Effects of personal relevance and simulated darkness on the affective appraisal of a virtual environment

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INTRODUCTION

This study investigated whether personal relevance influences the affective appraisal of a desktop virtual environment (VE) representing a prototypical Dutch polder landscape in different simulated (daytime and nighttime) lighting conditions. We use the term affective appraisal (Russell & Lanius, 1984; Russell & Snodgrass, 1987) to refer to emotional appraisals of an environment, to make a clear distinction with emotional response to that environment. Affective appraisals are the attributed emotional or affective qualities, or cognitions about possible object- or place- elicited holistic percepts (Russell & Snodgrass, 1987). Affective appraisal measures the evaluation of the significance of the environment for our personal wellbeing. Affective responses (emotion and mood) are the result of appraisal and occur if the environment is judged relevant for our goals and wellbeing (Lazarus, 1991).

Nighttime 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 or imagined dangers (Blöbaum & Hunecke, 2005; Gray, 1987; Lyons, 1980; 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, 2014a; Boomsma & Steg, 2014b; 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 nighttime VE should evoke the same (affective and behavioral) responses as a similar nighttime 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 convincingly 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). In contrast to immersive systems, the ecological validity of *desktop* (i.e., non-immersive) VEs for evoking darkness related emotional and behavioral responses is still unresolved. 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

80 most often reported causes of fear by video game players (Lynch & Martins, 2015). Although
81 perceived safety of VEs decreases with reduced lighting levels in a similar manner as in real
82 environments (Boomsma & Steg, 2014a; Boomsma & Steg, 2014b), previous studies observed
83 only a small effect of simulated darkness in desktop VEs on the user's behavioral and emotional
84 responses (e.g., Rohrmann & Bishop, 2002; Toet, van Welie & Houtkamp, 2009).
85
86 There may be several reasons why previous studies failed to find larger effects of simulated
87 darkness on the effective appraisal of desktop VEs. Rohrmann and Bishop (2002) compared the
88 affective appraisal of the daytime and nighttime versions of a simulated suburban environment.
89 Their participants watched video clips showing walkthroughs of the VE and judged their liking
90 and appreciation of the area and their personal safety related associations. They rated the
91 nighttime VE as more threatening and arousing than its daytime equivalent. However, the overall
92 threat ratings were below neutral (i.e., the environment was simply not perceived as very
93 threatening or arousing in any of the tested lighting conditions). The fact that the nighttime VE
94 was not considered very threatening may be a result of the fact that the overall light level in the
95 nighttime VE was still sufficient to get a good overview of the environment and the fact that the
96 soundtrack (sounds of passing traffic and footsteps) suggested social presence. Both factors
97 probably had a reassuring influence on the participants. Bishop and Rohrmann (2003) compared
98 the affective appraisal of a real urban park area with that of its simulated counterpart, both for
99 daylight and nighttime conditions. Their participants either performed a walkthrough of the real
100 environment (either in daytime or at night) or watched a video clip of a walkthrough of the
101 simulated environment (shown either in simulated daylight or darkness). Although the real and
102 virtual environments were both perceived as less pleasant and more threatening at night, the
103 differences in affective appraisal (i.e., differences in liking and appreciation of the area and
104 personal safety related associations) were small. Again this is probably due to a combination of a
105 relatively high level of ambient lighting and social presence: the participants were walked
106 through the real environment at night by the experimenter in groups of 10 (most likely resulting
107 in a strong sense of social presence), while the relatively well-lit VE also contained signs of
108 social presence (trams, cars, sounds). In a previous study (Toet, van Welie & Houtkamp, 2009)
109 we compared the affective appraisal of a desktop VE representing an old Italian village both for
110 simulated day- and nighttime conditions. We found only a small effect of simulated darkness on
111 the affective appraisal of the VE: observers appraised the nighttime version of the VE only
112 slightly less pleasant and more arousing than its daytime equivalent. We attributed this weak
113 effect to the fact that the VE had a cosy atmosphere, sufficient lighting to distinguish most
114 details of the environment, and a soundtrack that suggested social presence (music, people
115 singing, murmuring voices, etc.). Kim et al. (2014) compared people's fear rating and eye
116 movements in response to both actual nighttime outdoor environments and to images of the same
117 scenes. While their participants' eye fixation behavior was similar in both conditions, the image-
118 based environments were rated overall as less frightening than the actual environments.
119 Summarizing, although previous studies showed that images and desktop simulation of outdoor
120 nightscapes are appraised as somewhat less pleasant and more frightening than their daytime
121 counterparts, the overall effects were small, probably due to ameliorating factors like social
122 presence and relatively high levels of ambient lighting.
123
124 An important factor that has not been investigated in previous studies is the *personal relevance*
125 of a simulation. Personal relevance is the extent to which a VE itself or actions therein have real

