Effects of simulated darkness on the affective appraisal of a virtual environment

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This study investigated whether simulated darkness influences the affective appraisal of a desktop virtual environment (VE). In the real world darkness often evokes thoughts of vulnerability, threat, and danger, and may automatically precipitate emotional responses consonant with those thoughts (fear of darkness). This influences the affective appraisal of a given environment after dark and the way humans behave in that environment in conditions of low lighting. Desktop VEs are increasingly deployed to study the effects of environmental qualities and (architectural or lighting) interventions on human behaviour and feelings of safety. Their (ecological) validity for these purposes depends critically on their ability to correctly address the user's cognitive and affective experience. However, it is currently not known how and to what extent simulated darkness in desktop (i.e., non-immersive) VEs affects the user's affective appraisal of the represented environment. In this study young female volunteers explored either a daytime or a night-time version of a desktop VE representing a deserted prototypical Dutch polder landscape. The affective appraisal of the VE and the emotional response of the participants were measured through self-report. To enhance the personal relevance of the simulation, a fraction of the participants was led to believe that the virtual exploration tour would prepare them for a follow-up tour through the real world counterpart of the VE. The results show that the VE was appraised as slightly less pleasant and more arousing in simulated darkness (compared to a daylight) condition. The fictitious follow-up assignment had no emotional effects and did not influence the affective appraisal of the VE. Further research is required to assess on the validity of desktop VEs for both etiological (e.g., the effects of signs of darkness on navigation behaviour and fear of crime) and intervention (e.g., effects of street lighting on feelings of safety) research.

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Effects of simulated darkness on the affective appraisal of a virtual environment

Alexander Toet[1], Joske M. Houtkamp[2,3], Paul E. Vreugdenhil[2]

[1] TNO, Soesterberg, The Netherlands

[2] Department of Information and Computing Sciences, University Utrecht, Utrecht, The Netherlands

[3] Alterra Wageningen UR, Wageningen, The Netherlands

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Correspondence concerning this article should be addressed to:

Dr. Alexander Toet
TNO
Kampweg 5, 3769 DE Soesterberg, The Netherlands
Phone: +31 8886 65838
Fax: +31 346 353977
Email: lextoet@gmail.com

INTRODUCTION

This study investigated whether the affective appraisal of a desktop virtual environment (VE) representing a prototypical Dutch polder landscape is influenced by the simulated lighting conditions (daytime versus night-time).

Night-time outdoor environments are typically appraised as less pleasant and more frightening than their daytime equivalents (Bishop & Rohrmann, 2003; Loewen, Steel & Suedfeld, 1993). In the real world, ambient darkness evokes feelings of fear for personal safety (Box, Hale & Andrews, 1988; Cozens, Neale & Hillier, 2003; Nasar & Jones, 1997) and determines human (navigation) behavior (Warr, 1990), particularly in the absence of social presence (Painter, 1996). Ambient darkness elicits fear by concealing potential dangers (Blöbaum & Hunecke, 2005; Gray, 1987; Nasar & Jones, 1997; Warr, 1990) and can turn places that are pleasant during daylight into frightening places after dark (Hanyu, 1997; Nasar & Jones, 1997). As a result, many people (especially women) avoid leaving home or visiting certain places after dark (e.g. , Fisher & Nasar, 1992; Keane, 1998; Warr, 1985). Interventions like environmental design (Cozens & Love, 2015), lighting improvements (Fotios, Unwin & Farrall, 2015; Painter, 1996) and intelligent street lighting (Haans & de Kort, 2012; van Rijswijk, Haans & de Kort, 2012) may help to reduce fear and improve street use at night. VEs may be cost effective tools to design, evaluate and optimize such interventions (Boomsma & Steg, 2012; Cozens, Neale & Hillier, 2003; Nikunen & Korpela, 2012). However, their suitability for this purpose depends critically on their ability to correctly address the user's affective, cognitive and perceptual experience (Lewis, Casello & Groulx, 2012; Wergles & Muhar, 2009). This means that the affective appraisal of a VE should vary with ambient lighting in the same way as those of a similar real counterpart. In other words, a night-time VE should evoke the same (affective and behavioral) responses as a similar night-time real environment (i.e., the VE should be ecologically valid). The ecological validity of immersive daytime VEs for the study of feelings of fear and their impact on human navigation behavior in built environments has already been demonstrated (e.g., Park et al., 2008; Park et al., 2010; Park et al., 2011a; Park et al., 2011b). Also for an immersive system, it has been shown that simulated driving through dark virtual tunnels induces ecologically valid negative affect and corresponding startle responses (Mühlberger, Wieser & Pauli, 2007). Commercial desktop video games often use darkness in an attempt to evoke suspense and dread (e.g., Slender: www.slendergame.com, The Suffering: Midway Games, Silent Hill 2: Konami ; see also El-Nasr, 2006; Niedenthal, 2005). Darkness is indeed one of the most often reported causes of fear by game players (Lynch & Martins, 2015). However, it is not yet known how and to what extent simulated darkness in desktop (i.e., non-immersive) VEs affects the user's affective appraisal of the represented environment.

