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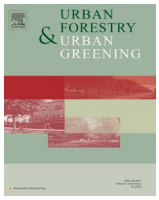

Is virtual reality a valid tool for restorative environments research?

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ABSTRACT

This study examines the validity of virtual reality for assessing the restorative quality of environments. In Study 1, participants ($N = 23$) visited a real natural and a real urban environment, after completing a task to induce mental fatigue (i.e., a Sudoku task). We found that perceived restorative characteristics, preference ratings, experienced pleasure and self-reported restoration were higher in a real natural environment compared to a real urban environment. Perceived restorative characteristics could predict pleasure and restoration for both the real natural and urban environments, as well as preference for the real natural environment. In Study 2, participants ($N = 26$) visited a virtual natural and a virtual urban environment, again following a mental fatigue induction. Findings showed that virtual simulations of a natural and urban environment elicit similar effects as real counterparts of these environments. Perceived restorative characteristics, preference, pleasure and restoration were higher in a virtual natural environment compared to a virtual urban environment. Additionally, perceived restorative characteristics could predict pleasure and restoration for both the virtual natural and urban environments, and preference for the virtual natural environment. We did not find significant differences in perceived restorative characteristics between the real and virtual butterfly garden. Moreover, similar restorative characteristics predicted preference, pleasure and restoration in the real butterfly garden and the virtual butterfly garden. These findings indicate that virtual reality can be a valid tool for restorative environments research.

1. Introduction

Our environment has a great impact on how we feel and behave. It is likely that a walk in a forest on a sunny autumn day will have a different effect than a walk in a crowded urban neighborhood. Insight in which factors influence how people experience different environments, and what kind of environments they prefer, can be very useful when designing or modifying environments. To understand how specific characteristics influence the way environments are experienced, ideally, researchers would systematically manipulate some characteristics in an environment while keeping all other factors in the environment constant. This level of control cannot be realized in real environments. Hence, suitable tools are needed to conduct such experiments. In this paper, we aim to examine if virtual reality can be a useful and valid tool for conducting controlled experiments. As a case in point, we study whether virtual reality can be a useful tool to study restorative environments, that is, environments that enable people to recover from mental fatigue and help people to replenish mental resources (Herzog et al., 1997; Berto, 2005; de Kort et al., 2006). Below, we first explain which factors affect the extent to which environments are restorative. Next, we explain virtual reality and why virtual reality can be useful for restorative environments research.

1.1. Restorative Environments

Research has shown that if we experience mental fatigue or stress, we benefit more from a walk in a natural environment compared to a walk in an urban environment. Nature provides opportunities for people to restore from mental fatigue (Hartig et al., 2003; Kaplan and Kaplan, 1989, and see also Joye and van den Berg, 2018) and psychological and physiological stress (Ulrich et al., 1991). People tend to experience more positive and less negative affect in nature compared to urban environments (Hartig et al., 1991, 2003). Furthermore, people tend to have a preference for natural environments over built environments (Laumann et al., 2003; Purcel et al., 2001) and urban environments are perceived to be more restorative when they include natural elements such as parks

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and gardens (Weber and Trojan, 2018). So, being in nature has three important positive outcomes: (1) restoration from stress or mental fatigue, (2) positive cognitive evaluations of the environment, and (3) positive affective responses. In the current paper we will refer to these outcomes as restoration, preference, and pleasure, respectively.

The Attention Restoration Theory (ART; Kaplan and Kaplan, 1989) proposed that the extent to which environments are restorative depends on perceived restorative characteristics. Extending previous research (Kaplan and Kaplan, 1989; Hartig et al., 1997; Laumann et al., 2001; Herzog et al., 2003; Bagot, 2004; Korpela and Hartig, 1996; Ivarsson and Hagerhall, 2008), Pals and colleagues distinguish five restorative characteristics that may contribute to outcomes of restoration, pleasure and preference, and thus explain why natural environments are more restorative than urban environments: fascination, novelty, escape, coherence, and compatibility[2] (Pals et al., 2009). First, natural environments are a source of fascination, which is defined as the degree to which one's attention is drawn effortlessly by objects in the environment such as flowers, animals, or waterfalls (Kaplan, 1995). As fascination requires no directed attention and as fascinated objects are processed effortlessly, one can restore from mental fatigue in fascinating environments. The second characteristic, novelty, means that the environment is new to someone or different than one's daily environment. For example, when you live and work in a city, a forest will be a relatively novel environment to you. The third characteristic, escape, implies being able to take your mind of unwanted distractions and reminders of your daily hassles and obligations, which will enhance restoration from mental fatigue. Coherence, the fourth characteristic, refers to the degree of coherence or harmony between all elements in the environment. Being in a harmonious and coherent environment is easy on the mind, hence restoration will more easily occur[3]. The final fifth characteristic, compatibility, is defined as the fit between the person and the environment. A setting is more restorative when it fits with what one aims at doing in that setting. In a compatible environment what the environment offers match with one's purpose of being there. As a result, activities are performed easily and effortlessly (Kaplan, 1995). While these restorative characteristics reflect different dimensions of restorative environments (Pals et al., 2009; Laumann et al., 2001), they are related to some extent. For instance, novelty and escape are related: when you are in a novel environment, there are probably less things that will remind you of your daily obligations, so you will be able to escape from stressful thoughts. Escape may also be related to fascination, because if your attention is spontaneously attracted, you are less likely to think about your daily hassles and obligations.

Research on restorative environments shows that fascination, novelty, escape, coherence, and compatibility can be experienced to various degrees in both natural and urban environments (e.g. monasteries, museums, or zoos; Kaplan et al., 1993; Ouellette et al., 2005; Pals et al., 2009; Annechini et al., 2020), while natural environments are generally more restorative than urban environments (Ulrich et al., 1991; Hartig et al., 2003; Menardo et al., 2019; Stigsdotter et al., 2017). Interestingly, it has not yet been systematically studied which physical factors make a particular environment more restorative than another environment. Most studies on restorative environments compare environments that differ from one another on a great number of aspects. Typically, a natural area is compared to an urban area, meaning that the environments vary on many different physical features (see for instance Ulrich et al., 1991; Hartig et al., 2003). Hence, many physical features vary at the same time, making it practically impossible to disentangle their effects on indicators of restorativeness. The few studies focusing on the effects of certain physical features in an environment mostly employed photographs or descriptions of natural environments in assessing if and how natural environments elicit outcomes of restoration, pleasure and preference (see Nordh et al., 2009, 2011). Findings from such studies provide initial insight on how specific physical features affect restorative quality of environments. For instance, it was found that the presence of elementary natural components like bushes, trees or grass enhances preference for these environments as well as their restorative quality more than decorative components like flowers and water fountains (Nordh et al., 2009, 2011). Yet, as these studies mostly used descriptions of natural environments or photographs, the question remains to what extent the effects could be generalized to real-life experiences.

