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Understimulation resembles overstimulation: Effects on school children's attentional performance, affect, and environmental preference

Henk Staats [a], Silvia Collado [b,*], Miguel A. Sorrel [c]

[a] Department of Social, Economic, and Organizational Psychology, Leiden University, the Netherlands
[b] Department of Psychology and Sociology, Universidad de Zaragoza, Spain
[c] Department of Social Psychology and Methodology, Universidad Autónoma de Madrid, Spain

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ABSTRACT

Research on restorative environments has long examined the benefits of nature exposure for people whose resources have been depleted due to a situation that is too demanding for the individual. We argue that people's resources can also be taxed in understimulating situations, in which there is a lack of sensory, cognitive, social and/or behavioral stimulation, leading to a need for recovery. Exploring this phenomenon forms the main objective of this study. Given the potential benefits that contact with nature in educational centres has for children, we chose young children (N = 145, Mage = 9.34) at school as participants. We conducted a 3 (stimulation: under, over, and control) by 2 (environments: natural, urban) by 3 (time: before stimulation treatment, just after, and after exposure to environment) mixed-mode experiment. The environments were simulated through a series of slides presented on a screen in the classrooms where also the initial part of the experiment took place. Our results show that both under- and overstimulating situations are taxing for children's capacity for attention, and that understimulation decreases children's positive affect. After overstimulation, exposure to natural scenes restored attentional capacities, while exposure to urban scenes did not. After understimulation, exposure to any of the environments (nature; urban) restored children's attentional capabilities and lifted their mood. Future research could focus especially on low stimulation/low meaning situations to better understand their negative effects on attention and mood.

Studies in environmental psychology, public health, and outdoor recreation suggest that contact with nature can alleviate some of the negative symptoms of our children's contemporary lifestyle, in societies characterized as WEIRD (Western, educated, industrial, rich, democratic; Henrich et al., 2010). Exposure to nature improves children's mental (Tillmann et al., 2018) and physical (Fyfe-Johnson et al., 2021) health, increases relaxation (Korpela et al., 2002), and improves children's mood (Bagot et al., 2015), and ability to focus (Wells, 2000). It might also enhance children's socio-emotional development (Mygind et al., 2023). Much of the research about the psychological benefits that contact with nature has for children is included in the realm of psychological restoration (Moll et al., 2022). Psychological restoration refers to the renewal or recovery of adaptive resources or capabilities that have become depleted in meeting the demands of everyday life (cf. Hartig 2004).

Restoration always occurs in the context of an activity that involves some form and degree of engagement with the sociophysical environment (e.g., Staats et al., 2010). Since its origins in the 1960s, research on restorative environments has increasingly become organized around psychoevolutionary or stress reduction theory (SRT; Ulrich 1983; Ulrich et al., 1991), and attention restoration theory (ART; Kaplan & Kaplan, 1989), which concerns the renewal of a capacity for directed attention. SRT and ART make assumptions about the lasting significance of natural environments, postulating that people will restore better in environments that have characteristics that were beneficial for survival during early evolution. The two theories propose that exposure to natural environments is, in general, more restorative than exposure to urban environments. These propositions have been supported by experimental and correlational research, both with adults and with children (Collado et al., 2017; Ohly et al., 2016; Staats, 2012). For instance, researchers have shown the restorative benefits of the presence of nature within the neighborhood (Kuo & Sullivan, 2001) or school grounds (Kelz et al., 2015), and of a natural view from home (Kaplan, 2001) or one's office (Chang & Chen, 2005).

* Corresponding author. Department of Psychology and Sociology, Universidad de Zaragoza, Ciudad Escolar, 44003, Teruel, Spain.
E-mail addresses: staats@fsw.leidenuniv.nl (H. Staats), scollado@unizar.es (S. Collado), miguel.sorrel@uam.es (M.A. Sorrel).

