Urban future: Unlocking Cycling with VR Applications

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ABSTRACT

Understanding how infrastructures and urban environments shape the highly differentiated cycling experiences calls for further investigation. The current study addressed this challenge by employing Virtual reality (VR) applications. Quantitative methods were combined with a video simulation approach to model demand for cycling under different scenarios. VR environment mirroring the streetscape of a Dutch city was created. Environment greenness (green vs. no green), Bicycle path width (wide vs. narrow), Traffic volume (low vs. high) were manipulated. Participants had to cycle within the environments created, and thus having VR bike experience translating real world bike ride. VR experiences and cycling behaviour in response to the manipulated factors were measured.

The results showed that participants enjoyed cycling most within green environment (than no green), and with wide (than narrow) bicycle lane. It was safer to cycle within wide bicycle path, and within low (than high) traffic volume. The environment was perceived as more aesthetic when cycling within green environment.

Regression modelling further explored the relationship between the parameters hypothesised to influence the VR experiences. The better the naturalness and presence were perceived, the higher was the engagement. The higher the engagement was, the more the VR experience was liked.

Current outcomes are unambiguous in showing that VR technology opens new avenues in addressing real-life problems with huge societal relevance, like improving urban environment infrastructure to unlock cycling and thus active transport.

Keywords: urban environment, cycling, active transport

Index Terms: Augmented and virtual realities, information interfaces and presentation, User/Machine Systems-Human Factors

1 INTRODUCTION

Active transport as cycling may not just improve personal health, but provides benefits to the environment and society. Not surprisingly then cycling is in the focus of transport, urban planning, and health research. Despite increasing interest across multiple disciplines, a review of the literature on cycling showed some serious shortcomings. From one side, understanding how infrastructures and urban environments shape the highly differentiated cycling experiences calls for further investigation. From other side, a methodological gap emerged, and thus, inviting new approaches to appropriately address the above challenge.

Virtual reality (VR) seems to provide such approach, to solve real-world problems outside the traditional (lab) research. Yet, the potential of VR in understanding the urban environment infrastructure, and in particular, to unlock cycling and thus active transport has not been explored in full.

Therefore, the current study embraced the challenge to unlock the potential of cycling by employing VR applications, in an attempt to provide a better understanding on the "hardware" of mobility systems, such as infrastructures and urban environments. In a simulated VR environment mirroring an existing city streetscape, participants were invited to cycle. The VR system was validated in pilots, showing that the simulation is a "good enough" representation of a real experience to be used for such a purpose. A standard bicycle was affixed to an electromagnetic trainer (Elite RealAxiom Wired), and the VR environment was presented via Oculus Rift CV2 headset. Having opportunity to experience VR world translating real-world scenarios, participants could gain a lifelike representations of travelling through different streetscapes. The streetscape scenarios were created by experimentally crossing the key factors hypothesized to modulate cycling behaviour.

Although cycling motivators and barriers have been addressed in various studies before, the literature is not univocal on the main determinants of cycling behaviour. While safety emerged as a major factor in earlier research [5,16], recent studies claimed that traffic safety has minor importance for adolescents' cycling [15]. Furthermore, it was argued that cycling experience may differentiate depending on the interplay between various infrastructure and urban environment factors. For example, when a well-separated cycle lane was provided, factors related to comfort and aesthetics showed to be more important than factors related to traffic safety [12].

The discrepancy in the literature calls for thorough exploration on the potential factors that might influence cycling behaviour. Note however, the discrepancy in previous studies may be partially due to the fact that different self-reports measures have been used, and thus, often lacking objectivity.

By contrast, incorporating VR approach may provide objective experience and direct observation measures. The currents study takes into account the advantages of the VR technology, and thus, hope to provide a furtherer understanding of cycling behaviour, and in particular how urban environments shape the highly differentiated cycling experiences.

