ARTICLE IN PRESS

Computers in Human Behavior xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Affective, anxiety and behavioral effects of an aversive stimulation during a simulated navigation task within a virtual environment: A pilot study

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Virtual reality
Negative affects
Anxiety
Movement behavior
Variability

ABSTRACT

This study investigated the impact of an aversive environmental stimulation on self-reported affective and anxiety states and movement behaviors during a simulated navigation task in a virtual environment (VE). In the experimental task, participants were asked to virtually navigate (within two consecutive sessions), from a starting point to a destination location, across a spatial configuration consisting in three successive corridors (A–C). In the first session, all corridors were non-aversive. In the second session, the corridor B contained an aversive stimulation (i.e., fire, smokescreen, and warning alarm). Fourteen participants were involved in the experiment. Self-reported anxiety and affective states were measured at the end of each session. However, movement indicators (i.e., execution, time, average speed, speed and trajectory variability) were recorded on-line during the experiment. Results showed a significant increased (i) level of self-reported negative affects and state-anxiety between the two sessions, and (ii) speed and trajectory variability between the two sessions, while the participants were in corridor B. In conclusion, these results support the experimental validity of virtual reality for the induction of negative affects and state-anxiety. The relationships between reported negative affects and state-anxiety and behavior are discussed.

1. Introduction

One of the most used theories of emotions, the biphasic model (Lang, 2000; Lang, Bradley, & Cuthbert, 1990, 1997, 1998), asserts that emotions are organized around two basic motivational systems: appetitive and aversive. The appetitive system is responsible for approach behaviors and involves preservative actions that underlie pleasant reactions; whereas the aversive system is responsible for avoidance or withdrawal behaviors that are activated in the context of threat and underlie unpleasant reactions (Bradley, Codispoti, Cuthbert, & Lang, 2001).

In this theoretical model, emotions are considered to be action dispositions, preparing the organism for either avoidance- or approach-related behaviors, interrupting ongoing behaviors and mental processes (Schupp, Junghöfer, Weike, & Hamm, 2003). Nevertheless, the direction of the response (i.e., approach or avoidance) of an individual depends on his/her affective motivated interpretation (i.e., appetitive or aversive) of the encountered stimulus. Thus, when an individual is confronted with a stimulus that she/he interprets as potentially threatening (i.e., a dangerous animal) she/he activates an avoidance response (i.e., freezing or running); whereas when she/he is confronted to a potentially pleasant stimulus (i.e., a potential mate) she/he would rather activate an approach response (i.e., courting).

Biphasic theorists propose that activation of either the appetitive and/or aversive systems affects the central nervous system (i.e., functioning brain), priming representations, associations and action programs that correspond to the immediate environmental context and are linked to the engaged motivational system (Schupp et al., 2003). Thus, emotions are motivational states that prime reactions in three different reactive systems: (i) expressive and evaluative language (i.e., verbal report); (ii) physiological changes mediated by the somatic and autonomic systems (i.e., galvanic skin conductance, heart rate, facial electromyography, blood pressure, etc.); and (iii) behavioral sequelae (i.e., patterns of avoidance, performance deficits, etc.) (Lang, 2000; Lang et al., 1998).

Based on the biphasic theory of emotions, researchers have recently focused on the relationships between the aversive system activation and locomotion (Brown, Doan, McKenzie, & Cooper, 2006; Brown, Gage, Polych, Sleik, & Winder, 2002; Gage, Selik, Polych, McKenzie, & Brown, 2003; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Pijpers, Oudejans, & Bakker, 2005; Pijpers, Oudejans, Bakker, & Beek, 2006; Pijpers, Oudejans, Holsheimer, & Bakker, 2003). More specifically, they have been interested in assessing whether state-anxiety resulting from fear of falling activation would have a direct influence on locomotion, following a process-oriented approach. This approach consists in examining simultaneously

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doi:10.1016/j.chb.2010.07.020

changes in outcome and movement execution (Pijpers et al., 2003, 2005, 2006). Since changes in movement behavior do not necessarily lead to changes in outcome, when an individual completed a locomotion task in a threatening condition, the outcome could be the same, whereas the movement execution may have been altered (Pijpers et al., 2003, 2005, 2006).

In the aforementioned studies, fear of falling was defined as a very brief emotional reaction that arises from participant's interpretation that the environmental context she/he walks through is potentially dangerous (i.e., a possible fall). Furthermore, anxiety is an aversive emotional and motivational state occurring in threatening situations (Eysenck, Derakshan, Santos, & Calvo, 2007). This concept was described in these studies as a time-extended state of worriness, apprehension or tension that occurs as a result of fear of falling activation and is related to the participants' subjective evaluation regarding the potential physical injury consequences of a possible fall.

