Journal of Environmental Psychology 90 (2023) 102105

Contents lists available at ScienceDirect

Journal of Environmental Psychology

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

Time perception in naturalistic and urban immersive virtual reality environments

G. Mioni *, F. Pazzaglia

Dipartimento di Psicologia Generale, Università di Padova, Italy

ARTICLE INFO

Handling Editor: Chiara Burattini

Keywords:
Time perception
Urban environment
Natural environment
Immersive virtual reality

ABSTRACT

Being in contact with natural environments is associated with better health and well-being and has beneficial effects on attention restoration. It also seems that perception of the experience duration changes in different environments, particularly natural versus urban. For instance, watching images of a natural environment can modulate individuals' attentional levels. The present study aimed to test the possible effects of the environment on time perception with an immersive virtual reality environment. We exposed 52 participants to either a natural or urban setting and asked them to perform three temporal tasks and estimate the duration of the walk. Results showed that after being immersed in a natural environment, participants felt less activated and happier compared to the urban setting. Furthermore, the environment modulated participants' perception of time, indicating that participants were more accurate and less variable when exposed to a natural compared to an urban environment.

1. Introduction

Previous studies indicate that immersion and being in contact with natural environments positively affect health and well-being (Schertz & Berman, 2019; White et al., 2019). Results indicate that being exposed to nature promotes beneficial effects, including improved attention and cognitive functions (Faber Taylor & Kuo, 2009; Mason et al., 2021; Taylor et al., 2001), lower stress (De Bloom et al., 2017; Korpela & Kinnunen, 2011), better mood (Bratman et al., 2015), and even reduced risk of psychiatric disorders (McCay et al., 2019, p. 32). To test the beneficial effects of nature on well-being and cognition, researchers have used a wide range of stimulus types, including images (Berry et al., 2015), sounds (Van Hedger et al., 2019), and real-world exposure (Davydenko et al., 2017; Berman et al., 2008; Bratman et al., 2015). All of these studies concluded that being exposed, even for a brief amount of time, to natural environments improved participants' cognitive performance relative to urban environments.

Why does being exposed to nature have beneficial effects on quality of life? The possible explanations cover stress reduction and attention restoration. Stress-reduction theory indicates nature's beneficial impact on the subjective emotional stress level, suggesting that positive and open emotional contact with nature lets a person reduce his/her stressful state. Indeed, non-arousing natural environments reduce stress and negative emotions while increasing positive effects by allowing a person to maintain higher levels of cognitive functions and promote psychological stress recovery (Ulrich et al., 1991). In fact, evidence has suggested that being exposed to nature can lower pulse rates, reduce cortisol levels, and improve immune functioning (Jo et al., 2019). More, Kaplan and Kaplan (1989) proposed the attention-restoration theory suggesting that some perceptual characteristics of natural environments capture a person's bottom-up involuntary attention and promote the restoration of attentional resources. Natural environments seem particularly restorative because they provide a chance to get away and contain fascinating, rich stimuli that easily engage involuntary attention, which allows people to act without needing to monitor their actions constantly (Kaplan & Kaplan, 1989). Some research conducted within this framework has reported improvements in concentration and directed attention to various stimuli after being in contact with nature (Berman et al., 2008; Stevenson et al., 2018).

Besides the advantageous effects on well-being and cognition observed when people are exposed to and in contact with nature, another observation often arises, our perception of time changes in different environments. A walk in the forests might be felt as subjectively longer or shorter than a walk in the metropolis is, even if the same objective time has passed. Most, if not all, people have experienced that subjective feeling of how time does not always match the objective time

* Corresponding author. Via Venezia 8, 35121, Padova, Italy.
E-mail address: giovanna.mioni@unipd.it (G. Mioni).

https://doi.org/10.1016/j.jenvp.2023.102105
Received 28 August 2022; Received in revised form 8 April 2023; Accepted 7 June 2023
Available online 17 August 2023

that watches report. From the first moment of our lives, we are constantly immersed in time, experiencing a continuously changing environment. The ability to track time over a wide range of durations is essential for efficient interaction with a continually changing world.

Altered subjective feelings of time are frequent in everyday life and can affect judgments and decisions (Tobin et al., 2010). Sometimes subjective feelings about time can have negative effects, favouring, for example, risk behaviours (Baumann & Odum, 2012; Kvam, Baldwin, & Westgate, 2023). Temporal misperception has also been linked to impulsive and unhealthy decision-making behaviours (Moreira et al., 2016; Teuscher et al., 2011; Wittmann et al., 2011; Wittmann & Paulus, 2008) and more severe neuropsychological impairments (Allman & Meck, 2012; Thönes & Oberfeld, 2015; 2017).

A crucial distinction is made when studying time between prospective and retrospective temporal judgments (Block et al., 2018). Prospective time refers to estimating duration as it occurs; under this scenario, a person knows that time is relevant and salient from the beginning and engages attentional resources to track time. According to the most common models of time perception, the subjective estimation of time depends on the number of pulses a pacemaker emits and stores in an accumulator during a timed event (Gibbon et al., 1984; Treisman, 1963). Specifically, the attentional gate model (Zakay & Block, 1995) posits that an attentional gate is positioned between the pacemaker and the accumulator; when attention is not entirely allocated to time, less temporal information is stored in the accumulator, and the temporal interval is underestimated (Block et al., 2018). Conversely, retrospective timing means thinking back and judging how long a given experience lasted; here, the request for time judgment is unexpected because an individual is not explicitly informed to keep track of time before the experience. The memory-based model best explains retrospective timing as it postulates that certain types and the number of information stored in memory during the relevant time interval provide the basis for retrospective time estimation (Zakay & Block, 2004; Zakay et al., 1994). Some have proposed that the duration of retrospective temporal judgments correlates with the amount of changes in cognitive context during the estimated interval, more rich stimuli and environments will be retrospectively estimated as lasting longer than less complex stimuli (Zakay & Block, 2004).

Few studies thus far have specifically investigated the causes of altered temporal experience when people are exposed to natural or urban environments. Berry et al. (2015) first demonstrated that being exposed to nature influenced participants' internal clock. The authors used a series of photos of natural or urban environments and asked participants to estimate the time that had passed since they arrived at the lab (retrospective timing). A time bisection task (prospective timing) was also included in which participants were instructed to estimate a series of temporal intervals as similar to a "short standard" or a "long standard" previously memorised. The results showed the environments did not affect prospective time, but participants who were exposed to natural environment images estimated that more time had passed since arriving at the lab than those who viewed photos of urban settings (retrospective time). Davydenko and Peetz (2017) asked participants to take a walk in natural or urban environments. After the walk, participants were asked to estimate its duration (retrospective time) and while still immersed in the same natural or urban environment, judge when 1 min had passed by raising their hands (prospective time). Participants overestimated the time they walked in nature compared to the time for the urban walk (retrospective time); in addition, participants took longer to raise their hand when estimated that 1 min had passed when exposed to nature compared to urban environments (prospective time).