Only a few studies have investigated the effects of simulated darkness on the affective appraisal of virtual outdoor environments. Rohrmann & Bishop (2002) compared the affective appraisal of the daytime and night-time versions of a simulated suburban environment. Their participants watched video clips showing walkthroughs of the VE. They rated the night-time VE as more threatening and arousing than its daytime equivalent. However, the overall threat scores were below neutral (i.e., the environment was simply not perceived as very threatening or arousing in any of the tested lighting conditions). The fact that the night-time VE was not considered very threatening may be a result of the fact that the overall light level in the night-time VE was still sufficient to get a good impression of the environment and the fact that the soundtrack (sounds of passing traffic and footsteps) suggested social presence. Both factors may have had a reassuring influence on the participants. Bishop & Rohrmann (2003) compared the affective appraisal of a real urban park area with that of its simulated counterpart, both for daylight and night-time conditions. Their participants either performed a walkthrough of the real environment (either in daytime or at night) or watched a video clip of a walkthrough of the simulated environment (shown either in simulated daylight or darkness). The real and virtual environments were both perceived as less pleasant and more threatening at night. The night-time VE was even perceived as more threatening than its real night-time counterpart. Previous studies have shown that people tend to pay more attention to details in a VE than in a real environment (Park et al., 2010; Toet & van Schaik, 2012). Because of the (simulated) darkness, participants probably had more problems distinguishing details in the night-time VE, which may have resulted in a more negative affective appraisal. In a previous study (Toet, van Welie & Houtkamp, 2009) we compared the affective appraisal of a desktop VE representing an old Italian village both for simulated day- and night-time conditions. We found only a minor effect of simulated darkness on the affective appraisal of the VE: observers appraised the night-time version of the VE only slightly less pleasant and more arousing than its daytime equivalent. We attributed this weak effect to the fact that the VE had a cozy atmosphere, sufficient lighting to distinguish most details of the environment, and a soundtrack that suggested social presence (music, people singing, murmuring voices, etc.). In addition, the task (to perform a reconnaissance of the village) had no personal relevance for the participants. It is known that events or situations that are appraised as relevant and significant to one's goals and wellbeing induce emotions more effectively than irrelevant ones (Freeman et al., 2005; Lazarus, 1991). For example, people experienced more fear in a real night-time environment (direct relevance for one's wellbeing) than in its virtual counterpart (no relevance for one's wellbeing: Kim et al., 2014). Simulations are therefore more likely to affect the user's emotional state when they have a higher degree of personal relevance (Hoorn, Konijn & van der Veer, 2003).