Brown et al.'s (2002, 2006) and Gage et al.'s (2003) studies have focused on the impact of state-anxiety on the gait pattern and the outcome of participants performing a walking task. During this task, the participants were asked to walk along the length of a path at a self-determined velocity while keeping their arms crossed in front of their chest and looking straight ahead. Fear of falling was activated by using and manipulating a natural environmental context (i.e., constrained and elevated floor) to confront the participants to a potential physical threat or danger. Results from these experimentations show that the most physically threatening conditions (i.e., constrained locomotion on an elevated floor) significantly modified participants' gait pattern and walking speed. Anxiety leads the individuals to increase the amount of time spent in the double support phase and to reduce stride length, resulting in lower locomotion speed.

In four consecutive studies, Nieuwenhuys et al. (2008) and Pijpers and his colleagues (2003, 2005, 2006) investigated the effect of state-anxiety on movement execution and outcome of participants executing a cliff-climbing task. During this task, the participants were asked to climb at a self-determined velocity along a horizontal route (i.e., a traverse) of a vertical artificial climbing wall. The fear of falling was elicited in a natural context, by building traverses on the climbing wall at different heights, in order to confront the participants with a potential physical threat. Results from these experiments demonstrated that the most physically threatening conditions (i.e., climbing on the traverse in the "high" altitude condition) significantly altered the participants' movement pattern and climbing time and speed (Pijpers et al., 2003, 2005). In particular, participants performed more explorative movements, produced less smooth trajectories, grasped the holds longer, and made slower movements from hold to hold.

To explain the effects of state-anxiety on locomotion, most of these researchers have resorted to the underlying attentional mechanisms: influences of heightened state-anxiety on movement behaviors and outcome are related to changes in attention (Brown et al., 2002, 2006; Eysenck et al., 2007; Gage et al., 2003; Nieuwenhuys et al., 2008; Pijpers et al., 2003, 2005, 2006). Indeed, following the self-focus or conscious processing hypothesis model (see Baumeister, 1984; Beilock & Carr, 2001; Eysenck et al., 2007; Masters, 1992; Mullen & Hardy, 2000 for more details), these researchers explained that threatening situations heightened state-anxiety and raised self-consciousness about correctly executing the locomotion task without falling, which in turn enhanced the attention paid to locomotion task's processes (Gage et al., 2003; Nieuwenhuys et al., 2008; Pijpers et al., 2003, 2005, 2006). Thus, increased attention leads to a step-by-step control of movement execution that is thought to disrupt or interfere with the normal automatic processing of the task (Beilock & Carr, 2001; Mullen & Hardy, 2000). This conscious monitoring, also called "deautomatization" (Mullen & Hardy, 2000) implies an increased level of cognitive control of movements or a reinvestment of cognition that typically reflects a temporary regression to a lower skill level (i.e., novice) or an earlier stage of perceptual-motor learning (Pijpers et al., 2003). Indeed, novice or less practiced task execution is thought to be based on declarative knowledge that is held in working memory and require an on-line step-by-step control and extensive attentional resources (Beilock, Wierenga, & Carr, 2002). In contrast to novices, expert or well-learned task execution is "automated"-controlled by procedural knowledge and requires little on-line attention and step-by-step control and operates mainly outside of working memory (Beilock et al., 2002). Consequently, when participants are anxious, they more cognitively control their movements during the task and movements have characteristics typically found in novice or in early stage of perceptual-motor learning (Pijpers et al., 2003, 2005). Thus, in anxious conditions, participants' movements require much effort and amplitude and are uncertain, clumsy, irregular, jerky, slow and less smooth and fluent (see Pijpers et al., 2003, 2005 for a review).

1.1. The present experiment

The aforementioned experimental studies have elicited fear of falling by using a natural environment (Gage et al., 2003; Nieuwenhuys et al., 2008; Pijpers et al., 2003, 2005, 2006). Within these ecological environments, participants were confronted to a real potential danger of physical injury risks. Whereas the literature (Reeve, 2005) underlines that the physical threat should be authentic, is it possible to induce negative affects and state-anxiety by using a virtual danger, involving partial determinants of a real danger? In particular, virtual reality (VR) technology enables us to manipulate selectively sensorial inputs (e.g., isolating sound and vision stimuli from haptic or odorant stimulation naturally found in real conditions). Will participants perceive this virtual physical threat as potentially dangerous? Will this induce changes in participants' self-report of negative affects and state-anxiety, movement behavior and outcome?