Using photographs or descriptions of nature and urban environments allows for zooming into the effects of one characteristic but may lack external validity. Real-life observations are high in external validity but bear the disadvantage of lack of experimental control, making it difficult to conclude which physical features affect restoration. To get more insight into causal relationships between specific characteristics of environments, perceived restorative characteristics and outcomes on restoration, preference, and pleasure, research would need to systematically vary some characteristic in the environment while keeping all other factors constant in realistic settings. Due to recent technological developments, a research tool has become available to examine the effect of the physical environment on restorative characteristics and outcomes of restoration, pleasure and preference in a controlled way in settings that are more realistic than photo's or descriptions of environments: virtual reality.

1.2. Virtual reality

Virtual reality (VR) is an artificial environment generated by computer software, presented in such a way that the user is able to interact with the environment, which allows for a sense of presence. Virtual reality can be experienced in different ways. There are, for example, variations in displays (e.g. head-mounted displays, wrap-around screens; Kallioniemi et al., 2017) and variations in the number of senses that are stimulated (e.g. sight, sound, touch, and smell; see Nukarinen et al., 2022 for an overview). Head-tracking systems contribute to depth perception in virtual reality combined with the use of stereoscopic displays, thereby making the experience more realistic (Wu et al., 2019; Slater, 2009; Bowman and McMahan, 2007). The technical qualities of the virtual environment, such as the size of the screens and the resolution of actual screen, which are also referred to as immersive technology (Sanchez-Vives and Slater, 2005), contribute to the experience of virtual reality by inducing feelings of presence (de Kort et al., 2006; Sanchez-Vives and Slater, 2005; Slater and Wilbur, 1997; Slater, 1999; Bruun-Pedersen et al., 2016a, 2016b). Notably, the sense of presence or 'being there' in virtual environments may influence the way people experience these environments (de Kort et al., 2006). A more realistic experience in the virtual environment would elicit a strong feeling of presence, even though people may be well aware of the fact that the environment is not real (de Kort and IJsselsteijn, 2006; Sanchez-Vives and Slater, 2005; Newman et al., 2022). VR offers great

[2] Kaplan and Kaplan (1989) have distinguished four restorative characteristics. Notably, they combined novelty (physical component of being-away) and escape (psychological component of being away) into one characteristic, 'being-away'. Following Laumann and colleagues (2001) and Pals and colleagues (2009), we propose that it is theoretically relevant to distinguish the physical component (novelty: being in different setting than usual), and the psychological component (escape: being able to escape from unwanted distractions and reminders of your daily obligations) of being away as two separate restorative characteristics. Research provided first empirical support for this distinction (Laumann et al., 2001; Pals et al., 2009), indicating that the distinction between the two being away components (i.e., novelty and escape) is empirically relevant too.

[3] Kaplan and Kaplan (1989) defined this component as 'extent', which reflected coherence as well as scope (referring to the scale of the environment, including the imagined or out of sight aspects). Following previous investigations (see Laumann et al., 2001; Hartig et al., 1997; Pals et al., 2009) we narrow down to the definition of extent to coherence (leaving out scope), referring to the degree of coherence between elements in the environment, and how well all elements go together.

opportunities and applications as a research tool as it may create realistic experiences of being present in another context while being immersed with a virtual environment. One application of virtual environments involves testing the effect of virtual natural environments on health and well-being (Bruun-Pedersen et al., 2016a, 2016b; Depledge et al., 2011; Yu et al., 2018; Frost et al., 2022), following from the premise that nature has a restorative function (Kaplan, 1995; Herzog et al., 2003). Such studies revealed important insights on factors predicting preferences for different natural environments or recreational potential of certain natural environments (Bruun-Pedersen et al., 2016a, 2016b; Depledge et al., 2011). But the question remains: Is VR a valid tool to study restorative environments?

To our knowledge, research on the validity of virtual reality as a tool in restorative environments research is scarce (Mattila et al., 2020; Browning et al., 2020; Bishop and Rohrmann, 2003; de Kort et al., 2003; Valtchanov et al., 2010). In one particular study, researchers compared responses to a virtual environment with responses to the real equivalent of this environment (de Kort et al., 2003). Findings revealed that evaluations for the real environment were generally more positive than evaluations for the virtual environment, probably because a lack of presence and immersion by the use of a single and small screen, thereby impairing the validity of virtual reality as a tool. Indeed, scholars mostly focused on disentangling which aspects of virtual reality would make it more realistic and therefore valid (e.g. technical qualities, feelings of presence), and rarely investigated if and why individuals experience similar levels of restoration, preference and pleasure in virtual and real environments. Virtual reality is particularly a relevant research tool when it would elicit similar responses as in real-life (Bishop and Rohrmann, 2003). As such, the validity of virtual reality is an important aspect to consider before it can be used in research on restorative environments.

1.3. Current study

The aim of the current study is to test the validity of virtual reality for assessing the restorative characteristics and the restorative quality of environments. We report results of two studies where we employ real and virtual environments of comparable natural and urban areas. We reason that virtual reality would be a valid tool, if we find the same pattern of differences in key variables when we compare real nature and urban environments versus virtual nature and urban environments.

Study 1 aimed to investigate the restorative characteristics and effects of restorative characteristics on restoration, pleasure and preference in real nature and urban environments. More specifically, in Study 1, we examined whether perceived restorative characteristics, and restoration, preference, and pleasure are higher in a real natural environment compared to a real urban environment. Second, we examined how the perceived restorative characteristics of both real environments are related to preference for these environments, pleasure, and restoration.

In Study 2 we examined whether perceived restorative characteristics, and restoration, preference, and pleasure in a virtual natural environment are higher than those of a virtual urban environment. Second, we examined how the perceived restorative characteristics of both virtual environments are related to preference for these environments, and pleasure and restoration in these environments.

Notably, we conclude that VR is a valid tool to study restorative environments if the following four hypotheses are supported. First, we reason that if real natural environments score higher on restorative characteristics and elicit stronger positive effects on preference, pleasure, and restoration than urban environments (Study 1), we should also find that virtual natural environments score higher on restorative characteristics and elicit more positive effects on preference, pleasure, and restoration than virtual urban environments (Study 2, Hypothesis 1). Second, one would expect that if restorative characteristics can predict preference, pleasure, and restoration for real environments (Study 1), restorative characteristics of virtual environments should also be able to predict preference, pleasure, and restoration for virtual environments (Study 2, Hypothesis 2). Third, we reason that there should be no differences in perceived restorative characteristics and evaluations for pleasure, preference and restoration for the real environment (Study 1) and its virtual equivalent (Study 2, Hypothesis 3). Fourth, we expected the same restorative characteristics to predict preference, pleasure and restoration for the real environment (Study 1) and its virtual equivalent (Study 2, Hypothesis 4).