In the following, we present consecutively the theory behind the study, the method and results. We further provide a discussion on the main findings, from the perspective of existing theories. Finally, we highlight how the outcomes of the current study may be successfully implemented in developing innovative VR applications to improve urban environment infrastructure, and thus, to unlock cycling and active transport.

2 THEORY

2.1 Cutting Edge Virtual Reality Experience

The notion of Virtual Reality (VR) biking has been introduced a while ago [3,4]. Only recently, however, the development of technology demonstrates indicators that multimodal VR environments are promising applications in enhancing outdoor biking [7]. In this respect, the implication of cutting edge 3D immersive simulation technology in exploring the impact of manipulations in streetscape and traffic environment design on

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cycling, requires first to understand the key parameters that determine VR experiences.

Naturalness emerges as a crucial parameter, taken that the interface (of the simulated environment) has to provide experience of a real outdoor bike ride. Naturalness, defined as believability of the depiction of the environment itself and events within the environment [6], could be achieved with the development of better systems, capable to enhance presence [2]. Presence was defined in terms of subjective experience of being in one place or environment [17]. Gratefully to the immersive technologies, good presence could be realized even when one is physically situated in another environment [11].

Perceived presence was assumed to further influence engagement [14]. In the context of 3D VR environments, engagement reflects the degree of involvement and immersion [6]. A recent study in the context of VR applications for art and entertainment, reported a causal relation between engagement and liking of the VR experiences [2]. The higher the engagement was, the more participants liked the VR experience. We take the above findings as corner stone to build around our hypotheses concerning the key parameters driving VR bike experiences, and the causal relationship between these parameters. We assume:

H1: The better the naturalness and presence are perceived, the higher the engagement will be.

H2: The higher the engagement is, the more the VR experience will be liked.

As the present study aims to provide a better understanding on how cycling experience is shaped by infrastructures and urban environments, we closely look at these.

2.2 Dynamically simulated infrastructures

In the current context, infrastructure is understood as the “hardware” of urban design [8]. It is not a static given, but rather it changes dynamically [10]. Although previous studies provided insights that infrastructural interventions may affect cycling [1,8], there is a discrepancy in finings. While safety emerged as a major factor in earlier research [5,16], recent studies claimed that traffic safety has minor importance for adolescents’ cycling [15]. Factors related to aesthetics (e.g., vegetation, nature), showed to be more important than factors related to traffic safety, especially when a well-separated cycle lane was provided [12].

Furthermore, note that there is a lack of understanding on how various elements in the urban environment and infrastructural interventions (e.g., bike lanes, traffic volume in terms of pedestrians, bikes, cars and other vehicles) might interact to produce holistic perceptions of the entire infrastructure, environment, and thus influence cycling experience. Therefore, the next step to advance in the present study is to examine the combined effects of various environmental factors.

Taken the above mentioned, we are interested to know how Environment greenness (green vs. no green), Bicycle path width (wide vs. narrow), and Traffic volume (low vs. high) influence cycling experience. As a start, we look at the cognitive (i.e. perceived safety) and affective (i.e. enjoyment of cycling) behavioural responses. We hypothesize:

H3: Safety is perceived to be higher when cycling within green (than no green) environment, on wide (than narrow) bike path, with low (than high) traffic volume.

Similarly, it is expected:

H4: Cycling will be enjoyed most within green environment, on wide bike path, with low traffic volume.

In addition, we ask how aesthetics of the environment influence cycling behaviour. Note that prior studies are not univocal concerning this issue.

3 METHOD

To test whether and how the parameters hypothesized above influence cycling behavior, a VR environment was created, mimicking the real streetscape of a Dutch city. In particular, Bicycle path, Green environment, Traffic volume were manipulated. Safety, Aesthetics and Enjoying the cycling were measured within the VR environment. After experiencing the VR, engagement, naturalness, presence, and liking of the VR environment were addressed.