This study investigates if simulated darkness influences the affective appraisal of a desktop VE representing a prototypical deserted Dutch rural area. Participants were requested to explore either a daytime or a night-time version of this VE. The only illumination provided in the night-time VE originated from some scattered streetlights along the roads and stars in the partly clouded sky, resulting in a very dark environment. In addition, there were no signs of social presence. In some conditions the participants were led to believe that the virtual walking tour would prepare them for a tour through a similar real environment. This fictional assignment served to enhance the personal relevance of the simulation. The combination of intense darkness, lack of social presence and enhanced personal relevance was used in an attempt to more effectively evoke darkness related feelings of fear. The affective appraisal of the VE and the emotional state of the participants were measured through self-report. The main hypothesis tested was that (H1) a desktop VE is appraised as less pleasant and more arousing in simulated darkness. Secondary hypotheses were that (H2) increased personal relevance of a VE enhances its emotion inducing capability and (H3) thereby amplifies the effects of simulated darkness on the affective appraisal of the VE.

METHODS

Materials

The virtual environment

The VE used in this study represents a prototypical Dutch polder landscape with some scattered houses, low-lying tracts of grasslands enclosed by dikes, roads, railway tracks, canals, and levees. It was originally developed as a training tool for levee patrollers by GeoDelft (now Deltares: www.deltares.nl) and Delft University of Technology, using the Unreal Engine 2 Runtime game engine (Harteveld et al., 2007). The simulation contains no people; only some birds flying around and several sheep in one of the grasslands. A soundtrack (representing wind and breaking waves) and visual dynamics (e.g., waving trees, water waves etc.) serve to enhance the realism and immersiveness of the simulation (Houtkamp, Schuurink & Toet, 2008). In the daytime condition the environment is lit by the sun. In the night-time condition streetlights along the roads and stars in the partly clouded sky provide the only illumination. We selected this environment since it is known that feelings of safety and human behavior vary most strongly with lighting levels in settings with low entrapment (access to refuge) and low concealment (open space; Blöbaum & Hunecke, 2005).

Set-up

The simulation was performed on a Dell OptiPlex 755 desktop computer (www.dell.com) equipped with an Intel Core 2 Duo CPU, running at 2.99 Ghz, 1.96 GB RAM, a NVIDIA GeForce 8800GT graphics card (www.nvidia.com), and a standard mouse and keyboard. The simulated environment was displayed on a 22″ Dell E228WFP Flat Panel Color monitor. Sound was provided through an Altec Lansing ADA215 speaker set (www.alteclansing.com).

The entire set-up was placed in an artificially illuminated room. The windows were covered to block the sunlight. The lights were on when the participants answered questionnaires or navigated through the daytime virtual environment. The lights were turned off (resulting in a dimly lit room) when the participants navigated through the night-time virtual environment.

Participants were comfortably seated in front of the monitor. They used the mouse and keyboard to navigate through the VE.

Measures

Environmental appraisal

The affective appraisal of the VE was measured using a subset of the 38 adjectives from a differential rating scale that was designed to assess the atmosphere of built environments (Vogels, 2008). The 11 selected terms represent each of its four principal affective dimensions (Vogels, 2008): *Cosiness* (*cosy, intimate, safe*; in Dutch: *behaaglijk, intiem, veilig*), *Liveliness* (*lively, inspiring, stimulating*; in Dutch: *levendig, inspirerend, stimulerend*), *Tenseness* (*tense, terrifying, threatening;* in Dutch: *gespannen, beangstigend, bedreigend*), and *Detachment* (*business, formal*; in Dutch: *zakelijk, formeel*). Each term was scored on a 7-point rating scale (-3 = *not at all*, 3= *very much*).

Fear of darkness in the real world

In the real world cues like darkness (day/night), novelty (familiar/unfamiliar) and lack of social presence are known to evoke fear of victimization and determine navigation behavior, especially in women (Fisher & Nasar, 1992; Warr, 1984; Warr, 1990). To check if this also applied to our female volunteers, we tested their susceptibility to each of these cues by scoring eight statements (*I'm very well able to find my way / in an unfamiliar environment / in a familiar environment at night / in an unfamiliar environment at night; I can orientate very well / in the dark / in daytime; I dare to walk by myself in an unfamiliar environment / at night / in daytime; I feel uncomfortable in the dark*) on a 7-point bipolar rating scale (-3 = *strongly disagree*, 3= *strongly agree*), prior to the main experiment.