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Both ART and SRT focus on restoration from a state in which the situation has been too demanding and the individual's resources to cope with those demands have diminished. In the ART framework, coping is conceptualized as the capacity to employ directed attention, and as the resource to be replenished after overuse. Accordingly, the description of restoration assumes an antecedent condition of depleted directed attention, or attentional fatigue. The majority of studies on restoration have considered attentional fatigue as the antecedent condition from which the person needs to be restored. As such, researchers have manipulated this antecedent condition through several means, like asking participants to remember how they feel after a long and demanding period of mental work (Staats et al., 2003) or to complete an attentionally demanding task (Collado & Manrique, 2020; Ohly et al., 2016). Given later developments in theory and empirical findings, we expand the concept of attentional fatigue to also apply to situations that are considered pleasant and fascinating but demanding. In the current study, theoretically inspired by ART, we refer to situations that surpass the individual's resources, as overstimulation. The research emphasis on overstimulating conditions makes sense as people often need to focus on tasks that require attentional effort (e.g., work, studying) while inhibiting distractions. However, other daily situations that require effort and tax attentional resources have been overlooked in restoration research. Specifically, we argue that there is a shortage of restoration studies that focus on the recovery from a lack of stimulation. Few researchers have called for the need for further examination of the possible benefits of exposure to nature for those who have experienced understimulating situations (Duvall, 2011; Whitehouse et al., 2001). In line with recent calls to extend theory and research concerned with the benefits of nature experience (Hartig, 2021; Stevenson et al., 2018), our study offers a first step to filling this gap in the literature by empirically examining the possible restorative effects of exposure to nature for understimulated children.

1. The curvilinear relation between stimulation and affect: optimal level theory

People are generally in need of stimulation, they are geared towards activity and not only to rest and absence of stimulation (Bexton et al., 1954; Hebb, 1955). People can be driven to despair when the environment offers too little stimulation, which thus creates a situation from which people may need recovery. That is elaborated in the concept of an optimal arousal potential. Arousal theorists suggest that individuals need an optimal level of stimulation, leading to a medium level of arousal, and that deviations from the optimal level (i.e., under-, over-stimulation) have detrimental consequences (Berlyne, 1960; Hebb, 1966; Wohlwill, 1974). Wohlwill (1966) considered the negative effects of being understimulated. He suggested that individuals spend a large part of everyday activity trying *"to heighten the level of incoming stimulation, by voluntary exposure to stimulus objects or situations that are novel, incongruous, surprising or complex"* (Wohlwill, 1966, p. 31). Understimulation may come as a lack of sensory, cognitive, social and/or behavioral stimulation (Wohlwill, 1974). A person can experience understimulation in several situations and environments, such as during hospitalization (Ulrich, 1984), while in prison (Ligthart et al., 2019), or at an elderly residence (Volkers & Scherder, 2011). It can also appear in more common environments and situations such as at work, at school, or at home, and lead to boredom. Boredom involves a state of nonoptimal arousal due to a mismatch between an individual's needed arousal and the availability of environmental stimulation (the arousal potential; see Berlyne, 1960; Hebb, 1966). In line with this definition, Eastwood et al. (2012, p. 483) describe boredom as an *"aversive state of wanting, but being unable to engage in satisfying activity"* with the cause of this aversive state attributed to the environment (e.g., "there is nothing to do"). In support of this explanation, Chin et al. (2017) found that while individual differences account for some variance in people's boredom, most of it is due to situational factors. According to Westgate and Steidle's (2020) Meaning and Attentional Component (MAC) model of boredom, boredom is especially likely to arise when the individual's resources surpass the situation's demands and the current activity does not comply with valued goals.