3.1 Participants

80 people (54 male and 26 female; 18 to 58 years old) took part in the study, conducted in The Netherlands. All had normal or corrected to normal vision. 28% reported that they have not experienced VR before. Majority seem to be experienced in cycling, 71% responded to cycle almost every day, and 16% at least once a week. 30 % reported to like cycling, and 49 % reported to like cycling very much.

3.2 Stimuli and Design

The VR environment featured a streetscape typical for a Dutch city (see Figure 1, for an example of the scene). For the purpose of the study 8 streetscapes (experimental conditions) were designed, after full crossing of the 3 experimental factors, namely Bicycle path width (wide vs. narrow), Environment greenness (green vs. no green), Traffic volume (low vs. high). Each participant experienced 4 out of 8 conditions, presented in random order and counterbalanced, as described below.

Figure 1: A screenshot of the VR environment.

3.3 Procedure and Settings

After a short introduction to the experiment, participants completed a consent form, agreeing to take part in the study. Then they were asked to comfortably sit on the bike (trainer adapted for the purpose of the experiment) and to wear the Oculus Rift headset.

The experiment started with a short practice session (300 meters long cycling segment) to familiarize with the environment and the task. Then 4 experimental blocks followed (each about 2min long). In each block, one of the 8 experimental conditions was presented. The order of blocks was randomized in advance, so that the experimental conditions are counterbalanced across participants, and completing a full conjoint trial.

At the end of each block, participants rated how safe was the environment, how aesthetic was the environment, and how much they enjoyed the cycling. Rating was conducted within the virtual environment by moving the head and staring at the desired answer, on a 7 point Likert scale (1=”not at all”, 7= “very much”).

After having cycled, participants had to complete a survey, screened on a laptop. The survey consisted of 3 parts. In the first part, the just experienced cycling segments have to be ranked in order from the most attractive to the least attractive. In the second part, perceived engagement, naturalness, presence, as well as liking of the VR experience were measured (see section

Instrument for details). There were few questions probing for any negative effects (e.g., nausea, headache). The third part addressed sociodemographics, e.g., age, gender, previous experience with VR, cycling experience. At the end, participants were debriefed and thanked for the participation.

Concerning the settings, the VR environment was created with C# and Unity3D game-engine environments by a third party, a professional VR developer studio. The VR application was run via PC on Oculus Rift CV2 headset. A standard bicycle was affixed to an electromagnetic trainer (Elite RealAxiom Wired) and was connected to the same PC, to transmit data concerning the virtual cycling movement parameters.

3.4 Instrument

Within the virtual environment, participants rated how safe, and how aesthetic was the environment, how much they enjoyed the cycling (on a 7 point scale, 1="not at all", 7=" very much").

Perceived Engagement, Naturalness, Presence, and Liking were measured in a survey, based on scales adapted from previous studies. The Engagement construct encompassed 9 items (e.g., "I felt involved in the displayed environment"). The construct Naturalness encompassed 4 items (e.g., "The displayed environment seemed natural"). The construct Presence encompassed 19 items (e.g., "I felt I was visiting the places in the displayed environment"). Engagement, Naturalness and Presence were designed based on questions adopted from Lessiter, Freeman, Keogh, & Davidoff (2001). The construct Liking encompassed 3 items (e.g., 'I would have liked the experience to continue'). The construct was developed based on previous studies exploring liking of VR applications (Bialkova & van Gisbergen, 2017). All items were measured on a 5-point Likert scale (1 = "strongly disagree", 5 = "strongly agree").

Few questions captured sociodemographic characteristics (e.g., age, gender). We asked about previous experience with VR (never, once, several times, many times). Frequency of cycling (almost every day, at least once a week, few times a month, less than once a month, I never cycle) and whether participants like cycling (on a 5-point Likert scale, 1 = "not at all", 5 = "very much").

3.5 Analytical procedure

We first performed a reliability check. All scales used demonstrated to be reliable (Cronbach's α's > .65).

ANOVAs were run to investigate whether there are significant differences in Engagement, Naturalness, Presence, Liking of the VR experience determined by previous VR experience (no experience, once, several times, many times). In addition ANOVAs tested how the above parameters are influenced by cycling experience and how much participants like to cycle.