The purpose of this study was twofold. First, it sought to investigate the efficiency of a virtual environment (VE) in inducing negative affects and state-anxiety in healthy volunteers. The VE was manipulated in order to activate fear of burning in participants. During this experimental task, the participants were asked to virtually navigate across three corridors (using joystick control) within two consecutive sessions: one in which all corridors were non-aversive and another one containing a corridor in which they will be exposed to an aversive stimulation (i.e., fire, smokescreen, and warning alarm). Therefore, the first hypothesis proposes that participants will report a significantly higher level of negative affects and state-anxiety when exposed to an aversive stimulation, as compared to a neutral one.

Second, this study examined whether negative affects and anxiety-induced by an aversive stimulation, would have an impact on the movement execution and outcome of participants engaged in a simulated navigation task controlled by a joystick. However, regarding that this study was relying on another physical danger than falling and that the results from the previous studies might be specific to the nature of this physical danger (Plutchik, 1980; Shaver, Schwartz, Kirson, & O'Connor, 1987), no a priori hypothesis were proposed on the direction (i.e., increase or decrease) of the effect of the aversive stimulation on the movement behavior indicators.

2. Methods

2.1. Participants

A total of 14 participants (4 women and 10 men) between the ages of 18 and 30 years (M = 23.50, SD = 3.48), undergraduates in

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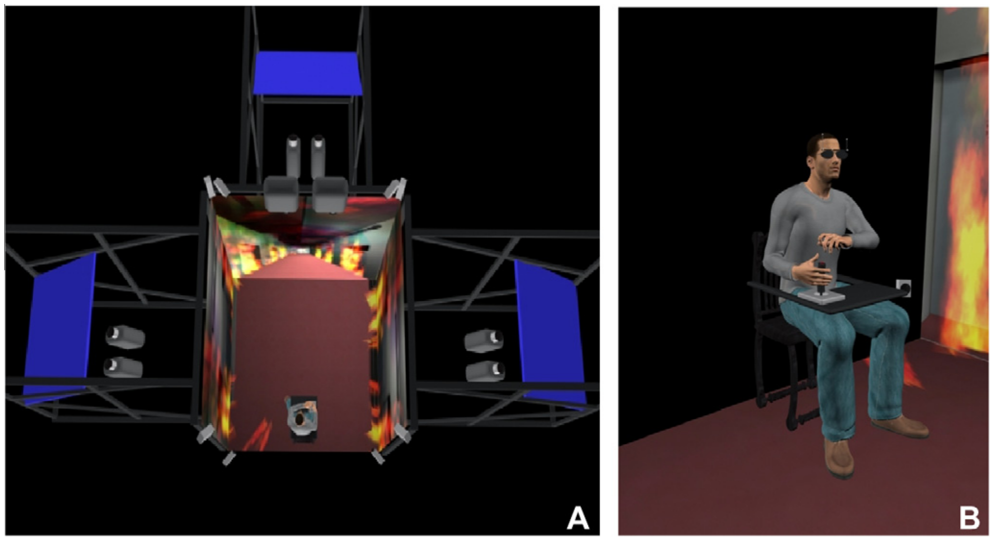

Fig. 1. Schematic representation of the immersive display. Note A: A virtual environment (VE) is generated via a cluster of five PCs. The environments are generated using 3DSmax Studio® 9.0 and Virtools® 4.0 software and displayed stereoscopically on four screens with three vertical faces of 400 × 300 cm (i.e., front, left and right) and one of 300 × 300 cm (i.e., ground). B: Participants are seated inside the CAVE, wearing custom eyeglasses with stereo filters (Infitec). Their displacement inside the CAVE is controlled using a wireless Saitek® joystick and recorded "in real time" during task completion in VEs. Finally, passive markers on the glasses are tracked in real-time by an ART® optical tracking system, in order to update sensorial stimulation as a function of the participant's position.