Taken together, these two studies seem to confirm different effects of natural and urban environments on the subjective passage of time but they profoundly differ for the experimental setting adopted. The issue of ecological validity in psychological assessment has been expressed a number of times over the years via discussions of the limitations of generalizing sterile laboratory findings to the processes normally occurring in people's everyday lives. An interesting way to test the different effects of naturalistic and urban environments on subjective experience of time in a controlled setting is by employing computer-generated artificial environments. Virtual technology offers higher levels of realism and a great level of experimental control than naturalistic settings (Parsons, 2015). In the present research, we further investigate if the time spent in nature differs from that spent in urban environments when participants are in virtual reality environments (VRE). The use of VRE is rapidly increasing in a range of applications because it offers higher levels of realism and a great level of experimental control compared to naturalistic settings. One characteristic of VRE used in the clinical context is that time is felt as compressed, indicating temporal underestimation (Chirico et al., 2016; Schneider et al., 2011).

According to the attentional gate model (designed to explain prospective time judgments; Zakay & Block, 1995), if attention is not fully oriented to time, fewer pulses reach the accumulator, producing a subjective feeling that less time has passed (temporal underestimation). Natural settings promote mindfulness and increase a state of relaxation (Howell et al., 2011; Macaulay et al., 2022), a sense of calm within the person (Korpela & Kinnunen, 2011), decreased stress levels (Daniels et al., 2022; Sudimac et al., 2022), and restored attention (Bratman et al., 2015; Capaldi et al., 2015; Schertz & Berman, 2019). Conversely, urban environments increase physiological arousal and exogenous attention (Laumann et al., 2003). We can then expect that participants decrease their arousal and increase their positive effects during exposure to the natural environment more than to the urban one. Further, we expect that participants' attentional resources will be more activated when exposed to urban compared to natural environments, resulting in prospective temporal underestimation. Concerning retrospective timing, according to the contextual-change model (Block & Zakay, 2004), remembered duration is a cognitive construction based on the availability of contextual changes encoded in memory during the time period. If more contextual changes are available for retrieval, remembered duration increases. If the urban video attracts more attention than the natural one does, we expect retrospective temporal overestimation for urban compared to natural videos.

Taken together, the present study aims at investigating the effect of natural and urban environments on prospective and retrospective time perception. For the first time, we tested participants in an immersive VRE, in which we controlled for the duration of the videos and the speed of the virtual walk. The order of video presentation was counterbalanced between participants. Individual differences in time perception were also considered. Finally, the perceived restorative value of the two environments was recorded, expecting higher scores for the natural environment, according to the existing literature. Moreover, even if previous studies examining psychometric properties of scales assessing perceived restorative (e.g., Hartig et al., 1996; Menardo et al., 2021) did not mention gender differences, other studies (e.g., Bolognesi, Toffalini, & Pazzaglia, 2023; Rosa et al., 2023) found gender differences in the restorative value of nature, with women more likely to recognize restoration properties than men. Therefore, we controlled for this variable expecting a stronger beneficial effect of the restorative value of nature on female participants.

2. Methods

2.1. Participants

Fifty-two university students from the Department of General Psychology (University of Padova, Italy) were tested, but six were excluded because no key press was done during the time production task. When asked at the end of the task about their performance they reported that they forgot to perform the prospective timing task during the video presentation.

Therefore, 46 university students were included in the study (mean age = 24.67 years old; *SD* = 3.64; male = 15). All participants had normal or corrected-to-normal vision; participants with neurological or psychological disorders and a history of drug or alcohol abuse were excluded from the study. Participants were randomly assigned to one of the two possible conditions based on the order of scenario presented, either Natural-Urban or Urban-Natural. Twenty-two were assigned to the Natural-Urban (mean age = 24.95 years old; *SD* = 4.44; male = 7) and 24 to the Urban-Natural (mean age = 24.42 years old; *SD* = 2.80; male = 8) condition. No difference regarding age was observed between groups (p = .623).

3. Materials

3.1. Questionnaires

The Subjective Time Questionnaire (STQ; Mioni et al., 2020; Wittmann & Lehnhoff, 2005) includes four parts consisting of questions concerning (a) the experience of the passage of present time, (b) a retrospective look at the time, (c) subjective feeling of time, and (d) metaphors of time. For the subjective feeling of present and past time, participants were instructed to respond to each question on a 5-point Likert scale with anchors 1 = very slowly and 5 = very fast. The third group of questions contains statements on the subjective experience of time that refer to the feeling of time pressure/time compression or to the feeling of time expansion/time affluence. Cronbach alpha for the time pressure/time compression scale is .78, and for the time expansion/time affluence is 0.79 (Wittmann & Lehnhoff, 2005). Finally, the fourth set of questions relates to temporal metaphors of speed or slowness of time; Cronbach alpha is .73 and .54, respectively (Wittmann & Lehnhoff, 2005). For the third and fourth sets of questions, participants were instructed to respond on a 5-point Likert scale with anchors 1 = strongly disagree and 5 = strongly agree.

The Self-Assessment Manikin (SAM; Bradley & Lang, 1994) is a non-verbal pictorial assessment technique that measures the subjective level of arousal and pleasure associated with a person's affective reaction. Participants were instructed to rate their level of arousal and pleasure on a 9-point scale from 1 = very sad to 9 = very happy for pleasure and 1 = very calm to 9 = very activated for arousal.

The Perceived Restorativeness Scale (PRS-11; Pasini et al., 2014) is an 11-item questionnaire to evaluate an environment's restorative quality. The questionnaire includes four subscales targeting the subjective feeling of "being away," "coherence" in the environment, "scope, " and "fascination." Participants were instructed to respond on a 11-point Likert scale from 0 = not at all to 10 = a lot and to evaluate how each sentence reflected their state and idea with the environment presented. Pasini et al. (2014) reported that this short version is invariant across countries (ΔCFI = 0.008; ΔRMSEA = 0.001) and across genders (ΔCFI = 0.004; ΔRMSEA = 0.006).

To measure cybersickness after the video presentation we used a reduced version (13 items) of the Revised Simulator Sickness Questionnaire (RSSQ; Kim et al., 2004). A reduced version was used to avoid fatigue. Cronbach alpha was .87 for the naturalistic and the urban conditions. Participants were asked to judge the level of comfort and discomfort on an 11-point Likert scale from 0 = not at all to 10 = very high.

3.2. Timing tasks

3.2.1. Time prospective tasks

We included two time prospective tasks in which participants were informed to estimate temporal intervals, the first was performed before and after watching the videos and one was performed while watching the video.

3.2.2. Time production task

Participants were instructed to produce a set of durations. A grey circle remained in the centre of the computer screen as long as the participants pressed the space bar. Each duration was presented three times and participants did a practice phase (one presentation for each duration) before the experimental phase. We asked participants to refrain from counting during the task.

3.2.3. Time production task

Just before presenting the naturalistic and the urban videos, participants were instructed to pay attention to the appearance of a red dot at the centre of the screen and to press the spacebar 1 min after the presentation of the dot.

3.2.4. Time retrospective task

At the end of each video, participants were asked to report the duration of the video just presented.