Regression modelling was conducted to test for any causal relations between Naturalness, Presence, Engagement and Liking of VR experience.

Concerning the measurements within the VR environment, data from three participants were excluded from further analyses, due to missing values (in some of the experimental cells). The remaining data were submitted to T-tests, to explore whether there was a significant difference in the way participants evaluated, respectively, Safety, Aesthetics and Enjoyment of cycling within the VR environment, with respect to the manipulated factors, namely: Environment greenness (green vs. no green), Bicycle path width (wide vs. narrow), Traffic volume (low vs. high), see Table 1 for a summary.

4 RESULTS

VR bike experience evaluation: Participants were equally engaged in the VR experience (M = 3.46), irrespective of their pervious VR experience (p > .2). Similar was the tendency for perceived naturalness (M = 3.51), presence (M = 3.07), and liking (M = 3.99). These parameters did not differ with respect to previous VR experience, all p's > .1.

There was no difference in perceived naturalness, presence, engagement, and liking of VR experience determined by cycling experience (all p's > .3), nor by how much participants like to cycle (all $p's$ > .2). Note that the study was conducted in the Netherlands, known as a bicycle-friendly country, with high rate active cycling [13]. Not surprisingly, majority of our respondents reported that they cycle regularly (71 % almost every day, and 16% at least once a week).

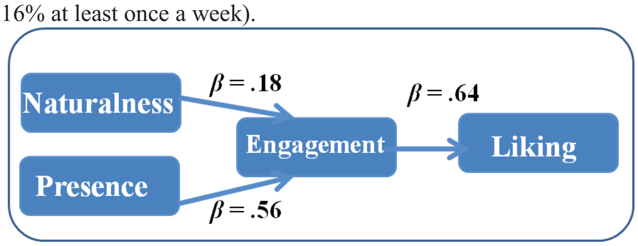

Figure 2: Summary of the regression modeling (regression coefficients)

The results from the regression modelling are clear in showing that both, naturalness and presence enhanced engagement (see Figure 2). Naturalness explained 27% of the variance in engagement, R^2 = .27, F(1, 78) = 28.50, p < .0001. Adding presence to the model significantly improved the explanatory power, R^2 = .46, F(2, 77) = 33.16, p < .0001. The better the naturalness (β = .18) and presence (β = .56) were perceived, the higher was the engagement. The higher the engagement was (β = .64), the more the VR experience was liked. Engagement explained 42% of the variance in liking, R^2 = .42, F(1, 78) = 55.25 p < .0001.

Behaviour change in response to Environmental factors: What is much more interesting in the present context, is whether and how the manipulated factors (Environment greenness, Bicycle path, Traffic volume) influenced respectively safety and aesthetic perception, and enjoying the cycling.

Table 1. Summary of the statistics (T-test outcomes)

Parameters	Means (*SE*)	T-test
Safety		
Green No green	M = 5.40 (SE=.13) M = 5.10 (SE=.13)	t(76) = 2.07, p = .041
Wide path Narrow path	M = 5.67 (SE=.12) M = 4.70 (SE=.16)	t(76) = 5.83, p < .0001
Low traffic High traffic	M = 5.39 (SE=.12) M = 4.97 (SE=.16)	t(76) = 2.75, p < .01
Enjoyment		
Green No green	M = 5.79 (SE=.11) M = 4.92 (SE=.13)	t(76) = 6.51, p < .0001
Wide path Narrow path	M = 5.59 (SE=.12) M = 5.11 (SE=.13)	t(76) = 3.18, p < .005
Low traffic High traffic	M = 5.43 (SE=.12) M = 5.19 (SE=.13)	p > .1
Aesthetics		
Green No green	M = 5.67 (SE=.11) M = 4.59 (SE=.13)	t(76) = 8.10, p < .0001
Wide path Narrow path	M = 5.29 (SE=.10) M = 5.03 (SE=.15)	p = .085
Low traffic High traffic	M = 5.13 (SE=.12) M = 5.10 (SE=.13)	p > .8