Emotional response to follow-up assignment

The participants self-reported their momentary feelings of pleasure, arousal and dominance using a validated 9-point pictorial rating scale (the Self-Assessment Manikin or SAM: Bradley & Lang, 1994). The SAM provides a simple, fast, and non-linguistic way of assessing emotional state along three dimensions, and is therefore highly suitable to measure transient (short term) emotional states. The SAM was applied twice: once just after the participants had read their assignment and before they started their tour through the virtual environment (to measure their emotional state directly after reading the task assignment), and once after they completed their virtual tour . This test served to check whether participants with a fictitious follow-up assignment (i.e., participants who believed they had to explore a similar real environment at a later stage experienced emotions that were different from those experienced by participants who performed the experiment without this assignment.

Emotional response to environment

Light and dark environments may induce different emotional states. Emotional state was measured through self-assessment using a validated Dutch translation of the Positive and Negative Affect Scale (PANAS: Watson, Clark & Tellegen, 1988; for the translation see: Engelen et al., 2006; Peeters, Ponds & Vermeeren, 1996). This is a list of 20 adjectives used to describe different emotional states: 10 states of Positive Affect (PA) and 10 states of Negative Affect (NA). The PA scale measures activity and pleasure, while the NA scale relates to fear and stress. Because of its length (and in contrast to the SAM) the PANAS is more suitable to measure longer lasting emotional states. Participants scored the extent to which they experienced each emotional state on a 5-point unipolar rating scale (1= *not at all or very slightly, 5= extremely*).

Presence

In the context of simulation and gaming the term presence usually refers to the subjective experience of 'being there' in the mediated environment (Schuemie et al., 2001; Slater & Wilbur, 1997). There are indications that the capability of a simulation to affect the emotional state of an observer increases with the feeling of presence (Baños et al., 2004a; Baños et al., 2004b; Baños et al., 2008; Riva et al., 2007). Since it is likely that increased personal relevance enhances feelings of presence, we used the Dutch translation of the Igroup Presence Questionnaire (IPQ, downloaded from http://www.igroup.org/pq/ipq; see Schubert, Friedmann & Regenbrecht, 2001) to test if the fictitious follow-up assignment affected perceived presence. The IPQ contains 14 questions that are scored on a bipolar 7-point rating scale.

Map drawing

At the start of the experiment the participants were informed that they were required to draw a map of the simulated area after completing their virtual walking tour. This instruction served to stimulate the participants to actively explore most of the simulated area, so that they would not linger in one part. In addition, it served to confirm the fictitious follow-up assignment: the participants in that group were led to believe that they could use their map to find their way in the real environment at a later stage. The maps the participants produced were not further analyzed in this study.

Game and navigation experience

Problems with navigation can degrade the perceived realism of a simulation (IJsselsteijn et al., 2000). Since frequent game players probably have acquired higher levels of navigation proficiency, the navigation through the VE may require less of their attention so that they may achieve higher levels of presence. To control for this effect we measured game experience by two questions ("*How frequently do you play 3D computer games?*" and "*How frequently do you use other virtual environments (e.g., Second Life)?*"), using a 5-point unipolar rating scale (1=*never, 5= very often*). In addition, the extent to which navigation in the present simulation required attention and interfered with task performance was measured after the exploration of the VE by two questions ("*Did you need your attention to navigate*?" and "*Did the navigation control hinder your task performance in the virtual environment*?") using a 5-point unipolar rating scale (1= *not at all, 5= very much*).

Experimental design

The main hypothesis was that simulated darkness in a desktop VE affects the perceived pleasantness and arousing qualities of the represented environment. Participants therefore explored either a daytime or a night-time version of a desktop VE, and gave their affective appraisal and emotional response. In addition, we tested whether personal relevance determines the affective appraisal. In two conditions the participants were therefore led to believe that the tour they were about to make through the VE actually would prepare them for a follow-up tour through a similar real-world area, either in the same or in opposite lighting conditions as used in the simulation (daylight / darkness). This fictitious assignment served to increase the personal relevance of the simulation. Enhanced personal relevance may affect the emotional state of the users and thereby indirectly their affective appraisal of the VE. As a result, the experiment had a 2×3 design: two simulated lighting conditions (daylight/darkness) and three fictitious follow-up assignment conditions (no assignment, or assignment related to either the same or opposite lighting conditions).