126 personal consequences and/or intrinsic importance for the user. It is known that events or
127 situations that are appraised as relevant and significant to one's goals and wellbeing induce
128 emotions more effectively than irrelevant ones (Freeman et al., 2005; Lazarus, 1991). For
129 instance, the emotional valence of visual scenes is significantly enhanced when they are paired
130 with short sentences inducing self-reference (e.g., "*this dog will attack you*" written underneath
131 the image of an aggressive dog: Walla et al., 2013). Simulations are also more likely to affect the
132 user's emotional state when they have a higher degree of personal relevance (Freeman et al.,
133 2005; Hoorn, Konijn & van der Veer, 2003). It has even been argued that presence and emotions
134 may be induced more effectively by enhancing the personal relevance of a VE rather than by
135 increasing its perceptual realism (Hoorn, Konijn & van der Veer, 2003). A result that appears to
136 confirm this hypothesis is the finding that the perceived risk of a health message presented in a
137 virtual environment is effectively increased when it is delivered by the user's virtual
138 doppelgänger (suggesting a direct link with one's own personal health: Ahn, Fox & Hahm,
139 2014). A lack of personal relevance may also explain why people experienced less fear in a
140 virtual nighttime environment (no relevance for one's wellbeing) than in its real-world
141 counterpart (direct relevance for one's wellbeing: Kim et al., 2014). Summarizing, it appears that
142 – next to social presence and relatively high levels of ambient lighting - a lack of personal
143 relevance may have been a fear-reducing factor in most previous studies investigating the effects
144 of simulated darkness in desktop VEs on human emotion and behavior. Hence, a lack of personal
145 relevance in these studies may have caused their finding that darkness related feelings of fear
146 induced by desktop VEs were much weaker than the feelings of fear that people experience in
147 similar real world conditions.
148
149 This study investigates if personal relevance can intensify the affective appraisal of a desktop VE
150 in simulated darkness. The VE represents a prototypical deserted Dutch rural area. Participants
151 were requested to explore either a daytime or a nighttime version of this VE. We selected an
152 environment with sufficient prospect (open spaces; low entrapment) since lighting is known to
153 affect feelings of safety most strongly in this type of environments (Blöbaum & Hunecke,
154 2005).The only illumination provided in the nighttime version of this VE originated from some
155 scattered streetlights along the roads and stars in the partly clouded sky, resulting in a very dark
156 environment. In addition, there were no signs of social presence. In some conditions the
157 participants were led to believe that the virtual walking tour through the VE would prepare them
158 for a tour through a similar real environment, either in the same or in the opposite lighting
159 condition as presented the experiment. This fictional assignment served to enhance the personal
160 relevance of the simulation. A combination of intense darkness, lack of social presence and
161 enhanced personal relevance was used in an attempt to more effectively evoke darkness related
162 feelings of fear. The affective appraisal of the VE (in terms of atmospheric parameters, as
163 detailed in the Measures section, and adapted from Vogels, 2008a) and the emotional state of the
164 participants were measured through self-report. Based on the results of previous studies we
165 expect that our desktop VE is appraised as less pleasant and more arousing in simulated darkness
166 than in simulated daylight. Our main hypothesis is that increased personal relevance of the VE
167 enhances this effect. More specifically, we expect (H1) that participants who explore the
168 nighttime VE with the assignment to visit to the corresponding real world environment at night
169 appraise the VE more negatively than participants without this assignment. In addition, we
170 expect that personal relevance also affects both the emotional response to the VE and the
171 participants' mood. That is, we expect that participants with the additional assignment

172   experience both (H2) more intense short term (emotions) and (H3) longer lasting (mood)
173   negative affective feelings than participants without this assignment .
174
175   Summarizing, our main hypotheses are that participants who explored the nighttime desktop VE
176   with the information that this experience serves to prepare them for a walkthrough of the
177   corresponding real environment by night (increased and negative personal relevance)
178   (H1): rate the VE as (H1a) less *Cosy* and (H1b) more *Tense*,
179   (H2): experience (H2a) less *Pleasure* and (H2b) more *Arousal,* and
180   (H3): experience (H3a) a larger decrease in *Positive Affect* and (H3b) a larger
181   increase in *Negative Affect*
182   than participants without this information.
183
184   Finally, we hypothesized that (H4) participants with a real world follow-up assignment
185   (increased personal relevance) experience a higher degree of presence in the VE than participants
186   without this information.
187

189

METHODS

191

Participants

193 A total of 72 female volunteers, aged between 17 and 32 years (M=22.2 years, SD=2.9 years)
194 participated in this experiment. A sample of young females was chosen because it is known that
195 this group is particularly susceptible to fear of darkness (Blöbaum & Hunecke, 2005; Loewen,
196 Steel & Suedfeld, 1993; Warr, 1984; Warr, 1990), and shows a greater risk awareness which also
197 extrapolates to virtual environments (Boomsma & Steg, 2012; Park et al., 2011a). Participants
198 were randomly allocated to one of the 6 experimental conditions, such that each condition was
199 performed by 12 participants. The participants were students of the Utrecht University (Utrecht,
200 The Netherlands) and were recruited by public announcements. The experiment was performed
201 in accordance with the Helsinki Declaration of 1975, as revised in 2013 (World Medical
202 Association, 2013), and ethical guidelines of the American Psychological Association. All
203 participants gave their written consent. Each participant received an incentive of 10 Euros for
204 taking part in the study.
205

Experimental design

207 Participants explored either a daytime or a nighttime version of a desktop VE, and gave their
208 affective appraisal and emotional response. In four conditions the participants were led to believe
209 that the tour they were about to make through the VE actually would prepare them for a follow-
210 up tour through a similar real-world area, either in the same (daylight VE with daylight follow-
211 up tour or nighttime VE with nighttime follow-up tour) or in opposite (daylight VE with
212 nighttime follow-up tour or nighttime VE with daylight follow-up tour) lighting conditions as
213 used in the simulation . This fictitious assignment served to increase the personal relevance of
214 the simulation. As a result, the experiment had a 2×3 design: two simulated lighting conditions
215 (daylight/darkness) and three fictitious follow-up assignment conditions (no assignment, or
216 assignment related to either the same or opposite lighting conditions).
217