Of interest to the current paper, a lack of meaningful external stimulation usually requires the individual to exert effortful control over his/her focus of attention to compensate for the lack of exogenous engagement of attention (Eastwood et al., 2012). Over time, these attentional capabilities will be depleted. A lack of stimulation can thus lead to negative consequences, including negative feelings like irritability, frustration and displeasure (Westgate & Steidle, 2020), impulse control deficits such as drug and alcohol abuse (LePera, 2011), risk-taking (Steinberger et al., 2017) and impaired attentional performance (Freeman et al., 2004). Interestingly, Kaplan (1995) described similar negative consequences for those whose attentional capabilities have been diminished due to excessive demands for concentration on issues of little interest. These consequences include errors in performance, being inefficient at problem-solving, not being able to inhibit impulses, becoming easily distracted, experiencing difficulties in developing and executing a plan, behaving in inappropriate or unhelpful ways, and negative feelings such as irritability. While both overstimulation and understimulation situations are detrimental to attention, task performance, and well-being (Freeman et al., 2004), only the restorative potential of exposure to nature to recover from overstimulated situations has been examined. Hence, it seems that two questions are unaddressed: The most obvious one being whether exposure to nature is restorative for understimulated people, while the second one is whether exposure to urban environments can do likewise, or even better.

2. Degree of stimulation and environmental preference

The second question touches upon an issue that previously has been conceptualized in different ways but clearly not in relation to understimulation. The stereotypical idea is that urban environments overload people (Milgram, 1970), and contact with nature compensates for this, due to its lower level of stimulation, of a kind that people can easily deal with. But we do not know whether this is always true nor if this is in particular true when in need of restoration, as there are reasons for a much more differentiated perspective, given that some activities in specific urban environments can also be experienced as restorative (e.g., Herzog et al., 1997; Staats et al., 2016). We also do not know whether understimulated people have the same environmental preferences (i.e., natural over urban environments) as overstimulated people. Here we see a conflict in explanatory mechanisms: If the depletion of attention causes the need for restoration, both after understimulation and overstimulation, it seems possible that natural environments can be more beneficial in both conditions. Reasoning from an optimal level of stimulation perspective, however, it seems in fact more likely that understimulated people might prefer stimulation-rich urban environments. The seminal paper by Ulrich (1984), describing the positive effects of a nature view for hospital patients, finished with the speculation that *"Perhaps, to a chronically understimulated patient, a built view such as a lively street might be more stimulating and hence more therapeutic than many natural views."* (Ulrich, 1984, p. 421). However, this is a speculation that has so far not given rise to systematic research. We are therefore conservative in developing hypotheses and will stick to the view that natural environments are more restorative than built ones, for overstimulated persons but also for understimulated persons, based on the depletion of attention framework. But we will provide possibilities to find the opposite outcome. Thus, this study aims to make a start by answering the two questions posed above.

3. The present study

Our primary aim is to take a closer look at the restorative effect that nature exposure may have on understimulated children. A lack of stimulation can have a profound negative effect on school-aged children and adolescents (Plummer, 2019). There is some evidence indicating that young people are most sensitive to a lack of external stimulation, more so than older people (Chin et al., 2017). This highlights the relevance of the issue for school-age children. At the same time, schools are characterized as imposing high demands on children, which might lead to resource depletion due to overstimulation. Considering this, we believe it is necessary to (a) explore whether exposure to natural scenes has restorative effects for both understimulated and overstimulated children, and (b) provide a meaningful comparison by looking at the restorative effect of natural scenes relative to those of urban scenes. We look at effects in particular for understimulated children, but make comparisons with overstimulated children and a control group not in need of restoration. We will look for effects on a cognitive level - an attentional task-, on affect, and on behavioral intentions, specified in the following hypotheses.

First, we expect a highly stimulating situation to diminish attentional capabilities and task performance (Stevenson et al., 2019), and to decrease positive affect (Kaplan, 1995). Similarly, we expect that a lack of stimulation leads to attentional costs, performance errors, and enhances negative affect (Eastwood et al., 2012). Therefore, we hypothesize that both an overstimulating situation and an understimulating situation will decrease children's performance in tasks that require the use of attentional resources (H1a) and will decrease positive affect (H1b).