3.3. Procedure

Participants were tested individually during one experimental session lasting approximately 60 min divided into two parts; the sequence of questionnaires and tasks were the same in both parts, but the order of immersive videos (naturalistic or urban) was counterbalanced between participants. Fig. 1 depicts a graphical representation of the experimental procedure. Participants were seated comfortably in the VRE provided by the Department of General Psychology (university of Padova) and undergo a structured experimental procedure. The Cave Automatic Virtual Environment (CAVE) represents an environment in which the user is placed in the centre of the room and is involved in a projection of image and sound with an immersive effect up to over 180° extension for video and 360° for audio. The procedure started with the STQ (Mioni et al., 2020; Wittmann & Lehnhoff, 2005) followed by the evaluation of the subjective level of arousal and valence using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994). Participants then performed the time reproduction task followed by a 5 min immersive video (Natural or Urban conditions). During the video, participants were asked to press a key on the keyboard after 1 min had passed since the red dot appeared on the screen (production timing task). At the end of the video, participants were asked to estimate the duration of the video (retrospective timing task), followed by the SAM and the time reproduction task. The first part ended with the Perceived Restorativeness Scale (PRS-11; Parisi et al., 2014) and the cybersickness questionnaire. We decided to propose the PRS-11 first to have it as close as possible to the end of the video. Participants then waited 30 min before starting the second part of the experimental session, which was similar to the first one except for the video presented and for the STQ questionnaire that was not presented a second time. During the 30 min break participants were free to read, check their cellphones and/or talk with the experimenter. Participants signed the informed consent form before starting the session. The study was approved by the ethics committee of Area 17 approved protocol reference number: 4544) Department of General of Psychology, University of Padova (Italy) and conducted according to the Declaration of Helsinki (59th WMA General Assembly, Seoul, 2008).

4. Results

4.1. Questionnaires

4.1.1. The Subjective Time Questionnaire

Regarding the STQ (Mioni et al., 2020; Wittmann & Lehnhoff, 2005), we calculated 10 indices that describe personal time experience; the first six questions describe the subjective feeling of the present as well as the past life periods. The remaining four indices are based on participants' responses in parts three and four of the questionnaire. We performed independent repeated measure ANOVAs with *Order* (Natural/Urban vs. Urban/Natural) and *Gender* (male vs. female) as between-subject factors

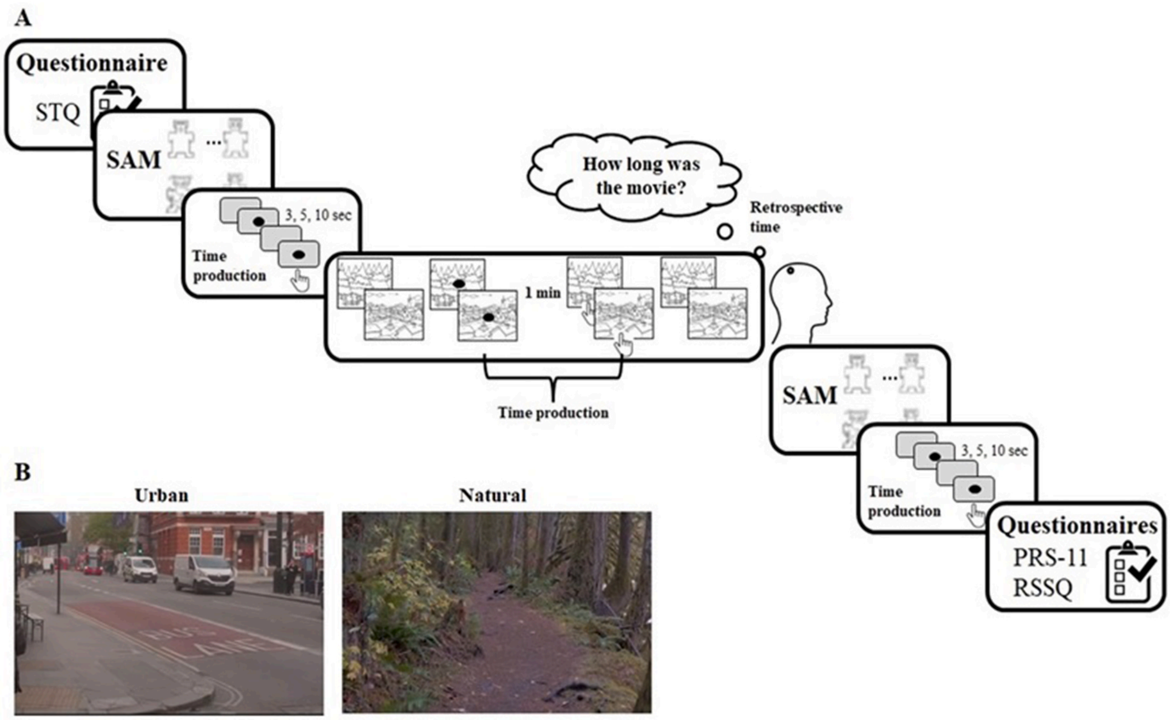

Fig. 1. (A) Graphical representation of experimental procedure. The image depicts the first part of the experimental procedure. After a 30-min break, participants underwent the same sequence of questionnaires and tasks. STQ = Subjective Time Questionnaire (Wittmann & Lehnhoff, 2005); SAM = Self-Assessment Manikin, (Bradley & Lang, 1994); PRS-11 = Perceived Restorativeness Scale (Pasini et al., 2014); RSSQ = Revised Simulator Sickness Questionnaire (Kim et al., 2004). (B) Examples of the Urban and the Natural scenarios.

were conducted (Table 1). Results indicated a significant interaction between *Order* and *Gender* [F (1,42) = 4.42, p = .041, η_p^2 = .09] for question number 3 (How fast did the previous week pass for you). No significant differences were observed after Bonferroni corrections. Also, we observed a significant effect of *Order* for question 4 (How fast did the previous month pass for you?) [F (1,42) = 4.65, p = .037, η_p^2 = .10] indicating that participants in the Natural/Urban condition had a feeling that time has passed more quickly the previous month compared to participants in the Urban/Natural condition. No other significant results were observed (all $p > .129$).

Table 1
Mean and standard deviation for the subjective time questionnaire as a function of the order of presentation and gender.

		Natural/Urban order	Urban/Natural order
		M(SD)	M(SD)
1 - How fast does time usually pass for you?			
	Male	3.43 (0.53)	3.25 (0.71)
	Female	3.33 (0.72)	3.25 (0.58)
2 - How fast do you expect the next hour to pass?			
	Male	3.29 (0.95)	2.75 (0.89)
	Female	3.33 (0.98)	3.50 (0.89)
3 - How fast did the previous week pass for you?			
	Male	4.57 (0.53)	3.50 (0.77)
	Female	3.87 (1.19)	4.06 (0.93)
4 - How fast did the previous month pass for you?			
	Male	4.29 (0.49)	3.38 (0.92)
	Female	4.13 (0.83)	3.75 (1.18)
5 - How fast did the previous year pass for you?			
	Male	3.86 (0.69)	3.13 (0.83)
	Female	3.60 (1.06)	3.56 (1.21)
6 - How fast did the previous 10 years pass for you?			
	Male	3.43 (0.53)	3.75 (0.71)
	Female	3.40 (0.74)	3.69 (0.87)
7 - Time Pressure			
	Male	3.89 (0.62)	3.35 (0.79)
	Female	3.83 (0.49)	3.75 (0.65)
8 - Time Expansion			
	Male	2.49 (0.65)	2.60 (0.50)
	Female	2.13 (0.43)	2.38 (0.72)
9 - Speed			
	Male	3.62 (0.36)	3.33 (0.53)
	Female	3.38 (0.85)	3.65 (0.52)
10 - Slowness			
	Male	1.95 (0.49)	2.12 (0.80)
	Female	2.00 (0.64)	2.42 (0.60)

4.1.2. *The cybersickness questionnaire*

Independent ANOVAs were conducted with *Environment* (Natural vs. Urban) as within-subject factors and *Gender* (male vs. female) as between-subject factors (Table 2). Results indicated no main effects neither interaction between variables for each question considered in the questionnaire.