Procedure

219 The timeline of the experimental procedure is shown in Fig. 1. After being welcomed to the lab,
220 the participants first answered some demographic questions, and some questions to assess their
221 propensity for fear of darkness in real-life and their gaming experience. Then their emotional
222 state was assessed for the first time through their responses to the PANAS questionnaire. Next,
223 they read their instructions, which informed them that they were about to explore a virtual polder
224 landscape for about 10 minutes, after which they would be asked to draw a map of the entire
225 area, including the off-the-road parts. Participants in the fictitious assignment conditions were
226 also asked to take part in a follow-up task, which involved a visit to the hypothetical real area
227 corresponding to the simulation, either in daytime or at night. They were told that they would not
228 receive any assistance during that visit, and that they would have to rely on their previous
229 experience in the VE to perform the real world exploration task. Directly after reading their

230 instructions the participants self-reported their current emotional state for the first time using the
231 SAM. Then, the participants explored the VE for 10 minutes. Afterwards, they filled out the
232 affective appraisal questionnaire, followed by the SAM and the PANAS (both for the second
233 time), and the IPQ presence questionnaire. Next, all participants drew a map of the virtual
234 environment. After drawing the map, they could give their comments about the experiment in
235 response to an open question. During a debriefing at the end of the experiment the experimenter
236 informed the participants about the real purpose of the experiment and asked them not to
237 communicate this to future participants. The total duration of the experiment was about 35 min
238 for each participant.
239

Materials

240

The virtual environment

241

242 The VE used in this study represents a prototypical Dutch polder landscape with some scattered
243 houses, low-lying tracts of grasslands enclosed by dikes, roads, railway tracks, canals, and levees
244 (see Fig.2). It was originally developed as a training tool for levee patrollers by GeoDelft (now
245 Deltares: www.deltares.nl) and Delft University of Technology, using the Unreal Engine 2
246 Runtime game engine (for full rendering details see: Harteveld et al., 2007). The simulation
247 contains no people; only some birds flying around and several sheep in one of the grasslands. A
248 soundtrack (representing wind and breaking waves) and visual dynamics (e.g., waving trees,
249 water waves etc.) serves to enhance the realism and immersiveness of the simulation (Houtkamp,
250 Schuurink & Toet, 2008). In the daytime condition the environment is lit by the sun. In the
251 nighttime condition streetlights along the roads and stars in the partly clouded sky provide the
252 only illumination. We selected this environment since it is known that feelings of safety and
253 human behavior vary most strongly with lighting levels in settings with low entrapment (access
254 to refuge) and low concealment (open space; Blöbaum & Hunecke, 2005).
255

Set-up

256

257 The simulation was performed on a Dell OptiPlex 755 desktop computer (www.dell.com)
258 equipped with an Intel Core 2 Duo CPU, running at 2.99 Ghz, 1.96 GB RAM, a NVIDIA
259 GeForce 8800GT graphics card (www.nvidia.com), and a standard mouse and keyboard. The
260 simulated environment was displayed on a 22″ Dell E228WFP Flat Panel Color monitor. Sound
261 was provided through an Altec Lansing ADA215 speaker set (www.alteclansing.com). The
262 sound level was such that the sounds of the simulation were clearly audible and at a realistic
263 level.
264

265 The entire set-up was placed in an artificially illuminated room. The windows were covered to
266 block the sunlight. The lights were on (about 400 lux horizontal illumination) when the
267 participants answered questionnaires or navigated through the daytime virtual environment. The
268 lights were turned off (resulting in a dimly lit room with less than 100 lux horizontal
269 illumination) when the participants navigated through the nighttime virtual environment. Since
270 the lower light level was within the mesopic range - similar to most real world night-time
271 outdoor scenes - the adaptation periods between both light levels was in the order of seconds

272 (about 10 s: see Adrian & Flemming, 1991). Monitor settings were kept constant throughout the
273 experiment.
274
275 Participants were comfortably seated at a distance of about 60 cm in front of the monitor. They
276 used the mouse and keyboard to navigate through the VE. The experimenter was seated behind a
277 second display placed on a desk at the other side of the room to the left side of the participant,
278 where he could unobtrusively monitor the participant's actions.
279

280 *Map drawing*

281 At the start of the experiment the participants were informed that they were required to draw a
282 map of the simulated area after completing their virtual walking tour. This instruction served to
283 stimulate the participants to actively explore most of the simulated area, so that they would not
284 linger in one part. In addition, it served to confirm the fictitious follow-up assignment: the
285 participants in that group were led to believe that they would be allowed to use the map they had
286 drawn based on their exploration of the VE to find their way in the corresponding real
287 environment at a later stage. The maps the participants produced were not further analyzed in
288 this study.
289

290 # Measures
291
292 This section briefly presents the questionnaires that were used in this study.
293
294 Experimental measures were questionnaires that measured respectively the participants' affective
295 appraisal of the VE and their affective responses (emotions and mood). Questionnaires that
296 measured respectively the participants' fear of darkness in real life, their sense of presence in the
297 VE, and their game and navigation experience, served as control measures.
298
299 For full details of these questionnaires see the Supplemental Information accompanying this
300 paper.
301

302 *Experimental measures*

303 *Affective appraisal*
304 To assess whether different degrees of lighting and personal relevance influenced the affective
305 appraisal of the VE we applied a subset of the 38 adjectives from a differential rating scale that
306 was designed to assess the perceived atmosphere of built environments (Vogels, 2008a). In this
307 context atmosphere is defined as the affective evaluation of the environment. Atmosphere gives
308 information about the expected effect of the environment on people's affective state (Vogels,
309 2008b). The 11 selected terms represent each of its four principal affective dimensions (Vogels,
310 2008a): *Cosyness* (*Cosy, intimate, safe*; in Dutch: *behaaglijk, intiem, veilig*), *Liveliness* (*lively,*
311 *inspiring, stimulating*; in Dutch: *levendig, inspirerend, stimulerend*), *Tenseness* (*tense, terrifying,*
312 *threatening;* in Dutch: *gespannen, beangstigend, bedreigend*), and *Detachment* (*business,*