2. Study 1

2.1. Method

2.1.1. Participants and design

Twenty-three students participated in Study 1 (9 men, 14 women; mean age 20.39; range 17–27 years). Monetary compensation was provided. The experiment had a within-subjects design with two environmental conditions: a butterfly garden (natural environment) and a shopping centre (urban environment). Because of the within-subjects design of the study, we scheduled two sessions for each participant; the time scheduled between two sessions varied from 1 to 12 days. We counterbalanced whether participants first went for a walk in the butterfly garden or the shopping centre, and participants were randomly assigned to each order condition[4]. Fourteen participants first went to the butterfly garden, 9 participants saw the shopping centre first.

2.1.2. Environments

The study took place in Emmen, a medium sized city in the north of the Netherlands. The natural environment was a human-made natural environment, namely the butterfly garden in Emmen Zoo (Fig. 1). The butterfly garden is a tropical greenhouse of approximately 1200 square meters. In the garden there are several pathways, a bridge, a pond, a small waterfall, benches, tropical plants, and about 1600 butterflies in various colors and sizes. Some other animals in the butterfly garden are hummingbirds, quails and tree frogs. A previous study found that this butterfly garden indeed scored high on perceived restorative charac-

Fig. 1. The butterfly garden (Study 1).

[4] Both in Study 1 and Study 2 we included order as a between subjects variable to rule out order effects. Order was not significant, so we will only discuss the main effects of the environmental conditions.

teristics (Pals et al., 2009). We compared the butterfly garden with an indoor shopping centre (see Fig. 2), to keep weather conditions between the two environmental conditions constant. The shopping centre is wind- and water-proof, giving it a comfortable temperature. There are 65 shops in the shopping centre and a square with benches in the middle of the centre. There were no natural elements in the indoor shopping center.

2.1.3. Procedure

The participants were welcomed in an office building of Emmen Zoo. Participants were told that we were interested in people's experiences of different environments. We did not tell participants anything about our expectations or the goal of the study, in order not to influence their responses. Upon arrival participants filled out an informed consent form. To make sure that all participants had comparable levels of mental fatigue, and therefore, a relatively similar need for restoration (Hartig and Staats, 2006), we induced mental fatigue in all participants with a Sudoku task. The participants were told that they had to solve as many Sudoku puzzles as possible within 50 min. Eight puzzles with four difficulty levels were available. Participants could choose which puzzle they wanted to try to solve. For every solved puzzle the participants could earn points; 1 point for easy puzzles, 3 points for medium puzzles, and 5 points for hard puzzles. Participants were told that the person with the highest number of points could win a VIP ticket to Emmen Zoo. By introducing such competition, we aimed at ensuring that participants would try to solve as many puzzles as possible in the given time, and that they would aim at solving the most difficult ones within their level of preference. After the Sudoku task, the participants were taken to the butterfly garden or the shopping centre.

To get from the starting position to the shopping centre, participants had to walk approximately 200 m. They crossed a cycle path and walked through a pedestrian area. To get to the starting position to the butterfly garden, participants had to walk approximately 100 m, passing through a pedestrian area as well as the zoo entrance. The butterfly garden is located near the zoo entrance, so the participants did not see any other exhibits on their walk to the butterfly garden. The participants were asked to walk through the environment (butterfly garden or shopping centre) at their own pace, and were asked to sit down and look at the surroundings at specific moments. The total time they spent in each environment was 50 min. After the walk the participants were taken back to the office where they filled out a questionnaire comprising the dependent measures. Prior to data collecting, the procedure has been reviewed by an Ethical Review Board of our University, in line with the rules of Dutch Ethical Conduct.

Fig. 2. The shopping centre (Study 1).

2.2. Measures

2.2.1. Perceived restorative characteristics

The Perceived Restorative Characteristics Questionnaire (PRCQ; Pals et al., 2009, see Appendix) was used to measure four perceived restorative characteristics (fascination, novelty, escape, and coherence) of the butterfly garden and the shopping centre. We excluded the restorative characteristic compatibility both in Study 1 and Study 2, as compatibility involves individuals' motivations and inclinations (what one would like or is trying to do) in a certain environment. In a real environment there are more possibilities for different kinds of behavior compared to a virtual environment. In a real environment for example a person would be able to pick flowers, which would not be possible in a virtual environment. For this reason we argued that a comparison between compatibility in a real environment and a virtual simulation of that environment is difficult to make. All perceived restorative characteristics items were put in random order and directly referred to either the butterfly garden or the shopping centre. Scores could vary from 1 (totally disagree) to 7 (totally agree). Higher means indicated higher fascination, novelty, escape and coherence. The reliabilities of the fascination, novelty, and escape scales were good (Cronbach's alpha >0.71, see Table 1). The reliability of the coherence scale was acceptable for the evaluations of the butterfly garden (Cronbach's alpha $=0.70$), but lower when assessing coherence of the shopping centre (Cronbach's alpha $=0.54$). As the coherence scale was reliable in Study 2, as well as in earlier research (Pals et al., 2009), we decided to maintain the scale for further analyses. We computed mean scores of items included in each scale.

2.2.2. Preference, pleasure and restoration

We measured preference for the environments using four seven-point semantic differentials: "I find the butterfly garden" or "I find the shopping centre": unattractive – attractive, unpleasant – pleasant, negative – positive, and not enjoyable – enjoyable. Participants indicated on four seven-point semantic differential items to what extent they experienced pleasure as they were walking through the environment: sad - happy, annoyance - pleasure, dissatisfied - satisfied, bored – content (Mehrabian and Russell, 1974). Restoration was measured using self-report measures, based on work by Staats et al. (2003). The scale included 5 items, like "Being in the butterfly garden/ shopping centre was relaxing", "Being in the butterfly garden/ shopping centre renewed my energy level", and "After walking in the butterfly garden/ shopping centre I was able to concentrate better". All three scales were reliable for both environments (Cronbach's alpha >0.71, see Table 1).

2.3. Results

2.3.1. Evaluation of real natural environment (butterfly garden) versus real urban environment (shopping centre)

We carried out repeated measures analyses comparing scores on all perceived restorative characteristics, and perceived preference, pleasure and restoration in the real butterfly garden and the shopping centre (see Table 1). The butterfly garden scored significantly higher on fascination, novelty, escape and coherence as compared to the shopping centre. Effect sizes ranged from.24 to.68, indicating small to medium effect size (see Table 1). The effect size was highest for novelty ($\eta_p^2 = .68$) and lowest for coherence ($\eta_p^2 = .24$). In addition, scores on restoration, preference, and pleasure preference were higher for the butterfly garden compared to the shopping centre. As such, findings confirmed our expectation that all perceived restorative characteristics and perceived preference, pleasure and restoration were rated significantly higher for the butterfly garden than for the shopping centre.