Sports Sciences at the University of Aix-Marseille II were recruited on a voluntary basis. All signed a consent form and were naïve concerning the purpose of the experiment. Trait-anxiety [Spielberger state-trait anxiety inventory – Y form (STAI-Y; Spielberger, 1983); Beck anxiety inventory respectively (BAI; Beck, Epstein, Brown, & Steer, 1988)] and medical information questionnaires fulfilled by the participants revealed that all meet the following criteria: (i) no psychiatric and neurological diseases; (ii) normal hearing and vision; (iii) non-use of any medication for psychological or emotional problems; and (iv) no trait-anxiety. All participants had scores lower than the cut-off value of 58 at the STAI-Y (M = 41.43, SD = 9.21) and 19 at the BAI (M = 8.79, SD = 6.39), as suggested by Spielberger (1983) and Beck et al. (1988), respectively.

2.2. Experimental apparatus

By means of a cluster of PCs with high-end graphics extensions, virtual environments were generated using 3DSmax Studio® 9.0 and Virtools® 4.0 software and projected inside a four-sided immersive display (Fig. 1).

2.3. Experimental set-up

During the experiment, participants were asked to seat in the middle of the display and perform a simple simulated navigation task controlled by a joystick. They were instructed to move outside an office inside a floor of a 3D textured model of the main building of the Sport Sciences Faculty of Marseille (Figs. 1 and 2). The task was to retrieve a document in the printer located in a reprography room and to put it on the desktop located in a meeting room. No constraints on completion time and performance were imposed to the participants.

This simulated navigation task was performed in two consecutive sessions. In details, participants had to move outside an office (slide 1, Fig. 2), turn right and move through corridor A (slide 2). Next, they entered corridor B, which could be "quiet" in the first session (slide 3, without aversive stimulation) or on fire in the second session (flames on the wall), with a smokescreen (visually simulated fog) and a warning alarm (slide 3′), with an aversive stimulation). The association of sound (warning alarm) and vision (flames, smokescreen) stimulation was meant to increase the potential effects, being related to a general hypothesis of the strength of multi-sensory.[1]

In the aversive condition the (virtual) dimension of the corridor B was the same as in the non-aversive-condition, because the flames were pasted on the wall (slide 3′). As a consequence, the size of the flames did not reduce the width of the corridor and thus affected participants' space to move inside the corridor. Moreover, nothing happened if participants touched the flames. Then, when moving out of corridor B, the eventual aversive-induction stimuli ceased. Subjects had to turn right (slide 4) and move to the reprography room (slide 5). Finally, they had to move outside of the reprography room and move (slide 6) to the meeting room (slide 7), their final destination. This last corridor C served only the purpose of setting a goal for participants. Behavior in this corridor was not analyzed.

This experiment[1] was focused on the effects of corridor B (being non-aversive in session 1 and aversive in session 2) on participants' behavior. This order was not counterbalanced since we wanted to avoid possible contamination effects of the aversive condition onto the non-aversive one (participants modifying their behavior in the non-aversive condition, because they expect fire in corridor B). However, we also included corridor A in the experimental design and analysis. This was meant to account for possible order effects on participants' behavior (corridor A was identical in the two sessions).

2.4. Self-reported measures

2.4.1. Trait-anxiety

The BAI of Beck et al. (1988) and the STAI-Y of Spielberger (1983) was used to evaluate participants' trait anxiety level. The French version of the BAI was validated in French by Freeston, Ladouceur, Thibodeau, Gagnon, and Rhéaume (1994). It includes a 21-item scale that measures the severity of participants' symptoms of anxiety. Each item are rated by the participants for the

[1] The authors which to thank an anonymous reviewer for this suggestion.