Participants

A total of 72 female volunteers, aged between 17 and 32 years (M=22.2 years, SD=2.9 years) participated in this experiment. A sample of young females was chosen because it is known that this group is particularly susceptible to fear of darkness (Blöbaum & Hunecke, 2005; Loewen, Steel & Suedfeld, 1993; Warr, 1984; Warr, 1990), and shows a greater risk awareness which also extrapolates to virtual environments (Boomsma & Steg, 2012; Park et al., 2011a). Participants were randomly allocated to one of the 6 experimental conditions, such that each condition was performed by 12 participants.

The experiment was performed in accordance with the Helsinki Declaration of 1975, as revised in 2000 (World Medical Association, 2000), and ethical guidelines of the American Psychological Association. All participants gave their written consent. Each participant received an incentive of 10 Euros for taking part in the study.

Procedure

After being welcomed to the lab, the participants first answered some demographic questions, and some questions to assess their propensity for fear of darkness in real-life and their gaming experience. Then their emotional state was assessed for the first time through their responses to the PANAS questionnaire. Next, they read their instructions, which informed them that they were about to explore a virtual polder landscape for about 10 minutes, after which they would be asked to draw a map of the entire area, including the off-the-road parts. Participants in the fictitious assignment conditions were also asked to take part in a follow-up task, which involved a visit to the hypothetical real area corresponding to the simulation, either in daytime or at night. They were told that they would not receive any assistance during that visit, and that they would have to rely on their previous experience in the VE to perform the real world exploration task. Directly after reading their instructions the participants self-reported their current emotional state for the first time using the SAM. Then, the participants explored the VE for 10 minutes. Afterwards, they filled out the affective appraisal questionnaire, followed by the SAM and the PANAS (both for the second time), and the IPQ presence questionnaire. Finally, all participants drew a map of the virtual environment.

Data collection and analysis

A web-based survey tool (http://www.surveymonkey.com) was used to apply all measures used in this study. The answers were stored online and were later uploaded to SPSS 18 (PASW Statistics) for further statistical analysis.

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RESULTS

Environmental appraisal

The results of the affective appraisal questionnaire are listed in Table 1.

The *Cosiness* of the daylight representation of the VE scored above neutral for all conditions. In contrast, the night-time representation scored mostly negative or near neutral on *Cosiness*. A two-way independent ANOVA showed a main effect for *Cosiness*: *Cosiness* scored significantly lower for the night-time environment than for its daytime equivalent ($F(1,66) = 10.90$, $p= .002$, partial □^{2}= 0.142). However, no significant effects were observed for the fictitious follow-up task. Also, no interaction effects were found.

The factor *Liveliness* scored negatively in all conditions. A two-way independent ANOVA revealed no significant main or interactions effects.

The factor *Tenseness* was rated significantly more applicable to the night-time representation of the VE than to its daylight version ($F(1,66) = 56.16$, $p= .000$, partial □^{2}=0.460). Again, no significant main or interactions effects were found.

The factor *Detachment* was scored consistently less than applicable to the VE in all conditions. No significant main or interactions effects were observed for this factor

Summarizing, the night-time version of the VE was experienced as significantly less cosy and more tense than its daytime equivalent. The independent fictitious follow-up task variable did not affect the affective appraisal of the VE.

Fear of darkness in the real world

The results listed in Table 2 show that the participants report that in real life they are typically less at ease at night than in daytime. At night they report to be less proficient at finding their way in an unfamiliar environment than in a familiar environment (2nd and 3rd statement). They claim that their orientation capability is better in daytime than in the dark (4th and 5th statement). When walking alone in an unfamiliar real environment they are more afraid in darkness than in daytime (6th and 7th statement). These findings agree with previous reports that young females are typically more afraid in the dark when they are alone and in an unfamiliar environment (Warr, 1990), and confirm that the participants in this study feel less comfortable in darkness in real life.