2.3.2. Predicting preference, pleasure, and restoration for the real butterfly garden

Second, we examined to what extent the restorative characteristics

Table 1
Estimated means, standard deviation and Cronbach's alpha scores for restorative characteristics and effects on preference, pleasure, and restoration for the butterfly garden and the shopping centre (Study 1). Results of repeated measures for the differences in restorative characteristics and effects on preference, pleasure, and restoration between the butterfly garden and the shopping centre ($N = 23$).

		Real environments							
		Butterfly garden			Shopping centre				
	n items	α	*M*	*SD*	α	*M*	*SD*	*F* (1,21)	*ηp*2
Fascination	5	.87	5.20	1.26	.78	4.13	1.10	10.83**	.34
Novelty	4	.71	4.74	1.30	.71	3.08	1.01	44.68***	.68
Escape	3	.79	4.61	1.39	.87	3.49	1.37	10.79**	.34
Coherence	3	.70	5.42	.91	.54	4.69	.92	6.56*	.24
Preference	4	.89	5.83	.83	.71	4.98	.67	11.12**	.35
Pleasure	4	.82	5.32	.78	.91	4.43	1.00	13.11***	.38
Restoration	5	.81	4.74	1.01	.86	3.71	1.18	14.82***	.41

Note. Restorative Characteristics, Preference, Pleasure, and Restoration were rated on seven-point scales with high numbers indicating higher levels of the specific variable.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

were related to preference, pleasure and restoration for the butterfly garden; bivariate correlations are shown in Table 2, and results of the regression analyses in Table 3. All correlations we discuss are statistically significant at $p < .05$. For the regression analyses, we checked for the assumptions normality,[5] linear relationships, homoscedasticity and multicollinearity. VIF values were all below 10 and the tolerance values were above.2, indicating no multicollinearity.

Preference for the butterfly garden correlated positively with all restorative characteristics (fascination, novelty, escape, and coherence). Regression analysis showed that 74 % of the variance in preference for the butterfly garden could be explained by the perceived restorative characteristics (see Table 3). Higher escape ratings and higher coherence ratings were associated with higher preference ratings.

Pleasure only correlated significantly with escape (see Table 2). Regression analysis showed that 38 % of the variance in pleasure was accounted for by the perceived restorative characteristics of the butterfly garden; this model was marginally statistically significant (see Table 3). Higher escape ratings were associated with higher experienced pleasure.

Restoration correlated positively with fascination and escape (Table 2). Regression analysis showed that perceived restorative characteristics of the butterfly garden could predict 80 % of the variance in restoration (Table 3). Higher escape ratings were associated with more restoration after walking in the butterfly garden.

Table 2
Correlations between restorative characteristics and preference, pleasure, and restoration, with the real butterfly garden above the diagonal and the shopping centre below the diagonal (Study 1).

	Fas	Nov	Esc	Coh	Pref	Plsr	Rest
Fascination	–	.72**	.62**	.40	.75**	.39	.51*
Novelty	.42*	–	.30	.31	.57**	.21	.37
Escape	.00	.27	–	.23	.65**	.55**	.85**
Coherence	.04	-0.22	-0.07	–	.61**	.41	.38
Preference	.44*	.08	.17	.31	–	.70**	.58**
Pleasure	-0.12	.06	.63**	.08	.42*	–	.61**
Restoration	.35	.32	.74**	.01	.22	.46*	–

Note. Fas = Fascination; Nov = Novelty; Esc = Escape; Coh = Coherence; Pref = Preference; Plsr = Pleasure; Rest = Restoration.
* correlation is significant at the.05 level.
** correlation is significant at the.01 level.

[5] The assumption of normality was violated for the variable "Preference". We did a square root transformation and carried out the regression analysis with the transformed data. The pattern of results with the transformed data was similar to that of untransformed data. For ease of interpretation, we are reporting the statistics for "Preference" with untransformed data.

2.3.3. *Predicting preference, pleasure, and restoration for the shopping centre*

Third, we examined to what extent the restorative characteristics were related to preference, pleasure and restoration for the shopping centre; bivariate correlations are shown in Table 2, and results of the regression analyses in Table 4.

Preference for the shopping centre correlated positively with fascination. Regression analysis revealed that, although fascination was positively related to preference for the shopping centre, the overall model including all perceived restorative characteristics could not explain a significant proportion of the variance in preference for the shopping centre (see Table 4).

Pleasure correlated positively with escape (Table 2). Regression analysis showed that 43 % percent of the variance in pleasure experienced in the shopping centre could be explained by perceived restorative characteristics (see Table 4). Higher escape ratings were associated with experiencing more pleasure.

Besides, restoration correlated positively with escape (Table 2). Regression analysis showed that perceived restorative characteristics of the shopping centre could predict 68 % of the variance in restoration (Table 4). Higher fascination ratings and higher escape ratings were associated with more restoration.

2.4. *Conclusion*

In Study 1 we found that perceived restorative characteristics (fascination, novelty, escape, and coherence) were indeed higher in the natural environment (the butterfly garden) than in the urban environment (the shopping centre). The perceived restorative characteristics of the natural environment were good predictors of experienced preference, pleasure, and restoration in the natural environment. Also, the perceived restorative characteristics of the urban environment could predict experienced pleasure and restoration in that environment, but not preference for that environment. Especially escape appeared to be a good predictor of restoration in both environments.

3. Study 2

In Study 2 we aimed to examine whether we can have a similar pattern of results as in Study 1 in the virtual environments. First, we examined whether the virtual natural environment would score higher on restorative characteristics, as well as on preference, pleasure and

Table 3
Regression analyses for restorative characteristics on preference, pleasure, and restoration ($N = 23$) for of the real butterfly garden (Study 1).

			95 % Confidence interval for ß					
	ß	*t*	Lower bound	Upper bound	R^2	*df*	*F*	*p*
Dependent Variable: Preference								
Fascination	.26	1.16	-.21	.72				
Novelty	.17	.93	-.21	.54				
Escape	.36	2.27*	.03	.69				
Coherence	.37	2.81**	.09	.64				
					.74	4, 18	12.95	<0.001
Dependent Variable: Pleasure								
Fascination	-0.05	-0.14	-.77	.67				
Novelty	.00	.00	-.58	.58				
Escape	.50	2.07*	-.01	1.02				
Coherence	.31	1.52	-.12	.74				
					.38	4, 18	2.78	.06
Dependent Variable: Self reported Restoration								
Fascination	-0.35	-1.77	-.75	.07				
Novelty	.26	1.67	-.07	.59				
Escape	.93	6.74***	.64	1.22				
Coherence	.22	1.95	-.02	.47				
					.80	4, 18	18.10	<.001

* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 4
Regression analyses for restorative characteristics on preference, pleasure, and restoration ($N = 23$) of the shopping centre (Study 1).