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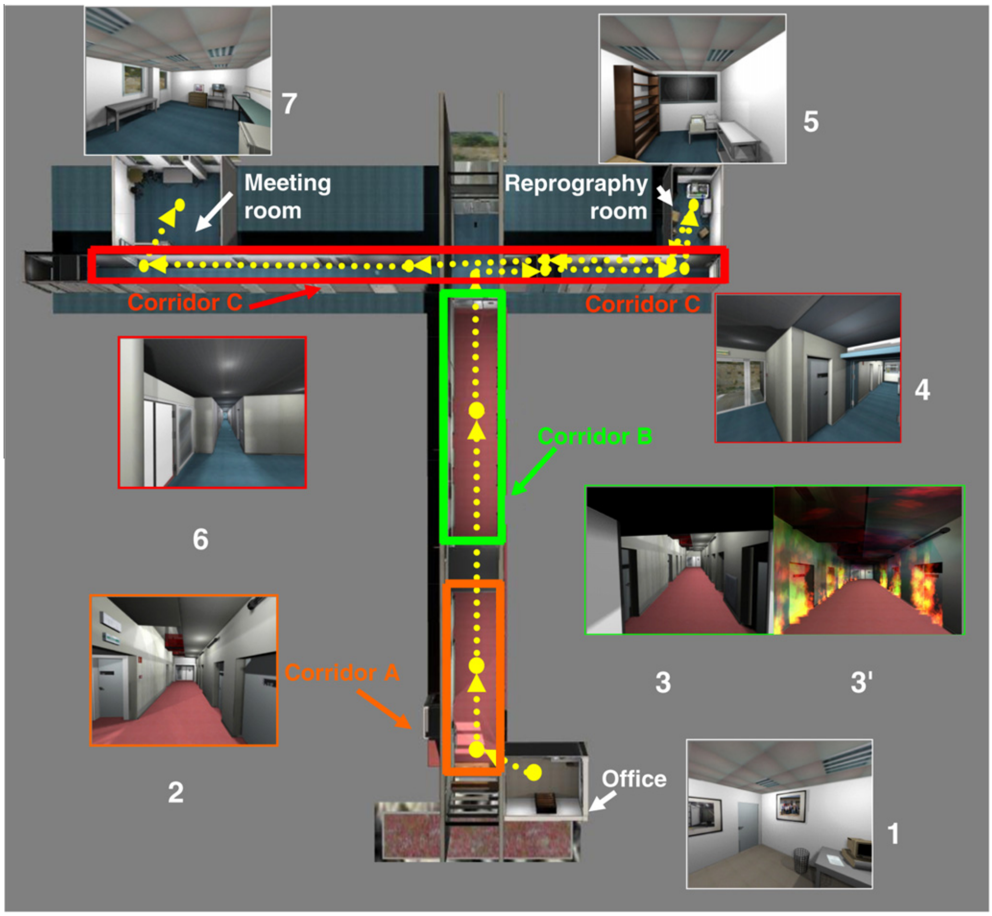

Fig. 2. Description of the virtual environment, with a representation of the participants' route. Note: 1: view of the office (i.e., start of the first and second sessions); 2: view of the corridor A in the first and second sessions; 3: view of the corridor B in the first session; 3′: view of the corridor B in the second session with smokescreen smoke, fire and warning alarm; 4: view of the right side of the corridor C in the first and second sessions; 5: view of the reprography room (i.e., retrieve a document) in the first and second sessions; 6: view of the left side of the corridor C in the first and second sessions; 7: view of the meeting room (i.e., drop the paper), that is the end of the experimentation in the first and second sessions.

"past week, including today" on a four-point Likert scale from: 0 = "not at all" to 3 = "severely, I could barely stand it". The ratings for each participant were then summed to obtain a total score of anxiety that taps the severity of anxiety symptoms. The possible range for this measure was 0–63, with higher scores corresponding to higher level of anxiety.

The French version of the STAI-Y was validated in French Canadian by Gauthier and Bouchard (1993). It includes a 20-item trait scale that measures the habitual level of anxiety of a participant. Participants rated each item on a four-point Likert scale from: 1 = "not at all" to 4 = "Extremely". The ratings for each participant were then summed to give a measure of trait-anxiety. The possible range for this measure was 20–80. In the present study, the internal consistency of global anxiety ($\alpha = 0.86$) scale of the BAI and that of trait ($\alpha = 0.89$) scale of the STAI-Y were both satisfactory.

2.4.2. State-anxiety

The state scale of the French Canadian version of the STAI-Y was used to assess participants' anxiety reactions to the VEs. This scale includes a 20-item state scale which measures the participant's current level of anxiety. Participants rated each items on a four-point Likert scale from: 1 = "not at all" to 4 = "Extremely". The ratings for each participant were then summed to give a measure on state anxiety. The possible range for this measure was 20–80. In the present study, the internal consistency of the state ($\alpha = 0.88$) scale of the STAI-Y was satisfactory.

2.4.3. Affective state

In order to provide information on participants' affective reactions to VEs, the French Canadian version and adaptation (Gaudreau, Sanchez, & Blondin, 2006) of the positive and negative affect schedule (PANAS; Watson, Clark, & Tellegen, 1988) was used. It comprised two affects' scales: positive (i.e., interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, and active), and negative (i.e., distressed, scared, nervous, jittery, afraid, upset, guilty, hostile, irritable and ashamed). The 20 items of this instrument were rated on a five-point Likert scale from: 1 = "very slightly or not at all" to 5 = "Extremely". The ratings for each participant were summed to give two affect measures: positive and negative. The possible ranges for these measures were 10–50 for both scales. In the present study, the internal consistency of the positive ($\alpha = 0.88$) and negative ($\alpha = 0.95$) scales of the PANAS were satisfactory.