313   *formal*; in Dutch: *zakelijk, formeel*). Each term was scored on a 7-point rating scale (-3 = *not at*
314   *all*, 3= *very much*).
315

316   *Emotional response*
317   We measured the participants' emotional response to the announcement of the fictitious follow-
318   up task and to the experience of the VE, to assess whether these events influenced their affective
319   state. Emotions are transient, relatively short lasting states of feeling, that are usually caused by
320   the appraisal of the relevance of specific event or environment for personal well-being: the more
321   relevant an environment or event, the more emotive it can be. The participants self-reported their
322   momentary feelings of pleasure, arousal and dominance using a validated 9-point pictorial rating
323   scale (the Self-Assessment Manikin or SAM: Bradley & Lang, 1994). The SAM provides a
324   simple, fast, and non-linguistic way of assessing emotional state along the principal emotional
325   dimensions of Valence, Arousal and Dominance (Mehrabian & Russell, 1974), and is therefore
326   highly suitable to measure transient (short term) emotional states. The SAM was developed by
327   Lang (1980) as an efficient alternative to the Semantic Differential Scale created by Mehrabian
328   and Russell (1974). In this study the SAM was applied twice: once just after the participants had
329   read their assignment and before they started their tour through the virtual environment (to
330   measure their emotional state directly after reading the task assignment), and once after they
331   completed their virtual tour. This test served to check whether participants with a fictitious
332   follow-up assignment (i.e., participants who believed they had to explore a similar real
333   environment at a later stage) experienced emotions that were different from those experienced by
334   participants who performed the experiment without this assignment.
335

336   *Mood*
337   Light and dark environments may induce different moods (a mood is a longer lasting affective
338   state that can not necessarily directly be linked to a discrete stimulus or event). Mood was
339   measured through self-assessment using a validated Dutch translation of the Positive and
340   Negative Affect Scale (PANAS: Watson, Clark & Tellegen, 1988; for the translation see:
341   Engelen et al., 2006; Peeters, Ponds & Vermeeren, 1996). This is a list of 20 adjectives used to
342   describe different emotional states: 10 states of Positive Affect (PA) and 10 states of Negative
343   Affect (NA). The PA scale measures activity and pleasure, while the NA scale relates to fear and
344   stress. A high PA is a state of high energy, full concentration and pleasurable engagement
345   whereas low PA is characterized by sadness and lethargy. The NA dimension is the degree of
346   distress and unpleasant engagement. High NA implies anger, disgust, guilt, fear and nervousness
347   while low NA implies calmness and serenity (Watson, Clark & Tellegen, 1988). Because of its
348   length (and in contrast to the SAM) the PANAS is more suitable to measure longer lasting
349   emotional states (moods). Participants scored the extent to which they experienced each
350   emotional state on a 5-point unipolar rating scale (1= *not at all or very slightly, 5= extremely*).
351

352   *Presence*
353   In the context of simulation and gaming the term 'presence' usually refers to the subjective
354   experience of 'being there' in the mediated environment (Schuemie et al., 2001; Slater & Wilbur,
355   1997). It appears that participants experience a higher sense of presence in a VE when they are

356 emotionally affected by it (Baños et al., 2004a; Baños et al., 2004b; Baños et al., 2006; Baños et
357 al., 2008; Gorini et al., 2011; Riva et al., 2007); for a recent review see: Diemer et al., 2015). It
358 has also been observed that a VE scenario more effectively induces emotions when it has
359 personal relevance (Baños et al., 2004a; Freeman et al., 2005). To assess whether the fictitious
360 follow-up assignment (personal relevance) enhances feelings of presence, we used the Dutch
361 translation of the Igroup Presence Questionnaire (IPQ, downloaded from
362 http://www.igroup.org/pq/ipq; see Schubert, Friedmann & Regenbrecht, 2001). The IPQ contains
363 14 questions that are scored on a bipolar 7-point rating scale. These items load respectively on
364 the factors Spatial Presence (SPR), Involvement (INV) and Realness (REA).
365

366 ***Control measures***

367 *Fear of darkness in the real world*
368 Simulated darkness in a VE is probably more likely to affect someone who is also affected by
369 darkness in the real world. In the real world cues like darkness (day/night), novelty
370 (familiar/unfamiliar) and lack of social presence are known to evoke fear of victimization and
371 determine navigation behavior, especially in women (Fisher & Nasar, 1992; Warr, 1984; Warr,
372 1990). To check if our female volunteers also felt less comfortable in darkness in real life (and
373 are therefore comparable on this aspect to populations observed in previous studies in the
374 literature), we tested their susceptibility to each of these cues by scoring eight statements (*I'm*
375 *very well able to find my way / in an unfamiliar environment / in a familiar environment at night*
376 */ in an unfamiliar environment at night; I can orientate very well / in the dark / in daytime; I*
377 *dare to walk by myself in an unfamiliar environment / at night / in daytime; I feel uncomfortable*
378 *in the dark*) on a 7-point bipolar rating scale (-3 = *strongly disagree*, 3= *strongly agree*), prior to
379 the main experiment.
380
381

382 *Game and navigation experience*
383 Problems with navigation can degrade the perceived realism of a simulation (IJsselsteijn et al.,
384 2000). Since frequent game players probably have acquired higher levels of navigation
385 proficiency, the navigation through the VE may require less of their attention so that they may
386 achieve higher levels of presence. To control for this effect we measured game experience by
387 two questions ("*How frequently do you play 3D computer games?*" and "*How frequently do you*
388 *use other virtual environments (e.g., Second Life)?*"), using a 5-point unipolar rating scale
389 (1=*never, 5= very often*). In addition, the extent to which navigation in the present simulation
390 required attention and interfered with task performance was measured after the exploration of the
391 VE by two questions ("*Did you need your attention to navigate*?" and "*Did the navigation*
392 *control hinder your task performance in the virtual environment*?") using a 5-point unipolar
393 rating scale (1= *not at all, 5= very much*).
394

395 *Open question*
396 The experiment ended with the question whether the participant had any comments about the
397 experiment.