Second, prior studies have shown that natural environments can be restorative for overstimulated people, both in terms of the recovery of attentional capabilities and positive affect (Hartig, 2021). At the same time, when suggesting opportunities for targeted interventions to reduce boredom, Westgate and Steidle (2020) propose that, when boredom is caused by a lack of demand (i.e., an understimulation situation), the individual should look for an interesting activity and/or increase the level of demand, provided these activities or challenges raise spontaneous attention. Because the depletion is supposed to be attentional we expect, in line with restoration theories, visual exposure to natural as compared to urban environments to be more restorative, i.e., increase attentional capabilities (H2a) and positive affect (H2b) for both under- and over-stimulated children. However, there is an alternative perspective: Starting from ART's premise that restorative environments are those that elicit involuntary, i.e., spontaneous attention (Kaplan, 1995), there are situations and environments that are urban that can also evoke involuntary attention. This is for example described by Herzog et al. (1997) who studied sports/entertainment settings and found these to be restorative. This opens the possibility that urban environments, generally perceived as more complex (Kaplan et al., 1972), could be more restorative than natural environments for understimulated children, craving stimuli (Silvia, 2008), both regarding attentional performance (H3a) and positive affect (H3b). We expect this to be a possibility when the urban environments are similar in aesthetic quality to the natural environments, a selection criterion for the environments to be shown in the experiment (see Collado & Manrique, 2020).

Third, when in need of restoration after overstimulation, people tend to prefer to walk in a natural environment instead of in an urban one (Hartig & Staats, 2006; van den Berg et al., 2003). In this study, our expectation is that over- and under-stimulated children will prefer to walk in a natural environment as compared to an urban one (H4a). However, for the same reasons provided in the alternative perspective described above, it may be the case that understimulated children prefer to walk in urban environments over natural ones (H4b) and that preference to walk in urban environments is higher for understimulated children compared to overstimulated ones (H4c).

4. Method

4.1. Participants and design

Data were collected in a state primary school in Spain. The study was approved by the Ethics Committee of Universidad Autónoma de Madrid (CEI 113–2234) as well as by the school board. Parents were sent an informed consent letter together with the study's information. The letter was sent to the parents with their child's daily agenda, and parents were asked to sign it if they agreed with their child's participation in the study. Most parents returned a signed authorization (92%). Children were also asked for consent and told that they were not required to participate in the study if they did not want to. They were also assured that they could stop their participation whenever they wanted. Children diagnosed with attentional deficits were also invited to participate, but their results were not considered for this study. One hundred and forty-five children (57.9% boys) aged 8–11 years old ($M = 9.34$, $SD = 1.02$) participated in this study.

The design of the study is a 3 (Stimulation; over, under, and control) by 2 (Environment; natural, urban) by 3 (Time; T0, before stimulation; T1, just after stimulation treatment; T2, after exposure to environment) mixed-mode design. As will be detailed below, the analyses involved studying 6 or 12 groups coming from two measurements (time points). Within the possibilities of data collection, we aimed for a sample size close to 150 which would allow for a statistical power above 0.90 to detect large effect sizes. Working with a sample of children made it difficult to obtain a larger sample size, which calls for caution in concluding the detection of small or medium effects, for which statistical power may not be high enough. Environmental exposure was done through a slideshow. Outcomes indicative of fatigue and restoration were recorded by means of two different measures: Performance on an attentional task and positive affect (both at T0, T1, T2). Environmental preference for a walk was registered at T2.

4.2. Experimental manipulations and procedure

Data collection 0 (T0) served as a baseline. Attention and positive affect were registered. Then, the first part of the experimental manipulation took place: Students' classes were randomly assigned to one of the three experimental conditions (overstimulation, understimulation, control).

The first part of the experimental manipulation lasted 15 min: In the Overstimulation condition, children were asked to individually complete a series of crosswords and riddles. They were asked to do it the best they could. In the Understimulation condition, children were asked to remain on their seats, with nothing on their tables. They were told that they had some time to think about whatever they wanted, and that the teacher would tell them when time was over. Children were not allowed to interact with their peers and the teacher made sure that pupils did not make fun of the situation. Children were assured this was not a punishment and that, in fact, some children find this reflection time satisfying. In the Control condition, children were told that they had free time. They had to remain in the classroom, and they could do whatever they wanted with two exceptions: Nothing against the rules (e.g., playing football in class) and nothing attentionally fatiguing (e.g., studying, reading, homework). For example, some children decided to talk in small groups, made a drawing in their notebooks, some children looked at their class pet (a turtle), and others walked around the class. To keep the three conditions as similar as possible, the class blinds were down (to avoid external distractions) and the lights were on. There was nothing written on the blackboard and the teacher and researchers were at the back of the classroom. Children in the three groups were promised a small reward afterward (i.e., sweets and stickers). The experiment was physically organized so that children were divided into six classrooms, two classrooms for each condition. This was done to facilitate the second part of the experiment (see below). The six classrooms were on the same school floor, very similar to each other, and children were familiar with them. After this first part of the manipulation, attention and positive affect were registered (T1).