Emotional response to follow-up assignment

The factors *Pleasure*, *Arousal* and *Dominance* were scored using the SAM, just before the participants started their exploration of the VE (T1) and afterwards (T2). The results are shown in Table 3. Statistical analyses were performed to test *(1)* whether the assignment of a fictitious follow-up real-world task affected the emotional states of the participants before they started

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their tour through the VE, *(2)* whether the VE experience itself affected their emotional states, and *(3)* whether there is an effect of the different experimental conditions (lighting level and fictitious follow-up assignment) on the emotional states of the participants at T2.

A 2×3 (lighting condition × fictitious task) ANOVA revealed no significant main effects or interaction effects for the factors *Pleasure*, *Arousal* and *Dominance*.

A paired-samples T-test shows that *Pleasure* significantly decreases after navigating the VE ($t(71) = 3.89$, $p = .000$). There are no significant effects of experiencing the VE on the factors *Arousal* and *Dominance*.

The pre-test values of all SAM factors significantly influenced their corresponding post-test values (*Pleasure*: $F(1,65) = 7.87$, $p = .007$; *Arousal*: $F(1,65) = 31.77$, $p = .000$; *Dominance*: $F(1,64) = 49.43$, $p = .000$). A 2×3 (lighting condition × fictitious task) analysis of covariance (ANCOVA) revealed no significant main effects or interaction effects for the factors *Pleasure* and *Dominance*. However, participants that experienced the dark VE scored significantly higher on *Arousal* ($F(1,65) = 6.56$, $p = .013$, partial $\eta^2 = 0.092$). No significant main effect or an interaction effect is found for the independent fictitious task variable.

Summarizing, the VE experience was significantly displeasing, while its night-time version had an arousing effect. The suggestion of a fictitious real world follow-up assignment had no emotional effects.

Emotional response to environment

Emotional state of the participants was measured twice with the Positive and Negative Affect Scale (PANAS), once before the participants had read their instructions (T1) and once after they finished their exploration of the VE (T2). The results are listed in Table 4. A paired-samples T-test showed that the VE experience significantly reduced the PA scores (scores at T2 are consistently lower than scores at T1), for each of the 6 conditions ($t(71) = 6.152$, $p = .000$).

A 2×3 (lighting condition × fictitious task) ANCOVA showed no significant main effects for lighting condition and for the fictitious follow-up task. However, a significant interaction effect was found ($F(2,65) = 3.92$, $p = .025$, partial $\eta^2 = 0.108$). Without a fictitious follow-up task (no personal relevance), the PA is significantly higher in the darkness condition than in the daylight condition ($t(22)= - 2.96$, $p = .007$). With the fictitious follow-up task (personal relevance), there is no significant difference between both lighting conditions.

Except for the daylight condition without a fictitious follow-up task, NA scores were all higher after experiencing the VE. However, this effect was not significant. A 2×3 (lighting condition × fictitious task) ANCOVA showed that the pre-test (T1) NA scores significantly determined the corresponding post-test (T2) scores ($F(1,64) = 28.92$, $p = .000$). There were no significant main effects for lighting condition and fictitious task.

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Summarizing, experiencing the VE reduced the positive mood and appeared to increase the negative mood of the participants, while the suggestion of a follow-up visit to a real world equivalent of the VE reduced their positive mood even further. When viewing the VE had no personal relevance for the participants (i.e., when they did not believe they would be required to explore a similar real world environment at a later stage) positive affect was significantly higher in the darkness condition.

Presence

Scores on the IPQ questionnaire were overall moderately positive (i.e., slightly higher than neutral). A 2×3 (lighting condition × fictitious task) MANOVA revealed no significant main or interaction effects. Thus, it appears that the participants experienced only a minimal degree of presence and involvement in most conditions.