398
399

Data collection and analysis

401 A web-based survey tool (http://www.surveymonkey.com) was used to apply all measures used
402 in this study. The answers were stored online and were later uploaded for further analysis. All
403 statistical analyses were performed with IBM SPSS 22.0 for Windows (www.ibm.com). For all
404 analyses a probability level of $p < .05$ was considered to be statistically significant.
405

407

RESULTS

Effects of personal relevance on environmental appraisal

410
411 The results of the affective appraisal questionnaire are listed in Table 1. The *Cosiness* of the
412 daylight representation of the VE was rated above neutral for all conditions. In contrast, the
413 nighttime VE was rated mostly negative or near neutral on *Cosiness*.
414
415 The data contained no outliers (from visual inspection of boxplots of the data) and the
416 assumptions of normality (verified by a Shapiro-Wilk test) and sphericity (verified by Levene's
417 test) were satisfied. We therefore performed a two-way independent ANOVA to assess the
418 effects of lighting and follow-up assignment (personal relevance) on the appraisal of the
419 environment.
420
421 The two-way independent ANOVA showed a main effect of ambient lighting on both *Cosiness*
422 and *Tenseness*. *Cosiness* was rated significantly lower for the nighttime environment than for its
423 daytime equivalent ($F(1,66) = 10.90$, $p= .002$, partial $\eta^2= 0.142$), while the factor *Tenseness* was
424 rated significantly more applicable to the nighttime VE than to its daytime counterpart ($F(1,66) =$
425 56.16, $p< .001$, partial $\eta^2=0.460$). This result confirms our assumption that the nighttime VE is
426 indeed appraised more negatively in simulated darkness than in simulated daylight, and agrees
427 with previous findings in the literature that desktop simulations of outdoor nightscapes are
428 typically appraised as less pleasant and more frightening than their daytime counterparts.
429
430 The two-way independent ANOVA showed that the fictitious nighttime follow-up task in the
431 real world had a small but significant effect on *Cosiness* for the nighttime VE ($F(1,22) = 4.381$,
432 $p= .048$, partial $\eta^2= 0.166$). Contrary to our hypothesis (H1a), the nighttime VE was appraised
433 as slightly more *Cosy* with a real world nighttime follow-up assignment compared to no
434 assignment. The fictitious nighttime follow-up task had no effect on the factor *Tenseness*
435 ($F(1,22) <1$, n.s.). Thus, our main hypothesis (H1) that participants who explored the nighttime
436 VE with the assignment to explore the corresponding real environment by night would rate the
437 VE as (H1a) less *Cosy* and (H1b) more *Tense* than participants without this assignment, is not
438 confirmed.
439
440 The two-way independent ANOVA also showed that the fictitious (either nighttime or daytime)
441 follow-up task in the real world also had no effect on both the *Cosiness* ratings and the *Tenseness*
442 ratings ($F(1,22)=3.687$, $p=.068$) for the daytime VE (in all cases: $F(1,22)<1$, n.s.).
443
444 The factor *Liveliness* was rated negatively in all conditions, while the factor *Detachment* was
445 rated consistently less than applicable to the VE in all conditions. A two-way independent
446 ANOVA revealed no significant effects of ambient lighting and the fictitious follow-up task on
447 these factors (in all cases: $F(1,22)<1$, n.s.).
448
449 Summarizing, the nighttime version of the VE was experienced as significantly less cosy and
450 more tense than its daytime equivalent. Apart from the (somewhat surprising) effect that the

451 nighttime VE was appraised as slightly more Cosy with a real world nighttime follow-up
452 assignment (compared to no assignment), we found no significant effects of a fictitious real-
453 world follow-up task on the affective appraisal of the VE.

454 **Effects of personal relevance on emotional response**

455 The factors *Pleasure*, *Arousal* and *Dominance* were rated using the SAM, just before the
456 participants started their exploration of the VE (T1) and afterwards (T2). The results are shown
457 in Table 2.

458
459 A Shapiro-Wilk test showed that the independent parameters (lighting condition and task) were
460 not normally distributed. We therefore used a non-parametric Kruskal-Wallis test to analyze the
461 results.

462
463 First we compared the *Pleasure* and *Arousal* ratings given by participants who explored the
464 nighttime VE with the fictional follow-up real world nighttime assignment to the ratings given
465 by participants without this follow-up task at T2 (just after explroing the VE). The results
466 indicate that neither the *Pleasure* ($\chi^2(1,22) = .986$, n.s.) nor the *Arousal* ($\chi^2(1,22) = .127$, n.s.)
467 ratings differ significantly between both groups. Thus, our hypothesis (H2) that participants who
468 explored the nighttime VE with the fictional follow-up real world nighttime assignment
469 experience (H2a) less *Pleasure* and (H2b) more *Arousal* than participants without this
470 assignment, is not confirmed.

471
472 Next, we compared the *Pleasure* and *Arousal* ratings between the groups who respectively
473 explored the nighttime and the daytime VE. Participants who explored the nighttime VE showed
474 both a significantly larger increase in *Arousal* (the difference between the measurements at T1
475 and T2: $\chi^2(1,44) = 4.989$, p=.027, $\eta^2=0.07$) and a higher level of *Arousal* just after experiencing
476 the VE (at T2: $\chi^2(1,44) = 7.457$, p=.006, $\eta^2=0.11$) compared to participants who explored the
477 daytime VE. No significant effect was observed for *Pleasure*. Hence, this result only partly
478 agrees with previous findings in the literature that desktop simulations of outdoor nightscapes are
479 appraised as less pleasant and more frightening than their daytime counterparts.