In the second part of the experiment, each of the three groups (i.e., overstimulation, understimulation and control) was split up into two subgroups (i.e., making six groups in total). Three subgroups, one of each of the three experimental conditions, were exposed to a PowerPoint presentation showing a series of natural scenes (14 scenes) and the three other subgroups to a PowerPoint presentation showing a series of urban scenes (14 scenes) (see *Environmental stimuli* below). The classroom conditions were the same as in part one, with the exception that the visual stimuli (i.e., nature/urban pictures) were projected on a screen situated in front of the classroom. Pictures, each shown for 30 s, would automatically pass from one to the next, so children would be exposed to the natural or urban scenes for 7 min. Data were collected for the third time immediately after this second part (T2).

4.3. Environmental stimuli

Given that natural images (e.g., a forest) used in previous studies (Berto, 2005; Hartig & Staats, 2006) are generally rated as more beautiful than manmade ones (e.g., cities), it is conceivable that beauty might act as a confounding variable and account for benefits traditionally attributed to nature (see Staats et al., 2003, p. 156). To control for beauty, we conducted a pilot test in which 14 children (*Mage* = 9.35, *SD* = 0.49) rated a series of natural and built scenes in terms of beauty. Children were asked "how beautiful do you think the picture shown is?", and responses ranged from 1 (not beautiful at all) to 4 (very beautiful). A research assistant was asked to search for pictures of mundane (non extraordinary) natural and urban scenes on the Internet. Previous research on restoration has shown that green areas and bodies of water are particularly restorative (Hartig & Staats, 2006) as well as urban plazas (Subiza-Perez et al., 2020; Tabrizian et al., 2018). Considering this, for the natural scenes, the assistant was instructed to look for pictures containing green areas and/or water. For the urban scenes, the assistant was asked to look for pictures of urban areas including plazas and quiet streets, and specifically avoiding busy roads and heavy traffic. For both natural and urban scenes, the research assistant was asked to select scenes in which walking seemed feasible. With those parameters in mind, the research assistant collected 49 pictures which were then screened by one of the article's authors. Following the initial screening, 42 natural and urban images were selected, mixed, and assigned to two different PowerPoint presentations (21 pictures per presentation). They were then projected on a big screen in front of the children's classroom (10 s per picture) and, to avoid children getting too tired of the tasks, they were rated on an individual basis on two separate days (i.e., on the first day children rated pictures in PowerPoint One and on the second day they rated pictures in Power Point Two). We then calculated the means for beauty and selected pictures that were within one standard deviation of the means (i.e., beauty could be considered similar; e.g., Collado & Manrique, 2020; Meidenbauer et al., 2020). That yielded 31 pictures (17 natural & 14 urban). To have an even number of natural and urban scenes, we discarded 3 natural scenes (those with the highest means), leaving us with 14 natural scenes and 14 urban scenes ($M_{\text{beauty Natural scenes}} = 3.21$, $SD = 0.34$; $M_{\text{beauty Built scenes}} = 3.12$, $SD = 0.37$; see Fig. 1). The whole set of pictures is available upon request to the authors. Participants in the pilot study did not participate in the experiment.

4.4. Measures

At each time of measurement, children individually received the same assignments and questions to register their capacity to direct attention and their positive affect.

