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Darkness-enhanced startle responses in ecologically valid environments: A virtual tunnel driving experiment

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Abstract

Using the startle reflex methodology, researchers have shown that darkness, a phylogenetically relevant aversive context for humans, elicits fear responses. The present study replicated these findings in an ecologically valid situation, a virtual tunnel drive. Furthermore, the study focused on the question whether the darkness-enhanced startle response is modulated by an additional task involvement of the participants. Startle responses were assessed during virtual tunnel drives with darker and brighter sections. Participants once actively drove the virtual car and once passively sat in the car as a passenger. We found more negative feelings during darker parts of the virtual tunnel and during active driving. However, facilitated startle reactions in darkness were restricted to passive drives. Furthermore, correlation analyses revealed that darkness-enhanced startle modulation was more pronounced in participants with lower state anxiety. These results extend earlier findings in an experimental paradigm using ecologically valid virtual environments. Further research should use virtual reality paradigms to address context-dependent research questions.

Keywords: Startle reflex; Context; Anxiety; Virtual reality

Animal research has shown that the neural mechanisms mediating emotional reactions (e.g., startle responses) to contextual stimuli differ from the mechanisms involved in conditioning of explicit threat stimuli. While the amygdala mediates fear responses to specific stimuli in object conditioning, the bed nucleus of the stria terminalis (BNST) is activated during longer-lasting contextual anxiety (Davis, 1998; Sullivan et al., 2004). In rats, a light-avoiding species, bright light produces anxiety reactions and enhanced startle reactions (Walker and Davis, 1997). The ‘‘light-enhanced’’ startle reaction has been found to be mediated by the BNST and to be affected by the availability of corticotrophin-releasing hormone (Lang et al., 2000).

Human studies in laboratory settings have confirmed reliable fear reactions in response to explicit threat stimuli (Lang et al., 1998). In contrast, studies examining contextual effects are rare. However, recent research – mainly by Grillon and co-workers – demonstrated context effects for humans (for review see Grillon, 2002). The finding of different neural networks mediating specific or context-related fear was confirmed in neuropsychological (Funayama et al., 2001) and psychopharmacological (Baas et al., 2002) studies.

The first of these studies investigated the effect of contextual anxiety, induced by attached shock electrodes and darkness, on startle response (Grillon and Ameli, 1998; Grillon et al., 1997). Results showed that absolutely dark laboratories and attached shock electrodes enhance startle responses in participants. Furthermore, Benzodiazepine was found to reduce ‘‘darkness-enhanced’’ but not cue-specific startle modulation (Baas et al., 2002). Thus, darkness seems to be a phylogenetically relevant aversive context. Because experiments on darkness-enhanced startle reactions in humans worked in a restricted laboratory setting, it remains unclear whether results could be replicated in less restrictive settings.

Furthermore, some results indicate that moderating factors change the emotional modulation of startle response during the presentation of explicit cues. While the emotional modulation of startle response on explicit cues could clearly be shown in passive perception paradigms, this modulation could not be found in participants that are actively involved in cognitive tasks (Hoffman, 1997). However, to our knowledge task-associated

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or personality variables that might modulate the contextual, ‘‘darkness-enhanced’’ startle reaction have not been investigated.

Recently, virtual environments were used both in research and therapy of anxiety disorders (e.g., Mühlberger et al., 2003; Ressler et al., 2004) as well as in experimental conditioning research (Baas et al., 2004; Grillon et al., 2006). Virtual reality (VR) is a technical development that may allow the reliable and valid assessment of both clinically relevant verbal and physiological fear reactions. VR provides the observer with a level of sensory realism that approaches the experience in the real world. Furthermore, it enables the experimenter to control the situation and most of the stimuli aspects. Both factors allow researchers to simulate realistic situations and induce emotions in a controlled, standardized way (Hoffman, 1998; Loomis et al., 1999). Additionally, the measuring of verbal, motor and physiological responses is possible and artifacts usually induced by uncontrollable factors in real environments (e.g., by body motion) are abandoned.

Using virtual reality to simulate an environment that is highly valid ecologically, the first question of the present experiment was whether darkness-enhanced startle response would also be found in a dark virtual environment during a standard passive perception condition. Therefore, we created virtual car driving scenarios that included darker and brighter tunnel sections. We decided to use tunnel drive scenarios because these are also relevant for specific phobias related to context cues, e.g., claustrophobia or tunnel phobia. The second question was whether the darkness-enhanced startle response is modulated by the participants’ involvement in a task. Based on the results described above, we supposed that the darkness-enhanced startle reaction might be reduced in the active steering condition relative to the passive condition. Additionally, we exploratorily analyzed potential associations between emotional valence and darkness-enhanced startle modulation and the influences of state anxiety on these two variables.