480
481 There were no significant differences between the SAM parameters in any of the other
482 experimental conditions.

483
484 Summarizing, simulated darkness makes our VE more arousing. However, we found no effects
485 of a fictitious real-world follow-up task on the emotional response to the VE.

486

487 **Effects of personal relevance on mood**

488 The emotional state of the participants was measured twice with the Positive and Negative Affect
489 Scale (PANAS): once before the participants had read their instructions (T1) and once after they
490 finished their exploration of the VE (T2). The results are listed in Table 3.

491
492 We quantified a mood change as the difference between the PA (Positive Affect) and NA
493 (Negative Affect) ratings obtained at respectively T1 and T2, and represented them by the
494 variables PADIFF = PA(T2) - PA(T1) and NADIFF = NA(T2) - NA(T1). The assumptions of

495   normality (verified by a Shapiro-Wilk test) and sphericity (verified by Levene's test) were
496   satisfied for the variables PADIFF and NADIFF.
497
498   First we investigated whether the experience of a dark VE affects mood. A one-sample t-test
499   showed that there was no significant difference between both the PA and the NA ratings
500   obtained at respectively T1 and T2 for participants who explored the nighttime VE without an
501   additional assignment (i.e., both PADIFF and NADIFF did not differ significantly from zero:
502   NADIFF t(11)=.789; n.s. PADIFF t(11)=-.722; n.s.). Thus, it appears that the exploration of the
503   dark VE did not affect the mood of the participants.
504
505   Next we investigated whether ambient darkness in the VE in combination with personal
506   relevance affects mood. We thereto compared the PADIFF and NADIFF measures between
507   participants who explored the nighttime VE with the fictional follow-up real world nighttime
508   assignment to the ratings given by participants without this follow-up task. The results indicate
509   that neither the PADIFF (F(1,22)<1.872, n.s.) nor NADIFF (F(1,22)<1, n.s.) measures differ
510   significantly between both groups. Thus, our hypothesis (H3) that participants who explored the
511   nighttime VE with the fictional follow-up real world nighttime assignment experience (H3a) a
512   larger decrease in *Positive Affect* and (H3b) a larger increase in *Negative Affect* than participants
513   without this information, is not confirmed by the present results.
514
515   Summarizing, we found no effects of a fictitious real-world follow-up task on the emotional state
516   of the participants.
517

518   **Effects of personal relevance on presence**
519
520   Table 4 lists the ratings for each of the factors on the IPQ questionnaire. The reliability of each
521   IPQ factor except GPR (*General Presence*, which consists of only a single item) was tested by
522   calculating the Cronbach's alpha. SPR (*Spatial Presence*) has a good internal consistency (α =
523   0.80 for 5 items). The factor INV (*Involvement*) has a lower but still quite acceptable consistency
524   (α = 0.72 for 4 items). The factor REA (*Realism*) has a low reliability (α = 0.45 for 4 items).
525
526   All factors except REA score mostly moderately positive (i.e., slightly higher than the neutral
527   score). Since there were no outliers and since the assumptions of normality and homogeneity
528   were satisfied we used a two-way ANOVA to further analyze the results from the IPQ. The
529   analysis shows that participants with a follow-up assignment in the real world did not experience
530   a significantly different level of GPR, SPR, INV or REA (F(1,70)<1, n.s.) than participants
531   without such an assignment. Thus, our hypothesis (H4) that participants with a real world follow-
532   up assignment experience a higher degree of presence in the VE than participants without this
533   information is not confirmed by the present results.
534
535   Summarizing, the participants experienced only a minimal degree of presence and involvement
536   in most conditions, while the perceived realism of the simulation was somewhat less than
537   neutral. We found no effects of a fictitious real-world follow-up task on the degree of presence
538   experienced by the participants.
539

540 **Fear of darkness in the real world**
541 The results listed in Table 5 show that the participants report that in real life they are typically
542 less at ease at night than in daytime. At night they report to be less proficient at finding their way
543 in an unfamiliar environment than in a familiar environment (2nd and 3rd statement). They claim
544 that their orientation capability is better in daytime than in the dark (4th and 5th statement). When
545 walking alone in an unfamiliar real environment they are more afraid in darkness than in daytime
546 (6th and 7th statement). These findings agree with previous reports that young females are
547 typically more afraid in the dark when they are alone and in an unfamiliar environment (Warr,
548 1990). Hence, the participants in this study are comparable to populations used in earlier studies
549 in the sense that they feel less comfortable in darkness in real life.
550
551 A Shapiro-Wilk test showed that the independent parameters (lighting condition and task) were
552 not normally distributed. We therefore used a non-parametric Kruskal-Wallis test to analyze the
553 results. The results showed that there were no significant differences between each of the size
554 experimental groups on any of the eight statements used to measure fear of darkness in the real
555 world. This implies that the participants were appropriately randomized over the experimental
556 conditions with respect to their fear of darkness in the real world.
557

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

566

CONCLUSIONS AND DISCUSSION

This study investigated whether increased personal relevance of a desktop VE (induced through a fictitious assignment to visit the corresponding real world environment at night) enhances the negative appraisal of the nighttime VE (H1), intensifies both short term (emotions; H2) and longer lasting (mood; H3) negative affective feelings, and enhances the experienced degree of presence in the VE (H4).