Game and navigation experience

More than half of the participants (N=44) did not play 3D computer games, while the rest only played *very occasionally* (N=14) or *sometimes* (N=13). Only one participant played 3D games *frequently*. Virtual environments were not used for other activities than gaming by 66 (83%) participants. The remaining 12 participants used virtual environments for other purposes only *very occasionally* or *sometimes*. Thus, the sample used in this study probably had not much game and navigation proficiency.

CONCLUSIONS AND DISCUSSION

This study investigated whether simulated lighting conditions (daytime versus night-time) influence the affective appraisal of a desktop virtual environment.

The main hypotheses of this study (H1) that a desktop VE is appraised as less pleasant and more arousing in simulated darkness is indeed confirmed by the present results: the night-time version of the VE was experienced as significantly less cosy and more tense than its daytime equivalent. The VE experience itself was significantly displeasing, while its night-time version had an additional arousing effect. The VE exploration task by itself also reduced the participants' positive mood and appeared to increase their negative mood. A possible explanation for this effect is the fact that several participants remarked (in response to an open question) that they frequently thought of their map-drawing task during their exploration of the VE, and they were not sure how well they would be able to perform that assignment. This insecure feeling may have negatively affected their mood.

In two conditions the participants were led to believe they were required to explore to a real environment corresponding to the one shown in the VE, in an attempt to enhance the personal relevance of the VE experience. However, this suggestion did not affect their emotional state, and also did not influence their affective appraisal of the VE. Hence, the secondary hypotheses that (H2) increased personal relevance of a VE enhances its emotion inducing capability and (H3) thereby amplifies the effects of simulated darkness on the affective appraisal of the VE, could not be verified.

Without the suggestion of a similar follow-up task in the real-world participants in the darkness condition experienced significantly higher positive affect. In combination with the finding that darkness in the VE had an arousing effect, this result suggests that participants found the night-time VE more exciting than its daytime equivalent when the experience had no personal relevance.

The present results showed only minor effects of darkness on the affective appraisal of the simulated desktop environment. To assess the ecological validity of this result, further studies must be conducted that compare the effects of these lighting conditions between real environments and their virtual counterparts. Until now such studies are scarce (e.g., Bishop & Rohrmann, 2003), possibly due to the many practical problems and confounding factors that occur in real world research.

Limitations of the present study

This study has several limitations.

One issue concerns the sensitivity of the instruments that are currently available to measure the affective appraisal of environments (e.g., such as the pleasure-arousal scales of Russell & Pratt, 1980 and the atmosphere metrics of Vogels, 2008, that were used in this study). While these instruments cover all aspects known to determine the emotional response to environments, they do not appear sensitive enough to distinguish responses to subtle effects or differences in the appraisal of environments (especially virtual environments: Houtkamp, 2012). Hence, these scales require further refinement to make them suitable to assess the validity of virtual environments for visualization purposes.

The degrees of presence and involvement experienced by the participants in this study were not high. This may partly be attributed to their lack of game and navigation proficiency. As a result, their navigation through the VE may have required additional attentional resources which could otherwise have been attributed to achieve a stronger sense of presence (de Kort et al., 2003). In addition, the virtual environment represented a low level of entrapment and concealment, and therefore may not have been potent enough to induce strong affective feelings, even in darkness.

All experiments in this study were performed during daytime. The participants navigated the night-time virtual environment in a room that was darkened by covering the windows and turning off the light. A recent study investigating the effects of 'night' and 'darkness' on feelings of fear found that the effect of fear stimuli is actually modulated by the time of day (circadian or day–night cycle): fear-provoking stimuli trigger more intense responses in the nighttime condition than in the equivalent daytime condition (Li et al., 2015). Thus, it seems that night amplifies fear signals and increases fear responses. This facilitation of nighttime threat responses may reflect an evolutionarily adaptive mechanism for an efficient processing of threat-related stimuli to avoid danger. Although the size of this effect is only small to medium, a replication of the current study in nighttime conditions might amplify the present results. To obtain ecologically valid results future simulation studies should therefore take the day-night cycle into account by performing measurements during a timeframe that corresponds to the simulated time of day (i.e., measure simulated nighttime conditions at night and measure simulated daytime conditions during the day).