2.5. Movement behavior indicators

In each session, the virtual displacement of individual participants, using the joystick, was time-coded and recorded starting from the entrance of a participant in the corridor A until the drop of the paper on the desktop located in the meeting room.[2] Nevertheless,

[2] Vertical head's movements of the participants inside the VEs with the use of the tracking system were also recorded, but they were not used in this study.

in order to (i) evaluate a possible learning effect related to repetition of the task, and (ii) focus on the effects of affective and anxiety-induction, only data from corridor A (i.e., place without affective-induction in both sessions) and corridor B (i.e., place with affective-induction in the second session) were analyzed (Fig. 2). The following dependent variables were derived from raw data:

Execution time (in seconds) was defined as the amount of time spent in both corridors (A and B) in each session.
Average speed (in meter per second) that is, the ratio between the distance covered by a participant in corridors A and B and the time she/he spent in the corridors A and B.
Standard deviation (SD) of speed (in meter per second) defined as speed variability in corridors A and B.
Trajectory variability or geometric index of entropy (in short "entropy") that is "the fluency of the curvature that arises from the displacement" of the participants when moving inside the VEs (Pijpers et al., 2003, p. 293). Cordier, Mendès France, Bolon, and Pailhous (1993), Cordier, Mendès France, Pailhous, and Bolon (1994) described entropy (H) by the following equation: $H = \log_n(2L/c)$, where L is the length of the curve or the distance (in meter) covered by a participant during his/her displacement in corridors A and B, and c the convex hull (envelope, in meters) of that curve.[3] According to these authors, a less fluent participants' displacement will give rise to a higher index of entropy.

2.6. Procedure

Before starting the experiment, the computer version of the demographic and medical information questionnaire, the BAI and STAI-Y trait-scale were presented individually to participants in standardized conditions (i.e., isolation in an office, inventory filled out by the participants, help with reading or comprehension when necessary). Then, the participants performed one training session on a PC workstation, in order to learn how to use the joystick as a navigation interface. Finally, right after completing the joystick training session, each participant performed two training sessions of the actual experimental simulated navigation task, without any aversive stimulation, using the same PC and monitor. In both of the sessions, the task was easily learned by the participants, and all of them successfully completed the task without difficulty.

During the experimentation, lasting 20 min, all participants performed the simulated navigation task during two consecutive sessions, first without aversive stimulation in corridor B, then with an aversive stimulation in corridor B. These two conditions were not counterbalanced, in order to neutralize any potential effect of the aversive condition on the neutral condition. Systematically and immediately after each session, participants were asked to fulfill the computer version of the PANAS and STAI-Y state-scale in the same standardized conditions as those for the BAI and the STAI-Y trait-scale. All participants successfully completed the simulated navigation task and fulfilled the questionnaires.

2.7. Statistical analyses

The Kolmogorov–Smirnov's test was first used to determine data normality among participants. Relative change scores between the first and the second session, for self-reported responses (i.e., STAI-Y state-scale and PANAS scales) and movement indicators (i.e., execution time, average speed, standard deviation of speed and entropy) were tested using several one-sample Student t test. A Bonferroni correction was applied for PANAS and navigation indicators data to minimize Type I error rate inflation due to the replication of the statistical analyses. The alpha error was set at 0.03 (i.e., 0.05/2) for the PANAS and at 0.02 (i.e., 0.05/3) for movement behavior indicators (i.e., execution time, average speed, standard deviation of speed).

[3] For more description about entropy development see Cordier et al. (1993, 1994).

3. Results

3.1. Anxiety and affective states responses across sessions

Descriptive statistics of the participants in STAI-Y state-scale and PANAS scales scores across sessions are provided in Table 1. According to the Bonferroni correction, the results from the one-sample Student t tests (Table 1) indicate, for the STAI-Y state-scale and PANAS negative-scale, a significant session effect with a large effect size. Analysis of score change (relative to zero) showed a significantly higher level of state-anxiety and negative affects in the condition in which corridor B is on fire, with smokescreen and warning alarm, as compared to the neutral one. Nevertheless, no significant differences were found in participants' positive-scale of the PANAS (Table 1).

