017), which reflects in reduced heart beats (Walker & Carrive, 2003), reduced mobility (Fanselow, 1994), and changes of body temperature (Hagenaars, Oitzl, & Roelofs, 2014). Collet, Petit, Priez, & Dittmar, 2005) found that electrodermal activity is lower in inescapable threat situations, which is a typical cue to trigger freezing behaviour. If we analyse our VR animation, participants were placed on the top of a very high building, where the most appropriate defensive response would be to slow down body movements (i.e. tonic immobility) accompanied by increased attention to the cues in the environment. Along with the reduced EDA, participants reported a significant increase of subjective level of distress, which is associated with a freezing reaction.

Although the EDA was reduced at the group level, analysis on the level of individual differences showed that anxious individuals had higher levels of the EDA during fear of heights. This was confirmed by our hypothetical model depicted on Figure 1, where we

expected that anxiety would be related to the higher level of subjective distress and the EDA during the fear of height. The underlying mechanism (Figure 1) of this relationship is that anxious individuals are prone to threat magnification (measured by Catastrophizing Pain Scale; CPS) which subsequently leads to the detection of physiological arousal (measured by Physiological Arousal Questionnaire; PAQ) which can, then, explain both subjective level of distress and elevation of the EDA. This confirmed the usefulness of RST in the prediction of the underlying mechanism of avoidance motivation.

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. There are several explanations why a 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. Earlier research has shown that instructing participants to accept unpleasant emotions can result in lower stress levels (Wolgast, Lundh, & Viborg, 2011).

Lowest subjective stress level in VR group is consistent with prior research that has shown how distractions can be effective and useful immediately after experiencing stress (e.g. Sheppes & Gross, 2011). In this study, participants were subjected to relaxing techniques right after stress exposure which may have made them prone to distracting attention on pleasant stimuli. Moreover, it is possible that VR acted as a positive distraction causing pleasant emotions in participants which can serve as a safety signals (Fredrickson, 1998). These findings have implications for early intervention in stressful events. It seems that both distractions using relaxing VR animations and short mindfulness interventions can be used in threatened individuals to reduce levels of stress. Since the highest subjective stress levels

were found in individuals with higher self-reported physiological reactions in the control group, it seems particularly important to apply relaxation techniques in such individuals.

Finally, in order to stabilize and reach average MM scores in relaxing conditions, an increase in physiological measures was required, but that has not happened in neither of the groups. Since the measurement of electrodermal activity lasted only three minutes, it is possible that it was too short to detect any change, at least on a physiological level. However, there has not yet been enough research in this area and this finding should be further tested.

Limitations

Although VR is very useful in the realistic inducement of emotional states, this study should be carefully interpreted, since it was not conducted study on clinical sample, which should be done in the future studies to confirm the generalisability and clinical relevance of our findings.

To conclude, we found that the EDA decreases during the experience of fear of heights on the group level, but anxious people tend to experience higher level of the EDA and subjective level of distress due to their tendency of threat magnification. Although both mindfulness and virtual reality were successful, the most effective strategy immediately to calm individuals after experiencing fear of height is distraction using virtual reality. That is, 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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