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Table 1(on next page)

Table 1. Affective appraisal of the VE in terms of *Cosiness*, *Liveliness*, *Tenseness* and *Detachment*.

Appraisals given by participants who explored either a daytime or night-time VE with respectively no additional assignment, or with the suggestion that they would be asked to traverse a corresponding real environment during either daylight or darkness (fictitious follow-up assignment). N=12 for each condition.

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Simulated lighting	Fictitious task	Cosiness		Liveliness		Tenseness		Detachment	
		M	SD	M	SD	M	SD	M	SD
Daylight	No task	0.25	0.88	-1.00	1.37	-2.56	0.67	-1.21	1.70
	Daylight	0.28	1.30	-0.56	1.15	-2.25	0.89	-1.17	1.67
	Darkness	0.50	1.12	-0.16	1.34	-1.94	0.87	-0.67	1.44
Darkness	None	-0.78	1.04	-0.53	1.41	-0.42	1.31	-1.29	1.05
	Darkness	0.06	0.91	-0.50	0.83	-0.61	1.29	-0.83	1.23
	Daylight	-0.75	1.02	-0.42	0.91	0.06	1.32	-0.92	1.40

Table 2(on next page)

Table 2. Results of the navigation and orientation questionnaire.

Statements	M	SD
I'm very well able to find my way in an unfamiliar environment.	0.25	1.60
I'm very well able to find my way in a familiar environment at night.	1.39	1.51
I'm very well able to find my way in an unfamiliar environment at night.	-1.00	1.51
I can orientate very well in the dark.	-0.15	1.32
I can orientate very well in daytime.	1.31	1.35
I dare to walk by myself in an unfamiliar environment in daytime.	2.38	1.03
I dare to walk by myself in an unfamiliar environment at night.	-0.32	1.54
I feel uncomfortable in the dark.	-0.19	1.55

Table 3 (on next page)

Table 3. SAM scores (rated on a 9-point scale).

Pleasure, arousal and dominance were rated before (T1) and after (T2) the exploration of the VE.

Simulated lighting conditions	Fictitious task	Pleasure T1		Pleasure T2		Arousal T1		Arousal T2		Dominance T1		Dominance T2	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Daylight	No task	6.50	1.24	5.42	1.93	3.17	1.12	2.58	1.51	6.00	1.95	6.17	2.04
	Daylight	6.67	1.16	6.17	1.70	3.17	1.59	2.75	1.60	5.25	1.55	5.00	1.28
	Darkness	6.83	0.94	6.25	1.49	2.83	1.03	2.92	1.73	5.42	1.56	5.67	1.61
Darkness	No task	6.92	1.38	6.25	1.49	3.00	1.54	3.50	1.31	5.58	1.88	5.50	2.28
	Darkness	5.42	1.68	5.25	1.66	3.25	1.55	3.58	1.51	4.73	2.15	5.27	1.45
	Daylight	6.75	0.62	5.17	1.27	3.58	1.56	3.83	1.34	5.58	1.31	5.17	1.47

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Table 4(on next page)

Table 4. The mean and standard deviation of the scores on the PANAS positive and negative affect scales.

Scores were given before reading the instructions (T1) and after finishing the VE exploration task (T2).

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Simulated lighting	Fictitious task	PA (T1)		PA (T2)		NA (T1)		NA (T2)	
		M	SD	M	SD	M	SD	M	SD
Daylight	No task	32.08	4.46	26.58	7.99	12.27	1.68	11.64	2.11
	Daylight	37.00	4.95	31.67	5.71	12.25	1.77	12.50	2.78
	Darkness	36.42	5.45	33.50	6.19	12.83	3.22	13.75	3.72
Darkness	No task	35.75	6.45	35.00	5.77	12.08	2.31	12.58	2.19
	Darkness	31.42	5.73	28.25	6.40	13.50	3.78	14.50	3.40
	Daylight	36.08	3.73	31.00	4.35	15.08	3.53	15.75	3.11

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Figure 1. Screenshots of the VE in daytime (a,b) and at night (c,d).