4.1.3. *The Self-Assessment Manikin*

Pleasure: Data were included in a repeated measure ANOVA with *PrePost* (Pre vs. Post) and *Environment* (Natural vs. Urban) as within-subject factors and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors. These and the following significant effects were followed by posthoc analyses performed with a Bonferroni correction to reduce Type I error rate, and the effect sizes were estimated with partial eta squared (η_p^2). Results showed a significant interaction between *PrePost* and *Environment* [F (1,42) = 12.37, $p < .001$, $\eta_p^2 = .23$] and between *PrePost* × *Environment* × *Order* [F (1,42) = 4.55, p = .039, η_p^2 = .10] (Fig. 2) indicating no differences between pre and post level of pleasure for Natural and Urban video in the Natural/Urban order of video presentation (all $p > .05$). Participants in the Urban/Natural condition indicated an equivalent level of pleasure before watching the videos ($p > .05$), a higher level of pleasure after watching the Natural video ($p = .021$), and a reduced level of pleasure after watching the Urban video ($p < .001$).

Arousal: Data were included in a repeated measure ANOVA with

Table 2
Mean and standard deviation for the cybersickness questionnaire were recorded after presenting the videos showing the natural and urban environments.

–		Naturalistic environment	Urban environment
		M (SD)	M (SD)
1. General discomfort			
	Male	2.67 (2.09)	3.33 (2.02)
	Female	3.68 (2.41)	3.61 (2.23)
2. Fatigue			
	Male	3.13 (1.88)	4.33 (2.26)
	Female	4.00 (2.45)	4.23 (2.25)
3. Drowsiness			
	Male	3.67 (2.19)	4.60 (1.72)
	Female	4.32 (2.36)	4.42 (2.72)
4. Headache			
	Male	2.47 (2.00)	3.07 (2.19)
	Female	2.74 (2.24)	2.90 (2.17)
5. Eyestrain			
	Male	4.73 (2.34)	5.00 (1.96)
	Female	5.26 (2.34)	5.48 (2.69)
6. Difficulty focusing			
	Male	4.47 (2.70)	4.33 (2.13)
	Female	4.39 (2.63)	4.48 (2.82)
7. Increased salivation			
	Male	2.60 (1.59)	2.60 (1.96)
	Female	2.23 (1.65)	2.13 (1.69)
8. Decreased salivation			
	Male	2.47 (1.81)	2.60 (1.76
	Female	1.71 (1.51)	1.94 (1.24)
9. Nausea			
	Male	2.00 (1.31)	2.47 (1.73)
	Female	1.84 (1.53)	1.87 (1.41)
10. Diff. Concentrating			
	Male	3.00 (1.93)	3.47 (1.92)
	Female	2.74 (1.77)	3.16 (2.22)
11. Blurred vision			
	Male	4.47 (2.39)	4.87 (1.85)
	Female	4.10 (2.64)	4.65 (3.09)
12. Dizzy			
	Male	2.27 (1.16)	2.13 (1.30)
	Female	2.29 (2.15)	2.23 (2.17)
13. Vertigo			
	Male	1.53 (1.13)	1.47 (1.06)
	Female	1.39 (1.31)	1.48 (1.23)

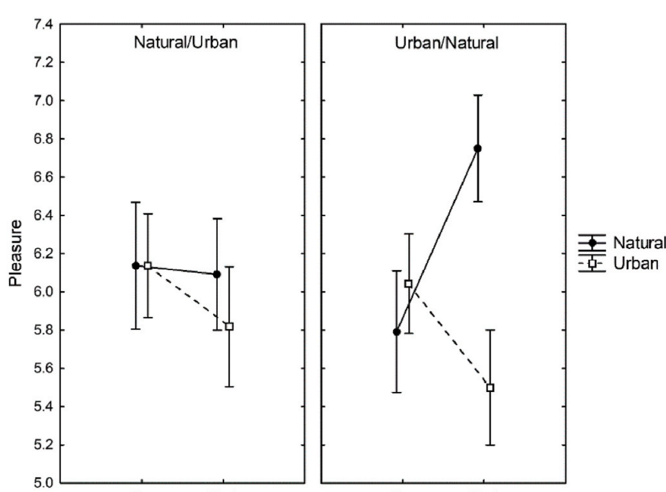

Fig. 2. Mean level of pleasure participants reported in the Natural/Urban and Urban/Natural order of presentation. The error bars indicate standard errors.

PrePost (Pre vs. Post) and *Environment* (Natural vs. Urban) as within-subject factors and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors. Results showed a significant interaction between *Environment* and *Order* [F (1,42) = 11.82, $p < .001$, $\eta_p^2 = .22$] indicating similar levels of arousal in the Natural/Urban order between environments ($p = .687$), but a significant difference between the environments was observed in the Urban/Natural order of presentation ($p = .012$). The level of arousal after watching the natural video did not change between the Natural/Urban and Urban/Natural order of presentation ($p > .05$), but participants reported a higher level of arousal after watching the urban video in the Urban/Natural condition compared to the Natural/Urban condition ($p = .046$). Moreover, we observed a significant interaction between *PrePost* and *Environment* [F (1,42) = 9.51, $p = .004$, $\eta_p^2 = .18$] (Fig. 3). Results showed a significant difference between levels of arousal after watching the videos ($p = .05$), but no significant difference before the videos presentation ($p > .05$). This modification in participants' level of arousal was determined by a reduced level of arousal between pre- and post-Natural video presentations ($p < .009$), but no difference between pre- and post-Urban video presentations was observed ($p > .05$).

4.1.4. *The restorative quality of environments*

Four independent repeated measure ANOVAs with *Environment* (Natural vs. Urban) as within-subject factor and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors were conducted. *Being Away*: A significant main effect of *Environment* [F (1,42) = 154.51, $p < .001$, $\eta_p^2 = .79$] was observed, indicating participants reported a higher feeling of being away after watching the Natural video compared to the Urban, independent of the order of video presentation (Fig. 4A). *Scope*: We observed a significant effect of *Environment* [F (1,42) = 11.76, $p < .001$, $\eta_p^2 = .22$] and a significant interaction between *Environment* and *Order* [F (1,42) = 5.44, $p = .025$, $\eta_p^2 = .19$] indicating a significant difference between environments in the Urban/Natural order of video presentation ($p < .001$; Fig. 4B). *Coherence*: We observed no main effect or interaction between variables (all $p > .111$, $\eta_p^2 = .06$) (Fig. 4C). *Fascination*: We observed a significant effect of *Environment* [F (1,42) = 18.33, $p < .001$, $\eta_p^2 = .30$] indicating a higher level of fascination after watching the Natural video (Fig. 4D).