			95 % Confidence interval for ß					
	ß	*t*	Lower bound	Upper bound	R^2	*df*	*F*	*p*
Dependent Variable: Preference								
Fascination	.48	2.22*	.03	.94				
Novelty	-0.13	-0.55	-0.61	.36				
Escape	.23	1.13	-0.20	.65				
Coherence	.28	1.40	-0.14	.70				
					.33	4, 18	2.20	.11
Dependent Variable: Pleasure								
Fascination	-0.11	-0.53	-0.53	.32				
Novelty	-0.04	-0.19	-0.49	.41				
Escape	.65	3.50**	.26	1.04				
Coherence	.13	.68	-0.26	.51				
					.43	4, 18	3.41	.03
Dependent Variable: Self reported Restoration								
Fascination	.36	2.42*	.05	.68				
Novelty	-0.03	-0.20	-0.37	.30				
Escape	.76	5.41***	.46	1.05				
Coherence	.04	.31	-0.25	.33				
					.68	4, 18	9.56	<0.001

* $p < .05$.
** $p < .01$.
*** $p < .001$.

restoration as compared to a virtual urban environment (Hypothesis 1). Second, we examined how the perceived restorative characteristics of both virtual environments are related to preference for the environments, pleasure, and restoration, in a similar way as in the real environments (Hypothesis 2). Third, we compared perceived restorative characteristics and restoration, preference, and pleasure of the real butterfly garden (Study 1) with those of the virtual butterfly garden (Study 2), and expected to find no differences between the restorative characteristics of the real and virtual butterfly garden (Hypothesis 3). Fourth, we expect that the same set of restorative characteristics would predict restoration, preference, and pleasure in the real (Study 1) and virtual (Study 2) butterfly gardens and real and virtual urban environments (Hypothesis 4).

3.1. Method

3.1.1. Participants and design

Twenty-six students (9 men, 17 women; mean age 19.5; range 18–23 years) participated in this study in exchange for course credits. The experiment had a within-subjects design with two environmental conditions: a virtual butterfly garden and a virtual urban neighborhood. Because of the within-subjects design of the study, participants had to come to the virtual reality centre for two sessions. The time scheduled between two sessions varied from 1 to 12 days. We counterbalanced the

order in which participants were exposed to either the virtual butterfly garden or to the virtual urban neighborhood, and participants were randomly assigned to each order condition. Fifteen participants first saw the virtual butterfly garden, 11 participants first saw the urban neighborhood.

3.1.2. The CAVE automatic virtual environment

Study 2 took place in the Cave Automatic Virtual Environment (CAVE, for a detailed description of the CAVE see Cruz-Neira et al., 1992; Cruz-Neira et al., 1993). The CAVE is a half-open cube with 2.5 m long edges, which has a stereo sound system. The stereo sound system did not have directional controls, and the sound simply stayed where it was as the user rotated their view. Three dimensional images were projected on 3 sides (front, left, rear projection) and the floor. A mirror is used to project the floor image from above. The system used active stereoscopy. Shutter glasses allowed the participant to see depth in the virtual environment and a head tracking device (a sensor that determines the position of the user within the cubicle) allowed the participants to see the virtual environment from their perspective at the given moment. The objects in the virtual environment appeared to be stationary, and the participants were able to look underneath objects or around virtual street corners or trees by simply moving their head around in the CAVE without any other interaction needed. Participants could walk in the cubicle and navigate through the virtual space using a joystick. Although the physical movement of participants through the virtual environment is more restricted compared to their movement in a real environment, exploring the virtual environment is still quite similar to exploring a real environment because the physical movement of participants in the CAVE is combined with "virtual" movement (navigation with the joystick).

3.1.3. Virtual environments

In the virtual "natural" environment condition we used a three dimensional virtual representation of the real butterfly garden we used in Study 1 (see Fig. 3). The VR developers visited the real butterfly garden and took photographs to get inspiration in modelling the virtual butterfly garden. The software used to make the 3D world was 3dsmax (from Autodesk.com) and in-house written software based on OpenScenegraph (http://www.openscenegraph.org/). Much like the real butterfly garden, the virtual garden contained tropical plants, flowers, a paved footpath, a pond with water plants, and a wooden bridge. Animation was used to simulate flying virtual butterflies and some butterflies were placed on leaves. For the background audio we used bird sounds. The virtual urban neighborhood (see Fig. 4) contained streets, terraced houses, apartments, parked cars and bicycles, a number of moving cars in the distance, parking meters, a bus stop, street lanterns, and glass collection bins. As background sounds distant car sounds were audible.

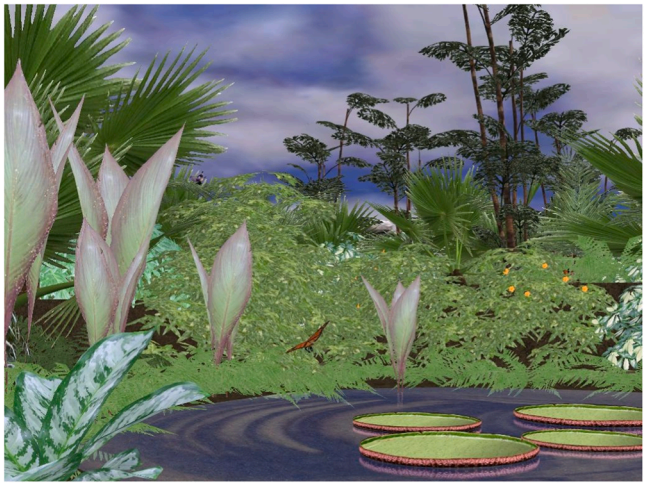

Fig. 3. The virtual butterfly garden (Study 2).

Fig. 4. The virtual urban neighborhood (Study 2).

By including many details, movement (butterflies, clouds, and cars), and sounds (birds and car sounds) we aimed to trigger the feeling of presence. The head tracking device may also enhance feelings of presence, as the virtual environment responds to the participant's position in the CAVE (Wu et al., 2019). Notably, a big aspect of the perceived realism comes from the accurate motion tracking via the head tracking device, which made it possible for participants to simply move their head around and explore the world and look behind objects.

3.1.4. Procedure

The participants were welcomed at the virtual reality centre. In order to conceal the real purpose of the study, participants were told that we were interested in people's experiences of different virtual environments. To make sure that all participants had comparable levels of mental fatigue, we again induced mental fatigue in all participants with the same Sudoku task as used in Study 1. Similar to in Study1, the participants were told that they had to solve as many Sudoku puzzles as possible within 50 min, and that the participant with the highest score would win a VIP treatment in Zoo Emmen. After the Sudoku task, participants were taken to the CAVE in a different room. Participants could explore the virtual environment (the virtual butterfly garden or the virtual urban neighborhood) for 20 min. After exposure to the virtual environment, participants filled out the questionnaire on a table near the CAVE.