In agreement with previous studies we found that simulated darkness does indeed negatively influence the affective appraisal of a desktop virtual environment: our nighttime version of the VE was experienced as significantly less cosy and more tense than its daytime counterpart. Simulated darkness also made the VE more arousing. However, we found no indications that personal relevance of the simulation intensifies these effects. Also, in general we found no effect of personal relevance on respectively the affective appraisal of the VE, short term or longer lasting affective feelings of the participants, and the degree of presence that participants experienced in the VE. Thus, the present results did not confirm any of our four hypotheses. Our finding that the nighttime VE was appraised as slightly more *Cosy* with a real world nighttime follow-up assignment compared to no assignment is rather unexpected and contrary to our expectations (hypothesis (H1a). Maybe the follow-up assignment stimulated the participants to perform a more detailed inspection of the VE which may have resulted in the impression that the dark environment was probably not so frightening as it appeared during an initial or more superficial inspection.

It seems that darkness has only a small effect on the affective appraisal of an outdoor nighttime scene simulated on a desktop system. This is in contrast to the effects that are typically reported in the literature for similar real world environments. This limits the value of desktop VEs as tools to assess and evaluate the effects of ambient lighting on human feelings of fear. Further research comparing human behavior in - and affective response to - real environments and their virtual counterparts in different lighting conditions is required to establish the reasons for this discrepancy. 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. For example, some parts of the real world may be difficult or even dangerous to access during darkness. In addition, dynamic environmental elements like moving traffic, clouds, birds and water movement can influence the affective qualities of the scenes, and give them different meanings to different individuals and groups (Houtkamp, 2012).

Limitations of the present study

This study has the following limitations.

The size of the experimental sample was limited. However, from an applied point of view, effects that do not reach significance with group sizes in the order of 10 or more participants are of limited applied relevance, especially when desktop VE's are used to evaluate situations with personal relevance.

610
611 One issue concerns the sensitivity of the instruments that are currently available to measure the
612 affective appraisal of environments (e.g., such as the pleasure-arousal scales of Russell & Pratt,
613 1980 and the atmosphere metrics of Vogels, 2008a, that were used in this study). While these
614 instruments cover all aspects known to determine the emotional response to environments, they
615 do not appear sensitive enough to distinguish responses to subtle effects or differences in the
616 appraisal of environments (especially virtual environments: Houtkamp, 2012). Hence, these
617 scales require further refinement to make them suitable to assess the validity of virtual
618 environments for visualization purposes.
619
620 The degrees of presence and involvement experienced by the participants in this study were
621 rather low. There may be several reasons for this finding. First, the perceived realism of the
622 simulation was somewhat less than neutral, which may have diminished the participants' sense
623 of presence. In addition, the virtual environment represented a low level of entrapment and
624 concealment, and therefore may not have been potent enough to induce strong affective feelings,
625 even in darkness. Finally, most participants did not have much game and navigation proficiency.
626 As a result, their navigation through the VE may have required additional cognitive resources
627 and may have distracted their attention from the VE, thus preventing them from achieving a
628 stronger sense of presence (de Kort et al., 2003).
629
630 The presence of the experimenter may have had a reassuring effect (social presence) on the
631 participants, thus limiting any possible negative emotional effect of the VE. In addition, it may
632 have distracted the participants from their task, thereby reducing their sense of presence.
633
634 Maybe the participants where not really convinced that they had to perform a follow-up
635 assignment. The fact that there was no difference observed for the SAM ratings at T1 between
636 participants who did and those who did not receive a follow-up assignment suggests that this
637 information did not cause significant concern. Future studies should make the follow-up
638 assignment more believable to achieve the expected effects, and should include a manipulation
639 check to ask participants how convinced they actually were about the task.
640
641 All experiments in this study were performed during daytime. The participants navigated the
642 nighttime virtual environment in a room that was darkened by covering the windows and turning
643 off the light. A recent study investigating the effects of 'night' and 'darkness' on feelings of fear
644 found that the effect of fear stimuli is modulated by the actual time of day (circadian or day–
645 night cycle): fear-provoking stimuli trigger more intense responses in the nighttime condition
646 than in the equivalent daytime condition (Li et al., 2015). Thus, it seems that night amplifies fear
647 signals and increases fear responses. This facilitation of nighttime threat responses may reflect an
648 evolutionarily adaptive mechanism for an efficient processing of threat-related stimuli to avoid
649 danger. Although the size of this effect is only small to medium, a replication of the current
650 study in nighttime conditions might amplify the present results. To obtain ecologically valid
651 results future simulation studies should therefore take the day-night cycle into account by
652 performing measurements during a timeframe that corresponds to the simulated time of day (i.e.,
653 synchronize actual and simulated time by presenting simulated nighttime conditions at night and
654 simulated daytime conditions during the day).
655