4.2. *Timing tasks*

For all timing tasks, the data were analyzed regarding the estimated-to-target-duration ratio (RATIO). The RATIO (RATIO = *Sd/Od*) was obtained by dividing each participant's time performance (*Sd* represents the subjective duration the participants expressed) by the time duration of the interval presented (*Od* represents the objective presented target duration; Mioni et al., 2014). The RATIO provided an index of the direction of errors, with coefficients above and below 1.0 being indicative

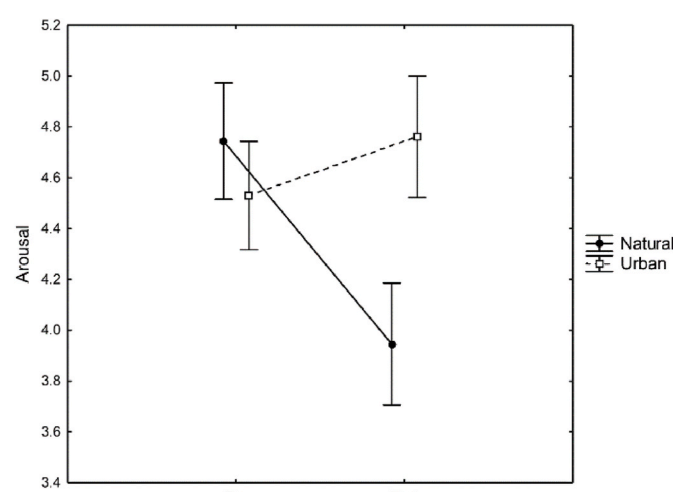

Fig. 3. Mean level of arousal participants reported before and after watching natural or urban videos. The error bars indicate standard errors.

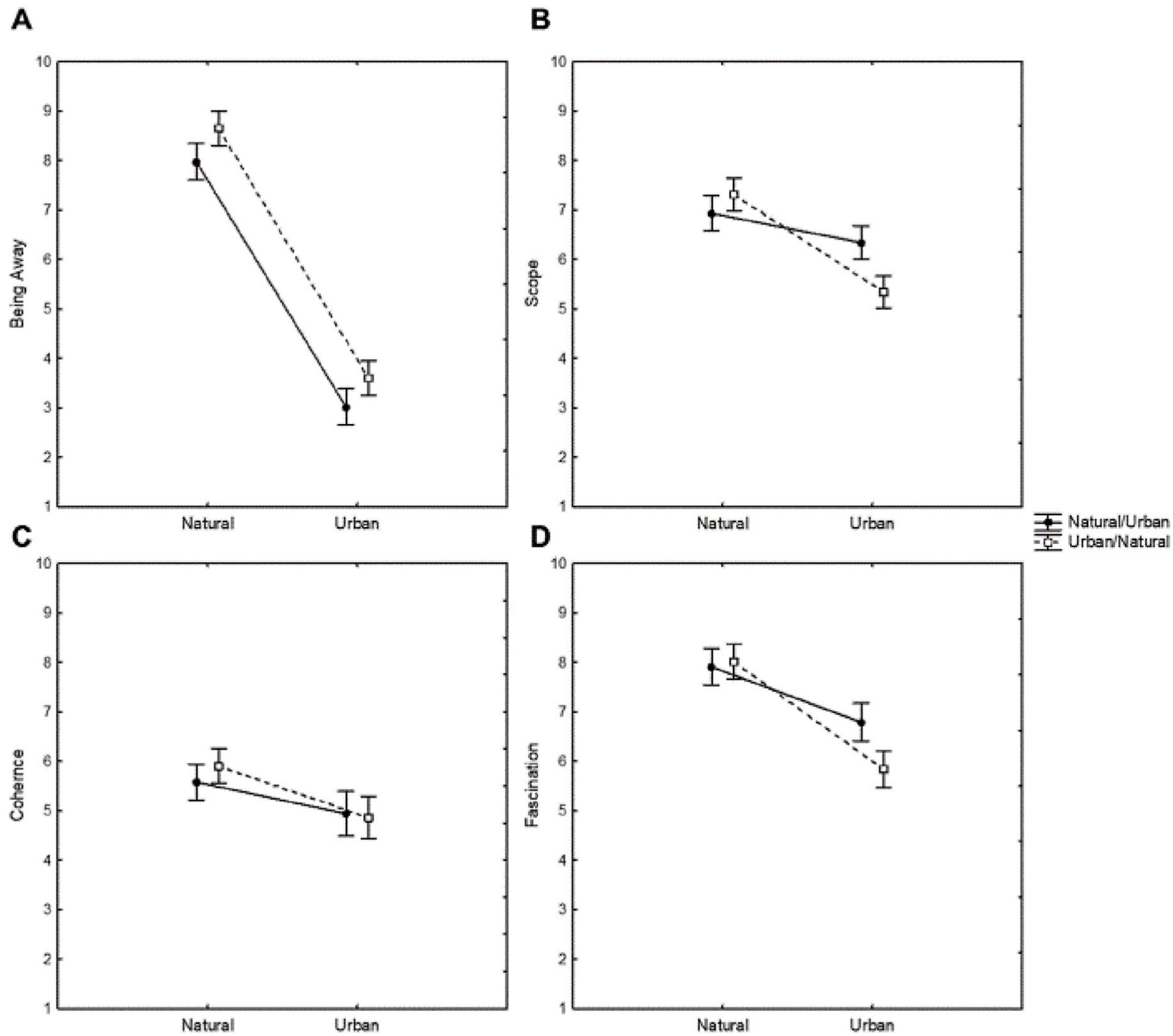

Fig. 4. Mean level of Being away (A), Scope (B), Coherence (C), and Fascination (D) as a function of the environment and order of video presentation. The error bars indicate standard errors.

of over-estimation and under-estimation, respectively.

4.2.1. Time prospective tasks

4.2.1.1. Time production task. A repeated measure ANOVA with *PrePost* (Pre vs. Post), *Environment* (Natural vs. Urban) and *Intervals* (3, 5, and 10 s) as within-subject factors and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors were conducted.

Results showed a main effect of *Intervals* [F (2,84) = 15.68, $p < .001$, $\eta_p^2 = .27$] indicating that participants underestimated time as the duration of the intervals to produce increased (3 vs. 5: $p = .97$; 3 vs. 10: $p < .001$; 5 vs. 10: $p < .001$). The effect of *Gender* was also significant [F (1,42) = 7.27, $p = .010$, $\eta_p^2 = .15$] indicating that female participants under-reproduce time more than male participants. Moreover, the interaction *Environment* × *Order* was significant [F (1,42) = 14.18, $p < .001$, $\eta_p^2 = .25$] indicating that participants overproduced time in the Natural/Urban condition in the Urban compared to the Natural condition ($p = .031$) and in the Urban/Natural condition while watching the natural compared to the urban video ($p = .049$). The interaction *PrePost* × *Environment* × *Order* was significant [F (1,42) = 4.66, $p = .037$, $\eta_p^2 = .10$] indicating that participants in the Natural/Urban tended to under-reproduce natural environment more than urban environment ($p = .036$). Overall, this interaction indicated that participants overproduced time in the second block of the experimental procedure irrespective of the video presented.