Concerning the Environment greenness (green vs no green), it determined a significant difference in how aesthetic the environment was perceived, t(76) = 8.10, p < .0001; and how participants enjoyed cycling in, t(76) = 6.51, p < .0001. The effect of greenness on safety perception just substantiated significance, t(76) = 2.07, p = .041, see Table 1 for details. A slightly different look at the data shows that aesthetics, safety and enjoyment were better evaluated when participants experienced cycling within green (green solid line) than in no green (red dashed line) VR environment, see Figure 3, top panel.

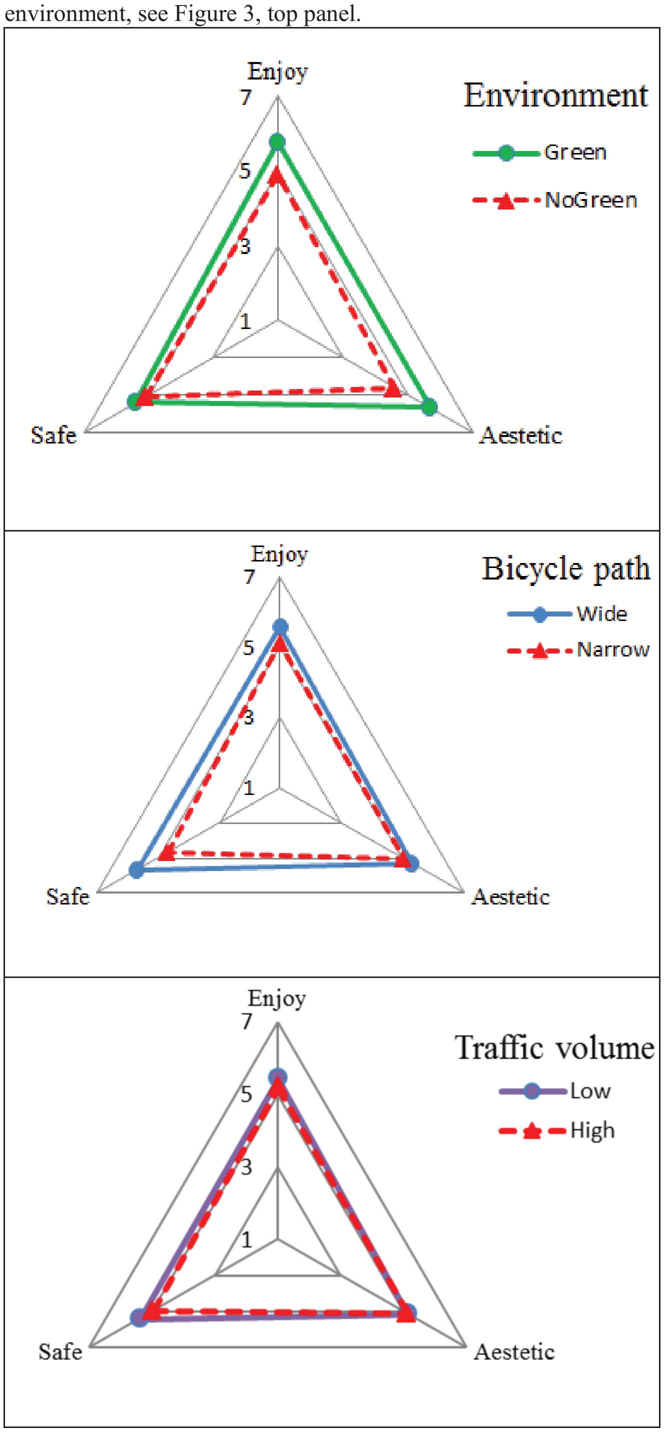

Figure 3: Key parameters hypothesized to modulate (VR) cycling

Concerning the Bicycle path width (wide vs. narrow), safety was perceived to be higher when cycling on wide than narrow path, t(76) = 5.83, p < .0001. Cycling was enjoyed more on wide than narrow path, t(76) = 3.18, p < .005. For aesthetics, the effect was not substantiated statistically, p = .085 (Figure 3, middle panel).