3.2. Measures

3.2.1. Perceived restorative characteristics

Similar to Study 1, the PRCQ (Pals et al., 2009) was used to measure four perceived restorative characteristics (fascination, novelty, escape, and coherence) of the virtual environments. Scores could vary from 1 (totally disagree) to 7 (totally agree). Again, all items were put in random order and focused on either the virtual butterfly garden or the virtual urban neighborhood. We explicitly asked the participants to evaluate the virtual environment and not the physical environment they were in (i.e. the CAVE itself). Again, we computed mean scores of items included in each scale; higher means indicated higher fascination, novelty, escape and coherence. Table 5 depicts means, standard deviations, and Cronbach's alpha's for each restorative characteristic separately for the two virtual environments. The reliabilities of all scales were moderate to high for both environments (Cronbach's alpha ranging between.70 to.91; see Table 5).

Table 5
Estimated means, standard deviation and Cronbach's alpha scores for restorative characteristics and effects on preference, pleasure, and restoration for the virtual butterfly garden and the virtual urban neighborhood (Study 2). Results of repeated measures for the differences in restorative characteristics and effects on preference, pleasure, and restoration between the virtual butterfly garden and the virtual urban neighborhood ($N = 26$).

		Virtual environments							
		Butterfly garden			Urban neighborhood				
	n items	*M*	*SD*	α	*M*	*SD*	α	*F* (1,24)	*ηp*2
Fascination	5	5.31	1.08	.88	3.36	1.29	.89	53.65***	.69
Novelty	4	4.61	1.24	.76	2.76	1.06	.83	45.13***	.65
Escape	3	4.91	1.32	.90	3.31	1.32	.91	38.90***	.62
Coherence	3	5.70	.78	.70	5.01	1.31	.84	25.30***	.51
Preference	4	5.98	.80	.90	4.50	1.32	.93	21.16***	.47
Pleasure	4	5.27	1.11	.94	4.28	1.26	.92	18.84***	.44
Restoration	5	4.89	1.15	.91	3.53	1.26	.90	26.54***	.53

Note. Restorative Characteristics, Preference, Pleasure, and Restoration were rated on seven-point scales with high numbers indicating higher levels of the specific variable.
*** $p < .001$.

3.2.2. Preference, pleasure, and restoration

We used the same scales to measure preference, pleasure and restoration in the virtual environments as used in Study 1. All three scales were reliable for both environments (Cronbach's alpha >0.90, see Table 5 for α's, mean scores and standard deviations). Again, we computed mean scores of items included in each scale.

3.3. Results

3.3.1. Evaluation of virtual natural environment (butterfly garden) versus virtual urban environment (urban neighbourhood)

To test Hypothesis 1, we carried out repeated measures analyses comparing scores on all perceived restorative characteristics, and perceived preference, pleasure and restoration in the virtual butterfly garden and the virtual urban neighborhood (see Table 5). Participants reported significantly higher fascination, novelty, escape and coherence for the virtual butterfly garden than for the virtual urban neighbourhood with small to medium effect sizes. Furthermore, preference, pleasure and restoration ratings were significantly higher for the virtual butterfly garden than the virtual urban neighborhood and participants experienced more pleasure after exposure to the virtual butterfly garden compared to the urban neighborhood. Also, restoration was higher after walking in the virtual butterfly garden compared to walking in the virtual urban neighborhood. We checked if the difference in number of days between the two sessions correlated with the degree of difference in responses to the two environments. None of the correlations were statistically significant, indicating that the difference in number of days were not related to the differences in response patters in the two sessions.

3.3.2. Predicting preference, pleasure, and restoration for the virtual butterfly garden

To test if effects on preference, pleasure and restoration experienced in the virtual butterfly garden can be predicted by perceived restorative characteristics of this virtual environment (Hypothesis 2), we carried out a regression analysis. All correlations we discuss are statistically significant at $p < .05$. For the regression analyses, we again checked for the assumptions normality, linear relationships, homoscedasticity and multicollinearity. VIF values were all below 10 and the tolerance values were above.2, indicating no multicollinearity.

All restorative characteristics, except novelty, correlated positively with preference for the virtual butterfly garden (see Table 6). Regression analysis showed that the perceived characteristics of the virtual butterfly garden explained 50 % of the variance in preference for the butterfly garden (see Table 7). Higher evaluations of escape, and coherence were associated with higher preference ratings.

Escape and coherence correlated positively with experienced pleasure (Table 6). The four restorative characteristics explained 45 % of the significant proportion of the variance in pleasure (see Table 7). Higher escape ratings were associated with higher ratings of experienced pleasure.

Table 6
Correlations between restorative characteristics, preference, pleasure, and restoration, with the virtual butterfly garden above diagonal and the virtual urban neighborhood (Study 2) below diagonal.

	Fas	Nov	Esc	Coh	Pref	Plsr	Rest
Fascination	–	.69**	.61**	.47*	.45*	.37	.71**
Novelty	.60**	–	.45*	.26	.19	.20	.56**
Escape	.38	.27	–	.33	.55**	.63*	.91**
Coherence	.30	-0.10	-0.18	–	.58**	.40*	.46*
Preference	.49*	.48*	.29	.13	–	.76**	.66**
Pleasure	.53**	.43*	.54**	.23	.73**	–	.63**
Restoration	.52**	.25	.83**	-0.08	.38	.56**	–

Note. Fas = Fascination; Nov = Novelty; Esc = Escape; Coh = Coherence; Pref = Preference; Plsr = Pleasure; Rest = Restoration.
* correlation is significant at the.05 level.
** correlation is significant at the.01 level.

All perceived restorative characteristics correlated positively with restoration in the virtual butterfly garden.

(see Table 6). Perceived restorative characteristics of the virtual butterfly garden could explain 88 % of the variance in restoration (see Table 7): higher escape ratings were associated with more restoration.

3.3.3. Predicting preference, pleasure, and restoration for the virtual urban neighbourhood

As for the virtual urban neighborhood, fascination, and novelty correlated positively with preference (see Table 6). Restorative characteristics did not explain a significant proportion of the variance in preference for the urban environment (see Table 8).

Fascination, novelty, and escape correlated positively with experienced pleasure (Table 6). Regression analysis showed that perceived restorative characteristics of the virtual urban neighborhood could explain 48 % of the variance in pleasure (Table 8). Higher escape ratings were associated with more experienced pleasure.

Fascination and escape correlated positively with restoration (Table 6). Perceived restorative characteristics could explain 75 % of the variance in restoration (Table 8). Both fascination and escape were significant predictors of restoration. Higher fascination and higher escape were associated with higher levels of restoration.

3.3.3. Comparing the evaluations of the real and virtual butterfly gardens

Because the virtual butterfly garden was based on the real butterfly garden in Emmen Zoo, we were able to make a direct comparison between the evaluation of these two environments. We first examined

Table 7
Regression analyses for restorative characteristics on preference, pleasure, and restoration ($N = 26$) of the virtual butterfly garden (Study 2).