3.2. Movement behavior across sessions

Descriptive statistics and results from movement behavior indicators across sessions in the corridors A and B are presented in Table 1. As illustrated in Table 1, series of one-sample Student t tests performed on execution time, average speed, speed variability and entropy did not reveal any significant score change (relative to zero) while participants were in corridor A. Nevertheless, significant effects from large to very large effect size were found for data from corridor B (Table 1). According to the Bonferroni correction, the results revealed that participants, while in corridor B: (i) exhibited increased speed variability; and (ii) had less fluent displacement (increased trajectory entropy) when they were exposed to the aversive stimulation, as compared to the neutral one. Furthermore, no significant differences were found in participants' execution time between the two sessions.

4. Discussion

Results from the present study show, as hypothesized, that participants expressed negative affects and were more anxious when confronted to an aversive stimulation, as compared to a neutral one. These results suggest that participants perceived a virtual physical threat (i.e., fire, smokescreen, and warning alarm) as potentially dangerous. VR technology was used to successfully manipulate sensorial inputs (i.e., isolating auditory – alarm – and visual stimuli – fire –from haptics and odor stimuli) to create an illusion of physical danger in participants. However, all of these stimulations were used in combination. It is thus unknown whether the state-anxiety and affective effects were due to the fire, the warning alarm, or the combination of both. Consequently, further experimental studies should test the respective and potentially cumulative effects on sound (warning alarm) and vision (flames, smokescreen) stimuli on induced state-anxiety and affective responses.[1]

In contrast to the literature which stresses the importance of objective danger (Reeve, 2005), the present study emphasizes that a virtual multi-sensory threat is able to elicit negative affects and state-anxiety in participants. Mühlberger, Bülthoff, Wiedemann, and Pauli (2007) recently reached similar conclusions, testing phobic fear induction during simulated driving. However, this latter study used a passive navigation task, therefore excluding behavioral assessment.

More precisely, in this study, when participants were engaged within an immersive VE, in which sound and vision stimuli, stereo-

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Table 1
Changes in anxiety and affective states and movement behaviors variables across sessions.

Anxiety/affective states variables		Session 1	Session 2[A]	*t*(13)	*p*	*d*					
STAI-Y state-scale	M	36.21	41.36	−2.927	0.01	0.78					
	SD	11.65	12.68								
PANAS negative-scale	M	15.79	18.43	2.442	0.03	0.63					
	SD	5.77	7.23								
PANAS positive-scale	M	32.29	31.14	1.157	0.27	0.31					
	SD	4.98	5.55								
Movement behaviors variables		Corridor A					Corridor B				
		Session 1	Session 2	*t*(13)	*p*	*d*	Session 1	Session 2[A]	*t*(13)	*p*	*d*
Execution time[a]	M	10.86	9.44	−1.396	0.19	0.37	6.93	6.36	1.008	0.33	0.27
	SD	5.90	3.70				2.35	2.47			
Average speed[b]	M	1.54	1.68	1.257	0.23	0.32	2.11	2.57	−2.200	0.04	0.60
	SD	0.39	0.57				0.64	0.87			
SD of speed[b]	M	0.91	0.96	0.601	0.56	0.19	0.85	1.43	−2.696	0.02	0.72
	SD	0.29	0.31				0.37	0.72			
Entropy	M	0.09	0.06	−1.568	0.14	0.43	0.003	0.02	−3.098	0.008	0.86
	SD	0.07	0.03				0.004	0.03			

Note. M: mean; SD: standard deviation; d: Cohen's effect size; STAI-Y: Spielberger's state-trait anxiety inventory – Y form; PANAS: positive and negative affect schedule.
[a] In seconds.
[b] In meter per second.
[A] During this session the participants were exposed to an aversive stimulation (i.e., fire, smokescreen and sound alarm) when entering in the corridor B.

scopic projection and real-time interaction were controlled, a simulated fire, smokescreen and warning alarm situation produced increased self-reported levels of negatives affects and state-anxiety. In this context, VR technology appears as a fruitful experimental tool to study the contribution of different sensorial modalities to self-reported feelings of negative affects and state-anxiety. From the present results, we suggest that state-anxiety has been induced by the perceptual integration of visual and auditory stimulation into a coherent world. Further work is required to understand the role of interaction (and action in general) in negative affects and anxiety-induction. More generally, this approach has to be theoretically linked to the general investigation of the determinants of the sensation of presence in VEs (Sanchez-Vives & Slater, 2005).