Concerning the traffic volume (see Figure 3, bottom panel), only the effect on safety was pronounced. It was safer to cycle within low than high traffic volume, t(76) = 2.75, p < .01

5 Discussion

The goal of the current study was to provide a better understanding on how infrastructure and urban environments shape the highly differentiated cycling experiences. In a simulated VR environment, mirroring the streetscape of a typical Dutch city, the infrastructure (Bicycle path, Traffic volume, Environment greenness) was manipulated. The influence of these factors on the cognitive (i.e. safety perception) an affective (i.e. enjoyment of cycling) responses were measured. The key parameters determining the VR experience (naturalness, presence, engagement, liking) were also captured. The results are unambiguous in showing that improved urban environment infrastructure may enhance cycling. In this respect, the VR bike application provides invaluable insights, namely by dynamically simulating infrastructures, the most appropriate combination of parameters unlocking cycling could be set.

5.1 Enhancing the Virtual Reality Experiences

The results confirmed a causal relation between the key determinants of the VR bike experiences. The better the naturalness and presence were perceived, the higher was the engagement (H1 confirmed). These outcomes nicely cohere with earlier assumption that perceived presence influences engagement [14]. Furthermore, the higher the engagement was, the more the VR bike experience was liked (H2 confirmed). These findings are univocal with recent studies in the context of VR applications for the entertainment industry [2]. Namely, increased naturalness and presence might improve engagement, and thus, enhance VR experiences and liking.

Interestingly however, neither prior VR experience nor cycling experience modulated the above mentioned parameters. Note the study was conducted in The Netherlands, a bike-friendly country with active cycling rate [13]. Majority of our participants also reported to cycle regularly, and to enjoy cycling. Thus, it would be worth to replicate the study in a country where cycling is not popular, and the infrastructure is not bike-friendly.

5.2 The Role of infrastructure

Infrastructure, understood as the "hardware" of urban design [8], changes dynamically [10] upon various factors. In the current study we focused on 3 factors, determined to be crucial in shaping highly differentiated cycling behaviour.

Cycling was enjoyed more within green than no green environment, and with wide than narrow bike lane. Surprisingly however, traffic volume did not modulate enjoyment (H4 partially confirmed). A plausible explanation could be that various infrastructural interventions may affect differently cycling [1,8]. Whether this explanation holds, could be addressed in a follow up study incorporating additional factors, i.e. land use (residential vs mixed).

Safety perception was better when cycling within wide (than narrow lane), green (than no green) environment, and low (than high) traffic volume. These findings confirm H3, and are in favour of previous studies claiming that safety is a major determinant of cycling [5,16].

Concerning aesthetics, only the green environment played a role. This does not necessarily confirm previous self-report studies claiming that aesthetics (e.g., vegetation, nature) are more important than factors related to traffic safety (i.e. lane width) [12]. By contrast, current results show that safety is a major determinant of cycling (H3 confirmed). Thus, it is all about how infrastructure interventions interplay in shaping cycling. In this respect, the present study clearly demonstrates that cutting edge VR technologies provide appropriate tools to explore and understand the underling mechanism of highly differentiated cycling behaviour.

6 In sum

The present research employed VR bike applications to model demand for cycling under different scenarios. The results showed that the interplay between various infrastructure factors (i.e. Bike lane, Traffic volume, Environment greenness) significantly modulate the cognitive and affective behavioural responses. Current outcomes should be considered by others when developing their VR systems in the context of urban planning, transport, logistics. Dynamically simulated infrastructures hereby provide invaluable insights in finding appropriate combination of parameters to unlock cycling, and thus shaping the urban future.

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