1. Methods

1.1. Participants

Thirty-two healthy psychology students were recruited and received course credit for participation. Written informed consent was obtained before participation. Exclusion criteria included current use of psychoactive medication (self report), not having a driver’s licence, or indications of substantial fear of driving (TAF driver or co-driver score $\geq$2.0, see below) (one participant). Data of five other participants had to be excluded from further analyses due to equipment failure (one), absent display of startle reactions (three), or too many artifacts (one). Therefore, 26 participants (19 women, age 19–47, $M = 22.31$, S.D. = 5.45) were included in all further analyses. Fear of tunnel driving ranged from 0 to 1.80 as a driver ($M = 0.74$; S.D. = 0.48) and from 0 to 1.40 as a co-driver ($M = 0.52$; S.D. = 0.38). Trait anxiety ranged from 23 to 57 ($M = 37.27$; S.D. = 8.16) and state anxiety from 22 to 54 ($M = 37.27$; S.D. = 8.16).

1.2. Apparatus

1.2.1. Model generation

The model was generated at the Max Planck Institute for Biological Cybernetics, Tübingen, Germany. Commercial 3D modeling software, such as Multi-Gen-Paradigm Creator (Richardson, USA) for the environment and the tunnels, and EOS Systems PhotoModeler (Vancouver, Canada) for the car, allowed us to create highly realistic 3D models. These applications were used to build the interior of the car (a VW Golf II). The software CyberSession that manipulated the environments during the experiment was written in-house in Visual Basic. The complete model contained 42,163 polygons overall. The rendering was completed with the Cortona VRML Renderer (ParallelGraphics, Dublin, Ireland).

1.2.2. Hardware equipment

Participants were immersed in a 3D virtual driving environment rendered by a PC with Pentium IV 1.8 GHz processor, 512 MB RAM, and NVidia Geforce FX 5600 graphic card with 128 MB graphic memory. We dispensed with stereoscopic rendering in order to achieve an optimal frame rate (minimum frame rate was 15 frames/s, average was 30 frames/s).

The visual cues were presented by a head-mounted display (HMD; *V6*, Virtual Research Corporation, Aptos, USA). The head position was monitored with an electro-magnetic tracking device (*Fast Track*, Polhemus Corporation, Colchester, USA) in order to adapt the field of view to head movements. Continuous, monotonous background car sounds of 83 dB(A), startle stimuli (40 ms bursts) of 103 dB(A), and rating requests for valence and startle stimuli were presented binaurally over headphones. A motion base with 6 degrees of freedom (Kraus Maffay Wegman, Munich, Germany) was used to manipulate the body position and to simulate motion. Additionally, a Momo Racing steering wheel with forced feedback (Logitech, Romanel sur Morges, Switzerland) was provided for the active driving condition.

1.2.3. Startle (EMG) measurement

The eye-blink component of the startle reflex was measured by recording electromyographic activity (EMG) from the M. orbicularis oculi muscle beneath the left eye with Ag/AgCl miniature electrodes attached with a constant inter-electrode distance (2.5 cm) across subjects with a Vitaport-I system (Becker Meditec Inc., Karlsruhe, Germany). The signal was sampled at 384 Hz and online rectified and integrated applying a time constant of 0.16 s and a bandpass filter of 1–300 Hz (3 dB).

1.3. Psychometric assessment

The *Fear of Tunnel Questionnaire* (TAF, Mühlberger, 2003) consists of 11 items describing situations representative for tunnel drives (e.g., ‘‘Driving into the tunnel’’; ‘‘Being in the middle of the tunnel’’). Items are rated on separate 5-point Likert-type scales, which range from 0 (not at all) to 4 (very much) regarding the fear elicited by the described situation while being in a tunnel as a driver or a co-driver. However, since the last item (‘‘Having left the tunnel’’) does not add to the assessment of the fear of tunnels, a mean score for the first 10 items is calculated. The mean score of the TAF ranges from 0 (no fear) to 4 (very high fear).

The *State-Trait Anxiety Inventory* (STAI, Spielberger et al., 1970, German version by Laux et al., 1981) asks how a person feels presently or habitually and reflects situational or habitual factors that may influence anxiety levels. Scores range from 20 to 80, with a higher score indicating a greater level of anxiety.

The *Emotional Valence* (actual mood) was assessed online during the drives on a scale ranging from 0 (very uncomfortable) to 100 (very comfortable). Participants were trained to use this scale directly before the virtual drives. Ratings were requested before each drive and at four assessment points per drive, one during each darker/brighter phase (see below).

The *Igroup Presence Questionnaire* (IPQ, Schubert, 2003) is a scale for measuring the sense of presence experienced in a virtual environment (VE). The IPQ has three subscales and one additional general item not belonging to a subscale. The three subscales emerged from principal component analyses and can be regarded as fairly independent factors. The subscale Spatial Presence assesses the sense of being physically present in the VE. The subscale Involvement measures the attention devoted to the VE and the involvement experienced. Finally, the subscale Experienced Realism measures the subjective experience of realism in the VE.

1.4. Design and procedure

After obtaining informed consent, which included the presentation of two startle probes, participants were seated in a chair in the middle of the VR