			95 % Confidence Interval for ß					
	ß	*t*	Lower Bound	Upper Bound	R^2	*df*	*F*	*p*
Dependent Variable: Preference								
Fascination	.12	.47	-0.42	.66				
Novelty	-0.19	-0.84	-0.65	.27				
Escape	.42	2.11*	.01	.83				
Coherence	.44	2.50*	.07	.81				
					.50	4, 21	5.17	.01
Dependent Variable: Pleasure								
Fascination	-0.04	-0.13	-0.60	.53				
Novelty	-0.15	-0.64	-0.62	.33				
Escape	.63	3.07**	.20	1.06				
Coherence	.25	1.37	-0.13	.63				
					.45	4,21	4.34	.01
Dependent Variable: Self reported Restoration								
Fascination	.13	1.03	-0.13	.39				
Novelty	.11	1.00	-0.12	.33				
Escape	.74	7.81***	.54	.94				
Coherence	.12	1.39	-0.06	.30				
					.88	5,20	39.43	<0.001

* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 8
Regression analyses for restorative characteristics on preference, pleasure, and restoration ($N = 26$) of the virtual urban neighborhood (Study 2).

			95 % Confidence Interval for ß					
	ß	*t*	Lower Bound	Upper Bound	R^2	*df*	*F*	*p*
Dependent Variable: Preference								
Fascination	.36	1.32	-0.21	.92				
Novelty	.12	.50	-0.38	.61				
Escape	.14	.64	-0.31	.58				
Coherence	.05	.23	-0.41	.51				
					.26	4,21	1.87	.15
Dependent Variable: Pleasure								
Fascination	.14	.63	-0.33	.62				
Novelty	.19	.98	-0.22	.61				
Escape	.49	2.74*	.12	.87				
Coherence	.29	1.59	-0.09	.67				
					.48	4,21	4.92	.01
Dependent Variable: Self reported Restoration								
Fascination	.34	2.14*	.01	.67				
Novelty	-0.13	-0.93	-0.42	.16				
Escape	.72	5.69***	.46	.98				
Coherence	-0.06	-0.49	-0.33	.21				
					.75	4,21	15.36	<0.001

* $p < .05$ * * $p < .01$.
*** $p < .001$.

whether people perceived the restorative characteristics of the virtual butterfly garden similarly as the restorative characteristics of its real equivalent (Hypothesis 3). For this purpose, the data from Study 1 and Study 2 were combined. We conducted a between subjects analysis ($N = 49$) with two environmental conditions (virtual butterfly garden versus real butterfly garden). Results from the t-test showed that there were no significant differences in the perceived restorative characteristics and in preference, pleasure, and restoration between the virtual butterfly garden and the real butterfly garden (see Table 9).

Next, we examined whether the same predictors that explain preference, pleasure and restoration in the real butterfly garden would explain preference, pleasure and restoration in the virtual butterfly garden in a similar way (Hypothesis 4). As expected, we found the same pattern of results for the real butterfly garden (see Table 3) and the virtual butterfly garden (see Table 7). Similarly, the pattern of results were similar when comparing the real urban environment (shopping mall, see Table 4) and the virtual urban environment (urban neighbourhood). Especially escape appeared to be a good predictor for preference, pleasure and restoration in both environments. In addition, we found the same pattern of results for the real (see Table 4) and virtual urban environment (see Table 8).

3.4. Conclusion

Study 2 showed similar results as Study 1. First, the results support our hypothesis that perceived restorative characteristics and perceived

Table 9
Mean scores of restorative characteristics, preference, pleasure, and restoration for the real butterfly garden (Study 1) and the virtual butterfly garden (Study 2). Results of t-test analysis of the differences between the means ($N = 49$).

	Butterfly Gardens				
	Real	Virtual	95 % CI of the Difference		
	M	*M*	Lower Bound	Upper Bound	*t*
Fascination	5.11	5.22	-0.57	.78	.31
Novelty	4.67	4.52	-0.88	.58	-0.42
Escape	4.54	4.83	-0.48	1.08	.77
Coherence	5.43	5.69	-0.20	.72	1.13
Preference	5.83	5.97	-0.32	.61	.62
Pleasure	5.30	5.24	-0.62	.50	-0.23
Restoration	4.65	4.80	-0.48	.77	.48

Note. Restorative Characteristics, Preference, Pleasure, and Restoration were rated on seven-point scales with high numbers indicating higher levels of the specific variable.

restorative effects are higher in a virtual natural environment than in a virtual urban environment. Second, similar to the findings with the real natural environment, the results showed that the perceived restorative characteristics of the virtual natural environment are good predictors of preference, pleasure, and restoration in this environment.

Third, our results indicate that there were no significant differences in perceived restorative characteristics, and preference, pleasure and restoration between the real and the virtual butterfly garden. Fourth, restorative characteristics predicted restoration, preference, and pleasure in a similar way in the real and virtual butterfly garden. In addition, the perceived restorative characteristics of the virtual urban environment could predict pleasure and restoration in that environment, but not preference, mimicking the findings of Study 1 with the real urban environment.

4. General discussion

We aimed at investigating the validity of virtual reality as a tool in restorative environments research in two studies. In line with our hypothesis, we found that restorative characteristics and effects on pleasure, preference and restoration were evaluated more positively in both the real and virtual natural environments as compared to the real and virtual urban environments, suggesting that the pattern of results is indeed similar in real and virtual environments (Hypothesis 1). These findings are in line with the literature comparing natural and urban environments in restoration potential (Hartig et al., 1991, 2003), and suggest that natural environments hold stronger restorative characteristics than urban environments.

Hypothesis 2 was also confirmed: restorative characteristics predicted preference, pleasure, and restoration for real environments as well as virtual environments; this was true for both the natural and urban environments. Findings fully supported Hypothesis 3 and 4, indicating that the same set of key predictors were associated with preference, pleasure and restoration in virtual and real environments. Together, these results suggest that virtual environments hold similar restorative characteristics and elicit similar responses relevant for restoration as real environments. Therefore, our results provide first empirical evidence that virtual reality can be a valid tool in restorative environments research.

It should be noted that although we found that virtual and real butterfly garden have been evaluated similarly in restorative characteristics, and in terms of preference, pleasure and restoration, we did not explore why participants evaluated the virtual and real environments in a similar fashion. It might have been that participants evaluated the virtual and real environments similarly on restorative characteristics for different reasons. For instance, the real butterfly garden might have been evaluated as fascinating because it speaks to multiple senses and allows for more space for exploration whereas the virtual butterfly garden might have been evaluated as fascinating because it is novel. Future research could examine the reasons for similar evaluations of restorative characteristics and restoration related outcomes for virtual and real environments. If real and virtual environments were evaluated similarly for the same reasons, this would provide further support to the idea that virtual reality is a valid tool to study restorative environments.