Beyond self-reported feelings of negative affects and state-anxiety, significant effect of the aversive stimulation on movement behavior was observed. Comparable effects were already reported by Brown et al. (2002, 2006), Gage et al. (2003), Nieuwenhuys et al. (2008) and Pijpers et al. (2003, 2005, 2006) in real settings and with another physical danger. They emphasize the potentiality of VR in this context. However, our results suggest that the alteration of movement behavior depends on the nature of a physical threat. In aforementioned studies, participants decelerated in order to avoid the potential physical injury of a fall. In the present study, the results show that the aversive stimulation did not significantly affect execution time, while speed variability was significantly increased. Results also reveal an increase in the spatial trajectory instability, only observed in corridor B during the aversive stimulation, as compared to the neutral one. This effect is certainly not due to an order effect (aversive stimulation after neutral one), since trajectory and speed variability are not significantly modified over the two sessions in corridor A (without any aversive stimulation). This pattern of results demonstrates that the control of the trajectory was specifically affected when participants were presented with an aversive stimulation. These results suggest that movement variability might be a general effect of induced negative affects and state-anxiety. Two main lines of reasoning can be evoked: (i) induced-anxiety resulted in an intention of the participants to "escape" from the burning corridor fire, explaining the increased variability. However, in attempting to escape from fire, their trajectory became less linear (oscillated more). The analysis of entropy in participants' trajectories reinforces this suggestion. In this sense, behavioral changes are a consequence of negative affects and anxiety-induction; (ii) movement variability represents a central effect of fear stimuli on movement execution patterns (Brown et al., 2002, 2006; Gage et al., 2003; Nieuwenhuys et al., 2008; Pijpers et al., 2003, 2005, 2006). Following these authors and a conscious processing model (Baumeister, 1984; Beilock & Carr, 2001; Eysenck et al., 2007; Masters, 1992; Mullen & Hardy, 2000), threatening situations, activating negative affects and increase state-anxiety, would raise self-consciousness about correctly navigating without danger, and consequently enhance the amount of attention allocated to the simulated navigation task. In other words, state-anxiety might induce a shift, at the behavioral level, from an automatic, low attention-consuming level of movement control, to a step-by-step conscious, level of control (Beilock & Carr, 2001). In this situation, using simulated navigation, the observed effects are compatible with this last hypothesis. In other words, the behavioral effects do not seem to depend on a particular effect or control device, and might be related to action control at the central nervous system level. However, further studies are required, in order to test whether such a "deautomatization" hypothesis, in behavioral terms, can be validated.

So far, we mainly discussed behavioral effects induced by a threatening stimulation within a VE. Like previous research, we might assume that the study's stimuli were a priori designed for inducing negative affects and state-anxiety. Consequently, one might accept the idea that such behavioral effects are related to participants' negative affects and state-anxiety. However, in the present study we took a step further. We directly investigated participants' self-reported negative affects and state-anxiety responses to the scenarios. Indeed, we found a significant effect of the aversive stimulation, as compared to the neutral one, concerning the state-anxiety and negative affects: participants reported to be more encountered negative affects and anxious when exposed to an aversive stimulation. This result is important, since it systematically evaluates the emotional state of a participant confronted to a VE.

In conclusion, this study support that the threatening scenario was successful at inducing negative affects and state-anxiety and debilitating participants' movement behavior. This is a first demonstration that participants may be exposed to an aversive stimulation in a VE. However, secondly, we cannot deduce from this analysis the causal link between negative affects, state-anxiety and movement behavior. Does the aversive stimulation induce

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negative affects and state-anxiety, which in turn induces behavioral changes? Alternatively, does the aversive stimulation induce directly transformations in central pattern generators, eventually at subcortical levels, with triggers changes in affective and anxiety states and movement control (Gage et al., 2003)? We certainly cannot answer this question in the present study.

Further research, investigating the hypothesis of state-anxiety-induced regression of automatic (trained) motor control toward conscious, on-line control might help tackle this question. Another line of development is also to enhance stimuli design and quality, in psychophysical terms, and to deepen the analysis of movement patterns. Finally, as we are able to analyze temporal aspects of participants' behavior during tasks execution, it would be valuable to develop an on-line analysis tool of the participants' affective and anxiety states, in order to evaluate temporal aspects of correlations between negative affects, state-anxiety and behavior within a fine temporal grain. This methodological aspect might be decisive in deciphering the causal links between negative affects, state-anxiety and behavior.

Acknowledgements

CNRS and University of the Mediterranean funded this research. The authors would like to thank Gérald Sylvestre for 3D modeling, Stéphane Gobron, Jean-Marie Pergandi and Cedric Goulon for scenario programming and data collection and Thelma Coyle for data analysis and modeling.

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