4.2.1.2. Time production task. Data were included in a repeated measure ANOVA with *Environment* (Natural vs. Urban) as within-subject factor and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors. Results showed a main effect of *Environment* [F (1,34) = 6.85, $p = .013$, $\eta_p^2 = .17$] indicating that participants generally underestimated time in particular while watching the urban video (Fig. 5A).

4.2.1.3. Time retrospective task. Data were included in a repeated measure ANOVA with *Environment* (Natural vs. Urban) as a within-subject factor and *Order* (Natural/Urban vs. Urban/Natural) and Gender (male vs. female) as between-subject factors. Results showed a main effect of *Environment* [F (1,42) = 7.50, $p = .009$, $\eta_p^2 = .15$] indicating that participants generally overestimated time in particular while watching the urban video (Fig. 5B).

5. Discussion

The present study was conducted to further investigate the different effects of natural and urban environments on the subjective experience of time in VRE. Previous studies reported beneficial effects of being

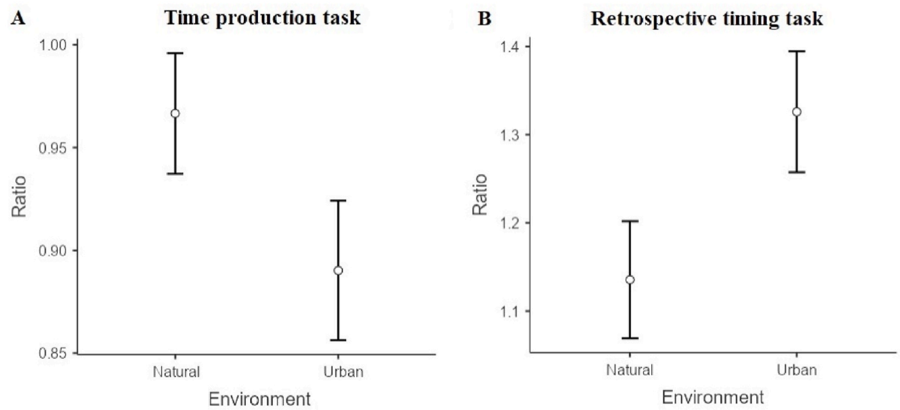

Fig. 5. Mean Ratio for the time production task (A) and retrospective time task (B).

exposed to the natural environment on well-being (De Bloom et al., 2017; Korpela & Kinnunen, 2011; Bratman et al., 2011) and cognition (Faber Taylor & Kuo, 2009; Mason et al., 2021; Taylor et al., 2001). Studies have also indicated that the subjective experience of time changes if participants are asked to estimate retrospectively how much time has passed in natural and urban environments (Berry et al., 2015; Davydenko & Peetz, 2017). The few studies conducted are very different in terms of methodological setting adopted: Berry et al. (2015) used a series of photos of natural or urban environments while Davydenko and Peetz (2017) tested participants outside a controlled laboratory setting and asked them to walk in natural and urban environments. Using VRE offers high levels of realism and greater levels of experimental control than in naturalistic settings. Here, for the first time, we have controlled in a within-subject design, the different effects of a naturalistic and virtual environment on the subjective perception of time. Further, this was the first study that explore the distinctive effects of urban and natural environments in different components of time processing (i.e., prospective and retrospective timing).

Concerning the results observed from the questionnaire, participants did not differ regarding subjective feelings of passage in relation to Natural/Urban or Urban/Natural order of the videos presented. Results of the STQ questionnaire (Mioni et al., 2020; Wittmann & Lehnhoff, 2005) indeed indicated that participants had a similar feeling of time passing at present (“How fast does time usually pass for you?“) or past (“How fast did the previous 10 years pass for you?“) moments. Surprisingly, we only observed a difference between groups regarding the subjective feeling of time during the last month (How fast did the previous month pass for you?). Participants in the Natural/Urban condition had a feeling that time has passed more quickly the previous month compared to participants in the Urban/Natural condition. In addition, no differences between groups were observed concerning the feeling of time pressure, time expansion, and the metaphors of time.

Results from the PRS-11 questionnaire (Pasini et al., 2014) indicated a higher perceived restoration when exposed to nature compared to urban environments. Only for the coherence subscale, we did not observe a difference between being exposed to natural and urban environments in our participants. This is in accordance with Hartig et al. (1996), who found that coherence subscale scores were differentially sensitive to the site characteristics in comparison with being-away and fascination evaluations. In particular, in our study participants reported higher restorative scores when exposed to natural videos compared to urban ones. Interestingly, a significant interaction also emerged between environment and order of presentation for the subscale “scope.” Participants in the Urban/Natural condition increased their perception of being in an environment without boundaries to limit their movement and exploration after watching the natural compared to the urban video. The results were similar for the SAM concerning the level of arousal and pleasure. Participants generally reported an increased level of arousal and decreased level of pleasure after being exposed to the urban video compared to the natural one. The fact that the negative impact of the urban environment was more evident in the Urban/Natural condition compared to the Natural/urban condition can be interpreted in line with the beneficial effect of the natural environment on psychological and cognitive well-being. It is possible that watching the natural environment first has acted as a protective factor reducing the negative impact of watching a video showing an urban environment. Also, our results can be interpreted in line with the two most important restoration theories (Attention Restoration Theory; Kaplan & Kaplan, 1989; and Stress Reduction Theory; Ulrich, 1983). In both, it is stated that the restorative effects of nature take place when an organism is in a state of stress and/or cognitive fatigue. It may be that the vision of the urban video, with the urban typical soundscape, traffic and crowding had induced stress in participants, which favoured the successive restoration. Future studies should further investigate this issue. Taken together, results obtained from the questionnaires confirm the beneficial effects of being exposed to a natural environment compared to an urban one, even when participants are in VRE.

More germane to the present study are the data concerning the temporal tasks. We selected three timing tasks, two defined as prospective tasks and one to tap retrospective timing. No effect of environments was observed for the time production task performed before/after the videos. Participants equally produced the temporal intervals before and after watching the videos. Berry et al. (2015) also failed to find an effect of natural and urban environments when tested with a time bisection task. Despite some methodological differences between production and bisection tasks, these measures have some similarities that might explain our and Berry et al.’s (2015) results. In both tasks, participants were first informed about the reference intervals that had to be used as anchor durations for the subsequent temporal judgments in the case of the time bisection task (Kopec & Brody, 2010) or accurately produced in the case of the time production task (Mioni, 2018). It is possible that participants (university students) were able to create a stable representation of reference intervals in reference memory and use it to perform the tasks subsequently. Also, it is important to note that the strongest effect of emotional stimuli on time occurs when the emotional manipulation is done during the interval to be timed. We have observed a main effect of gender indicating that female participants tended to underestimate time more than male participants. Our results are in line with previous studies indicating a tendency in women to underproduce time (Block et al., 2000; Espinosa-Fernández et al., 2003; Glicksohn & Hadad, 2011; Hancock et al., 1994).