656

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660

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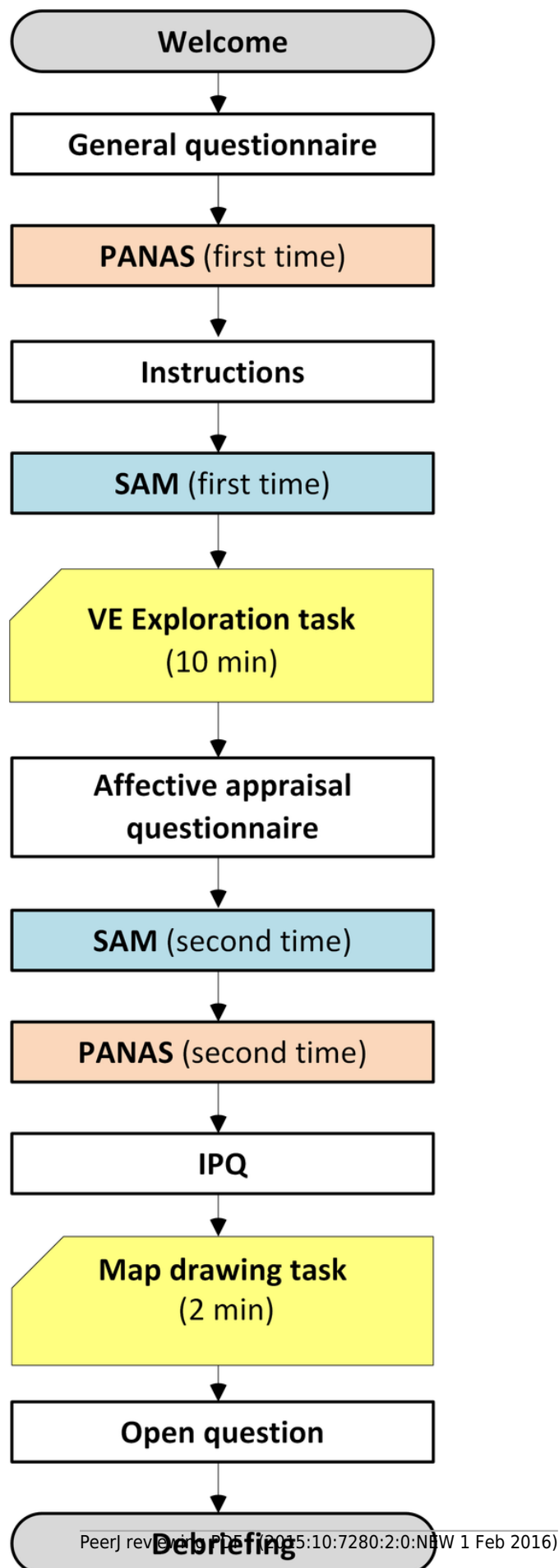
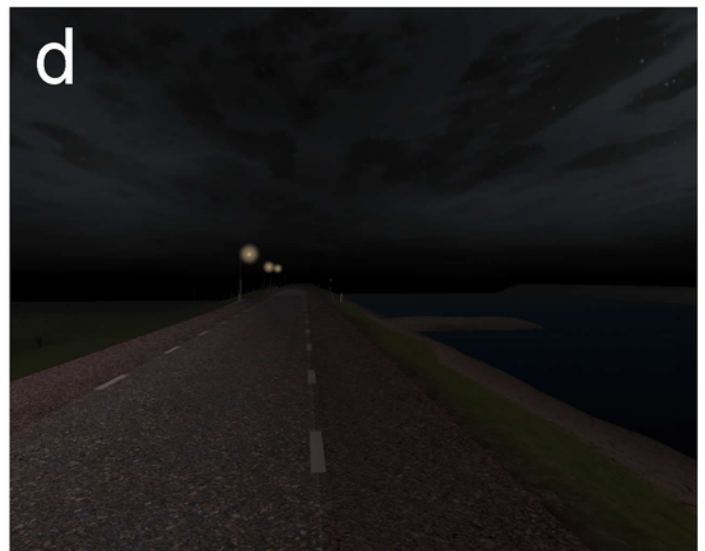
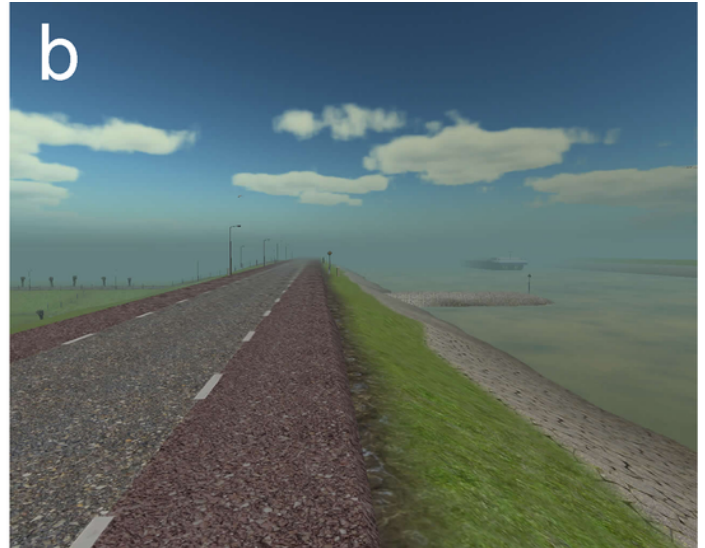
874

1

Timeline of the experimental procedure.

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

Affective appraisal of the VE in terms of *Cozyness*, *Liveliness*, *Tenseness* and *Detachment*.

Appraisals given by participants who explored either a daytime or nighttime 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.

2

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

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

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

2

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

The mean and standard deviation of the ratings on the PANAS positive and negative affect scales.

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

2

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

The mean and standard deviation of the ratings on the Igroup Presence Questionnaire (IPQ).

Simulated lighting	Fictitious task	GPR		SPR		INV		REA	
		M	SD	M	SD	M	SD	M	SD
Daylight	No task	0.83	1.47	0.35	0.95	0.54	1.26	-0.33	0.76
	Daylight	0.58	1.56	0.48	0.99	0.58	1.01	-0.29	0.77
	Darkness	1.42	1.38	0.63	1.22	0.35	1.36	-0.4	1.07
Darkness	No task	1.17	1.19	0.78	0.97	0.58	0.96	0.02	0.70
	Darkness	0.42	1.44	0.62	1.16	-0.15	1.19	-0.25	0.93
	Daylight	1.00	0.95	0.97	0.90	1.00	0.78	-0.1	0.88

Results of the navigation and orientation questionnaire.

2

5

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