Interestingly, we found that perceived restorative characteristics did not significantly predict preference for the real urban environment, nor for the virtual urban environment. This might have been the result of lack of statistical power, as the sample size was relatively low in both studies and comprising only students. Among the restorative characteristics, escape appeared to be the best predictor across different outcomes related to restoration, for both virtual and real natural and urban environments. Future research should therefore focus on why escape is a key predictor of preference, pleasure and restoration in environments. Coherence was particularly a good predictor of restorative effects in virtual and real natural environments rather than in urban environments, meaning that it is important to keep all elements fitting into each other in natural settings to induce restorative effects (see also Pals et al., 2014). Findings also revealed that fascination, which is a key component of restorative experience described in ART (Kaplan and Kaplan, 1989) did not always predict pleasure, restoration and preference for real and virtual environments. Similar findings have been reported before (see Herzog et al., 2003). More research is needed to understand why fascination might fall short on predicting restorative experiences.

In the current study, we did not control for one's acquaintance with virtual environments. One's familiarity with virtual environments might affect evaluations of virtual environments. For instance, if one is highly acquainted with virtual environments, such as via video-gaming, then one might not find such environments very novel compared to another person who is not acquainted with virtual reality. Future research could examine the effects of familiarity on evaluations of virtual environments. In addition, due to some practical constraints, the duration of the walk differed somewhat between the virtual and real environments, which may have affected the study results. Future studies could opt for more control over time spent in each environment, and investigate whether restorative effects vary based on the length of manipulation. It should also be mentioned that while we used the same context (i.e., butterfly garden) to test effects for the real and virtual natural environments, we used different contexts for the real (i.e., shopping mall) and virtual (urban neighbourhood) urban environments. Although both the shopping mall and the neighbourhood fell under the category of urban environment and led to similar findings, future research might aim at using the exact same context in the real and virtual counterparts of the urban environments as well. In addition, studies are needed to test the robustness of our findings. These studies could include other types of (natural as well as urban) environments in order to test generalizability of the findings to different environments. Future studies could also employ different measures and inspect whether similar findings are found, trying to avoid conceptual overlap as much as possible.

The task that we used to induce mental fatigue in participants had different levels that participants could choose from, meaning that not everyone was subjected to the exact same task. We refrained keeping the difficulty level of the Sudoku task constant, because that might have confound the mental fatigue induction as this may have been a very easy task for some of the participants and very difficult task for others (depending on participants' ability). Thus, we purposely used a Sudoku task with four difficulty levels for participants to choose from, to ensure that all participants had comparable levels of mental fatigue prior to being exposed to the virtual and real environments, and thus would have a similar need for restoration. We introduced a contest to motivate participants perform well in the Sudoku task. To win the contest they needed to solve as many puzzles as possible, with more difficult levels bringing more points to the participant. We reasoned that because of this, participants would have a similar need for restoration at the end of the contest. While we assume that our manipulation induced a similar

mental fatigue level in all participants, we cannot be sure whether this was indeed the case. Future studies could include alternative mental fatigue manipulations to address this limitation, by employing tasks with one level of difficulty that would be somewhat equally challenging for all participants. Alternatively, researchers could run studies at the end of a busy workday or at the end of an exam period for student samples (see Hartig and Staats, 2006), which would ensure a more naturalistic manipulation of mental fatigue.

Our study has important methodological and practical implications. Notably, our study provides initial evidence that virtual reality can be used as a valid methodological tool in restorative environments research. By the use of virtual reality as a tool, theories could be tested more thoroughly by having controlled experiments to examine how specific physical features of certain environments or designs influence perceived restorative characteristics, and thereby the restorative quality of environments (see Pals, Steg, Dontje, Siero, & van der Zee, 2014). By allowing for the systematic manipulation of environmental and design characteristics, virtual reality would help extend current theories on restorativeness.

An important practical implication of our study is that designers and urban planners can use virtual reality to find out how people experience their designs before they are actually built. In virtual environments it is easier to spot possible shortcomings in the design, allowing designers to optimize their design or compare multiple designs before commissioning construction companies to execute the project involving high cost- and time-efficient investments. Although the initial costs of creating a virtual environment may be considerable as programming virtual environment calls for individuals with considerable skill in programming and interfacing (Blascovich et al., 2002), it would be not as expensive as actually building the design. Once a basic environment is programmed, it can be used as a starting point to conduct numerous experiments, making only relevant changes in that virtual environment for each subsequent experiment. Besides, virtual environments might be of interest in restorative environments research and for practice as they might offer many possibilities to help reduce stress, particularly for people with no immediate access to restorative environments (see de Kort et al., 2006; de Kort and Ijsselsteijn, 2006). An important practical implication of our study is that as virtual environments seem to be a good proxy to real environments, practitioners might make use of virtual environments in interventions aimed at restoration.

To summarize, the current study examined if virtual reality could be used as a valid research tool in restorative environments research. We found that restorative characteristics were evaluated more positively, and ratings of preference, pleasure and restoration were higher in both the real and virtual natural environments, as compared to the real and virtual urban environments. We also found that restorative characteristics were related to preference, pleasure and restoration both in the real and virtual environments. In addition, evaluations of restorative characteristics and preference, pleasure and restoration were similar in the virtual and real butterfly gardens. Notably, the same restorative characteristics predicted preference, pleasure and restoration in virtual and real natural or urban environments. As such, our findings suggest that virtual reality can be a valid tool in restorative environments research, providing new avenues for research and practice.

CRediT authorship contribution statement

Berfu Ünal: Formal analysis, Writing – review & editing. **Roos Pals:** Conceptualization, Methodology, Data-Collection, Formal analysis, Writing. **Linda Steg:** Supervision, Conceptualization, Methodology, Review & Editing, Funding acquisition. **Frank Siero:** Supervision, Conceptualization, Methodology, Review & Editing, Funding acquisition. **Karen van der Zee:** Supervision, Conceptualization, Methodology, Review & Editing, Funding acquisition.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Roos Pals's Ph.D. project was funded by the Emmen Zoo Wildlands.

Appendix. Perceived Restorative Characteristics Questionnaire (Pals et al., 2009)

Instruction

To what extent do you agree with the following statements?
(1 = totally disagree, 7 = totally agree).
For example:

	Totally Disagree						Totally Agree
In the VE I see things I have never seen before.	1	2	3	4	5	6	7

Coherence

Everything I see in the VE belongs there.
Everything I see in the VE goes well together.
Everything I see in the VE fits there.

Novelty

There are many new things to see in the VE.
In the VE I see things I have never seen before.
The VE is very different than my daily environment.
The VE is original.
The VE is unique.

Escape

In the VE I can forget about my obligations.
In the VE I feel that I am away from everything.
When I am in the VE I feel free from my daily routine.

Fascination

There are many beautiful things to see in the VE.
There are many things in the VE that attract my attention effortlessly.
There is much to discover in the VE.
There are many interesting things to see in the VE.
Being in the VE makes me wonder about many things.

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