More interesting are the results of the production task obtained while watching the videos; participants were asked to press a key when 1 min had passed since a red dot appeared at the centre of the video. Participants were more accurate when producing 1 min while watching the natural video and underestimated time when exposed to the urban video. Our results are in line with Davydenko and Peetz's (2017), indicating the effect of environments on the subjective experience of time. We discuss our results according to the attentional gate model (Zakay & Block, 1995, 2004). This model posits that the subjective experience of time depends on the amount of temporal information stored in the accumulator, which is the amount of attention dedicated to time modulates. If attention is driven away from time, less temporal information is stored in the accumulator, producing a subjective underestimation. Because urban environments are less restorative and require more attentional resources, it is possible that attentional resources were taken away from time. Concerning the time reproduction task, we observed that participants were more accurate when judging the duration of the natural video and overestimated time when exposed to the urban video. This result is in line with the prospective timing data; in fact, if participants engaged more attentional resources watching the urban video, it is possible that they recalled more information and therefore overestimated time (contextual-change model; Block & Zakay, 2004). Our results concerning retrospective time contrast what Berry et al. (2015) and Davydenko and Peetz (2017) reported. The procedure adopted was quite similar. Indeed, in all studies, participants were asked to estimate retrospectively how long was their subjective experience with the natural or urban environments. However, Berry et al. (2015) used images, Davydenko and Peetz (2017) asked participants to walk in underground university tunnels that connected campus buildings (urban) or along a river on the edge of campus (nature), and in our study, we used 5-min videos of a walk in the woods or in a metropolitan city.

We acknowledge that the present work has some limitations. Firstly, gender unbalanced composition of our sample. It is important to note that our participants were recruited from a psychology department, therefore, our resulting sample is clearly not balanced, also females are in general more inclined to agree to participate in studies (Dickinson et al., 2012). Future studies should consider limiting gender unbalancing.

The present study adds to the current knowledge of how being exposed to different types of environments might affect participants' perception of time as well as gives important insights into the use of VRE in experimental and clinical settings. Indeed, using a virtual reality environment can enhance the "sense of presence" and have interesting implications for researchers, interested in understanding how the flow of time is perceived in a virtual environment as well as clinicians interested in innovative ways to elicit and modulate emotions through multisensory cues.

In conclusion, the present study compared the effects on prospective and retrospective time estimation tasks after virtual walking through two outdoor, natural and urban, environments. The use of VRE allowed us to control the timing and walking speed in the two conditions. Results indicated interesting differences in time estimation (prospective and retrospective timing) between the natural and urban environments, in accordance with expectations derived from timing models. Further studies would be necessary to better define what specific characteristics of the administered natural and urban environments (e.g., complexity, richness in stimulation, openness, etc.) are likely to produce the observed effects in time perception.

Data availability statement

The data that supports the findings of this study are openly available together with analysis syntaxes on https://osf.io/cp3w2/

Acknowledgements

The information in this manuscript and its content has never been published either electronically or in print. There is no financial or other relationship that could be interpreted as a conflict of interest affecting this manuscript. This research received no specific grant from any funding agency, commercial or not-for-profit sectors. This work was conducted within the scope of the project "use-inspired basic research," for which the Ministry of University and Research has recognized the Department of General Psychology of the University of Padova as "Dipartimento di Eccellenza". The authors wish to thank Valeria Furriolu and Luigi Micillo for their valuable help in the data collection phase.

References

Allman, M. J., & Meck, W. H. (2012). Pathophysiological distortions in time perception and timed performance. *Brain, 135*(3), 656–677.

Baumann, A. A., & Odum, A. L. (2012). Impulsivity, risk taking, and timing. *Behavioural Processes, 90*(3), 408–414.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*(12), 1207–1212.

Berry, M. S., Repke, M. A., Nickerson, N. P., Conway, L. G., III, Odum, A. L., & Jordan, K. E. (2015). Making time for nature: Visual exposure to natural environments lengthens subjective time perception and reduces impulsivity. *PLoS One, 10*(11), Article e0141030.

Block, R. A., Grondin, S., & Zakay, D. (2018). Prospective and retrospective timing processes: Theories, methods, and findings. In *Timing and time perception: Procedures, measures, & applications* (pp. 32–51). Brill.

Block, R. A., Hancock, P. A., & Zakay, D. (2000). Sex differences in duration judgments: A meta-analytic review. *Memory & Cognition, 28*, 1333–1346.

Bolognesi, M., Toffalini, E., & Pazzaglia, F. (2023). Perceived psychological restorativeness in relation to individual and environmental variables: A study conducted at poetto beach in sardinia, Italy. *Sustainability, 15*, 2794. https://doi.org/10.3390/su15032794

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59.

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning, 138*, 41–50.

Capaldi, C. A., Passmore, H.-A., Nisbet, E. K., Zelenski, J. M., & Dopko, R. L. (2015). Flourishing in nature: A review of the benefits of connecting with nature and its application as a wellbeing intervention. *International Journal of Wellbeing, 5*(4), 1–16. https://doi.org/10.5502/ijw.v5i4.449. do i:.

Chirico, A., Lucidi, F., De Laurentiis, M., Milanese, C., Napoli, A., & Giordano, A. (2016). Virtual reality in health system: Beyond entertainment. A mini-review on the efficacy of VR during cancer treatment. *Journal of Cellular Physiology, 231*(2), 275–287.

Daniels, S., Clemente, D. B., Desart, S., Saenen, N., Sleurs, H., Nawrot, T. S., … Plusquin, M. (2022). Introducing nature at the work floor: A nature-based intervention to reduce stress and improve cognitive performance. *International Journal of Hygiene and Environmental Health, 240*, Article 113884.

Davydenko, M., & Peetz, J. (2017). Time grows on trees: The effect of nature settings on time perception. *Journal of Environmental Psychology, 54*, 20–26.

De Bloom, J., Sianoja, M., Korpela, K., Tuomisto, M., Lilja, A., Geurts, S., & Kinnunen, U. (2017). Effects of park walks and relaxation exercises during lunch breaks on recovery from job stress: Two randomized controlled trials. *Journal of Environmental Psychology, 51*, 14–30.

Dickinson, E. R., Adelson, J. L., & Owen, J. (2012). Gender balance, representativeness, and statistical power in sexuality research using undergraduate student samples. *Archives of Sexual Behavior, 41*, 325–327. https://doi.org/10.1007/s10508-011-9887-1

Espinosa-Fernández, L., Miró, E., Cano, M., & Buela-Casal, G. (2003). Age-related changes and gender differences in time estimation. *Acta Psychologica, 112*(3), 221–232.

Faber Taylor, A., & Kuo, F. E. (2009). Children with attention deficits concentrate better after walk in the park. *Journal of Attention Disorders, 12*(5), 402–409.

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences, 423*, 52–77.

Glicksohn, J., & Hadad, Y. (2011). Sex differences in time production revisited. *Journal of Individual Differences, 33*(1), 35–42.

Hancock, P. A., Arthur, E. J., Chrysler, S. T., & Lee, J. (1994). The effects of sex, target duration, and illumination on the production of time intervals. *Acta Psychologica, 86*(1), 57–67.

Hartig, T., Korpela, K., Evans, G. W., & Gärling, T. (1996). *Validation of a measure of perceived environmental restorativeness (Göteborg Psychological Reports, 26:7)*. Göteborg: Department of Psychology, Göteborg University.

Howell, A. J., Dopko, R. L., Passmore, H. A., & Buro, K. (2011). Nature connectedness: Associations with well-being and mindfulness. *Personality and Individual Differences, 51*(2), 166–171.

Jo, H., Song, C., & Miyazaki, Y. (2019). Physiological benefits of viewing nature: A systematic review of indoor experiments. *International Journal of Environmental Research and Public Health, 16*(23), 4739. https://doi.org/10.3390/ijerph16234739

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge, UK: Cambridge University Press.

Kopec, C. D., & Brody, C. D. (2010). Human performance on the temporal bisection task. *Brain and Cognition, 74*(3), 262–272. https://doi.org/10.1016/j.bandc.2010.08.006

Korpela, K., & Kinnunen, U. (2011). How is leisure time interacting with nature related to the need for recovery from work demands? Testing multiple mediators. *Leisure Sciences, 33*(1), 1e14.

Kvam, P. D., Baldwin, M., & Westgate, E. C. (2023). Cognitive mechanisms underlying subjective value of past and future events: Modeling systematic reversals of temporal value asymmetry. *Decision, 10*(1), 1.

Laumann, K., Gärling, T., & Stormark, K. M. (2003). Selective attention and heart rate responses to natural and urban environments. *Journal of Environmental Psychology, 23*(2), 125–134.

Macaulay, R., Lee, K., Johnson, K., & Williams, K. (2022). Mindful engagement, psychological restoration, and connection with nature in constrained nature experiences. *Landscape and Urban Planning, 217*, Article 104263.

Mason, L., Ronconi, A., Scrimin, S., & Pazzaglia, F. (2021). Short-term exposure to nature and benefits for students' cognitive performance: A review. *Educational Psychology Review*. https://doi.org/10.1007/s10648-021-09631-8

McCay, L., Bremer, I., Endale, T., Jannati, M., & Yi, J. (2019). *Urban design and mental health*. Urban Mental Health.

Menardo, E., Brondino, M., Hall, R., & Pasini, M. (2021). Restorativeness in natural and urban environments: A meta-analysis. *Psychological Reports, 124*(2), 417–437.

Mioni, G. (2018). Methodological issues in the study of prospective timing. In *Timing and time perception: Procedures, measures, & applications* (pp. 79–97). Brill.

Mioni, G., Stablum, F., McClintock, S. M., & Grondin, S. (2014). Different methods for reproducing time, different results. *Attention, Perception, & Psychophysics, 76*, 675–681. https://doi.org/10.3758/s13414-014-0625-3

Mioni, G., Wittmann, M., Prunetti, E., & Stablum, F. (2020). Time perspective and the subjective passage of time in patients with borderline personality disorders. *Timing & Time Perception, 8*(1), 86–101.

Moreira, D., Pinto, M., Almeida, F., & Barbosa, F. (2016). Time perception deficits in impulsivity disorders: A systematic review. *Aggression and Violent Behavior, 27*, 87–92.

Parsons, T. D. (2015). Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in Human Neuroscience, 9*, 660.

Pasini, M., Berto, R., Brondino, M., Hall, R., & Ortner, C. (2014). How to measure the restorative quality of environments: The PRS-11. *Procedia-Social and Behavioral Sciences, 159*, 293–297.

Rosa, C. D., Larson, L. R., Collado, S., Cloutier, S., & Profice, C. C. (2023). Gender differences in connection to nature, outdoor preferences, and nature-based recreation among college students in Brazil and the United States. *Leisure Sciences, 45*(2), 135–155.

Schertz, K. E., & Berman, M. G. (2019). Understanding nature and its cognitive benefits. *Current Directions in Psychological Science, 28*(5), 496–502.

Schneider, S. M., Kisby, C. K., & Flint, E. P. (2011). Effect of virtual reality on time perception in patients receiving chemotherapy. *Supportive Care in Cancer, 19*(4), 555–564.

Stevenson, M. P., Schilhab, T., & Bentsen, P. (2018). Attention restoration theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *Journal of Toxicology and Environmental Health, Part A B, 21*(4), 227–268.

Sudimac, S., Sale, V., & Kühn, S. (2022). *How nature nurtures: Amygdala activity decreases as the result of a one-hour walk in nature*.

Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2001). Coping with ADD: The surprising connection to green play settings. *Environment and Behavior, 33*(1), 54–77.

Teuscher, U., & Mitchell, S. H. (2011). Relation between time perspective and delay discounting: A literature review. *Psychological Record, 61*(4), 613–632.

Thönes, S., & Oberfeld, D. (2015). Time perception in depression: A meta-analysis. *Journal of Affective Disorders, 175*, 359–372.

Tobin, S., Bisson, N., & Grondin, S. (2010). An ecological approach to prospective and retrospective timing of long durations: A study involving gamers. *PLoS One, 5*(2), Article e9271.

Treisman, M. (1963). Temporal discrimination and the indifference interval. Implications for a model of the internal clock. *Psychological Monographs, 77*(13), 1–31.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*, 201–230.

Van Hedger, Nusbaum, H. C., Clohisy, L., Jaeggi, S. M., Buschkuehl, M., & Berman, M. G. (2019). Of cricket chirps and car horns: The effect of nature sounds on cognitive performance. *Psychonomic Bulletin & Review, 26*, 522–530.

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., … Fleming, L. E. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports, 9*(1), 1–11.

Wittmann, M., & Lehnhoff, S. (2005). Age effects in perception of time. *Psychological Reports, 97*(3), 921–935.

Wittmann, M., & Paulus, M. P. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences, 12*(1), 7–12.

Wittmann, M., Simmons, A. N., Flagan, T., Lane, S. D., Wackermann, J., & Paulus, M. P. (2011). Neural substrates of time perception and impulsivity. *Brain Research, 1406*, 43–58.

Zakay, D., & Block, R. A. (1995). An attentional gate model of prospective time estimation. In M. Richelle, V. D. Keyser, G. D. Ydeualle, & A. Vandierendonck (Eds.), *Time and the dynamic control of behavior* (pp. 167–178). Liege: University of Liege Press.

Zakay, D., & Block, R. A. (2004). Prospective and retrospective duration judgments: An executive-control perspective. *Acta Neurobiologiae Experimentalis, 64*(3), 319–328.

Zakay, D., Tsal, Y., Moses, M., & Shahar, I. (1994). The role of segmentation in prospective and retrospective time estimation processes. *Memory & Cognition, 22*(3), 344–351.