Attention. The CARAS-R test (Thurstone & Yela, 2012) assesses the ability to quickly and correctly perceive similarities and differences in partially ordered stimulation patterns. It measures perceptual and attentional skills through 60 graphic items made up of schematic drawings of faces with elementary lines. The task to be carried out is to determine which of the three faces that make up each element is different from the other two. The time given for this task was 3 min and the participant's score was the total number of correct responses (which could range from 0 to a maximum of 60). Previous studies analyzing test-retest reliability found values above 0.80 (e.g., Suárez-García et al., 2020) and internal consistency around 0.90 (Thurstone & Yela, 2012).[1]

Positive affect. Children's positive affect was registered with the smiley-test developed by Van den Berg et al. (2017). It includes 8 emotions (content, happy, confident, angry, tired, anxious, quiet, and sad) and each one was displayed on a Likert-Type scale ranging from 1 to 4. The two ends of the scale (i.e., not happy-very happy) were illustrated with matching smiley faces. A single score referring to the presence of positive emotions (i.e., positive affect) was formed by averaging the 8 items (the negative affect items were previously re-coded). The resulting positive affect scale showed good reliability (Cronbach's α at T0 = 0.64; T1 = 0.73; and T2 = 0.64).

Environmental preference. All participants according to their condition (Nature, Urban) were presented with 14 images reflecting those scenarios and for each image they responded to the question "*Would you like to walk here?*" using a preference scale from 1 = Not at all to 4 = Very much". The average of these 14 scores was calculated to form the Preference score. The scale showed good reliability (Cronbach's α = 0.88 and 0.89 for Nature and Urban preference responses, respectively).

4.5. Data analyses

The data and the R code are available at https://osf.io/rezmx/?view_only=92303e11f41346b8a436337b18f0223b. We conducted the analysis involving the attention and positive affect scores within a mixed-effects framework since we have longitudinal data, in which multiple observations of the same individual are collected. Random intercepts for participants were included in the random part of the models. A first model was estimated to assess the effect of stimulation condition and included as fixed effects Time (T0, T1) and Stimulation Condition (under-stimulation, over-stimulation, control). The second model assessed the effects after exposure to the visual stimuli and included as fixed effects Time (T1, T2) and Environment (natural, urban). In the case of the preference scores, since preference was not measured at different time points, it was analyzed as a standard two-factor ANOVA with fixed effects Stimulation (under-stimulation, over-stimulation, control) and Environment (natural, urban).

In the mixed models, *T0*, *control,* and *urban* were set up as the reference category of their corresponding factors. The statistical significance of the main and interaction effects was examined, and the interpretation of significant effects was done by examining the parameters estimated by the model and the comparisons between all the relevant pairs of marginal means. Tukey's correction of the significance level was considered to control Type I error rate. Partial eta-square was computed to assess the effect size. Effect sizes in the intervals [0.010, 0.059), [0.059, 0.138), and [0.138, ∞) were considered small, medium, and large effects, respectively (Cohen, 1988). Statistical analyses were performed using R Statistical Software (R Core Team, 2021). These analyses were run with the R packages webPower (Zhang & Mai, 2023), lme4 (Bates et al., 2015), nlme (Pinheiro et al., 2020), sjstats (Lüdecke, 2021), lsr (Navarro, 2015), statpsych (Bonett, 2023), and emmeans (Lenth, 2022).

[1] In order to speed up data collection and in view of the high reliability reported in previous studies, the person in charge of data collection did not record for each participant his or her response to the 60 individual items but kept only the total number of correct answers. Thus, reliability indicators could not be computed for the current sample.

Fig. 1. Sample pictures for each environmental condition.

5. Results

Descriptive statistics for our outcome measures at T0, T1 and T2 are provided in Table 1.

5.1. *Effects of level of stimulation on attention and positive affect (from T0 to T1)*

According to H1, Attention (H1a) and Positive Affect (H1b) decrease for children in both over- and understimulating conditions at T1, relative to baseline and compared to the control group. Table 2 shows that the two-way interaction of Time by Stimulation is significant for both Attention ($F(2, 142) = 10.82, p < 0.001$ and Positive Affect ($F(2, 142) = 109.27$, $p < 0.001$, respectively). The effect size is larger for Positive Affect [0.59 with 95%-CI (0.52, 0.65)] than for Attention [0.13 with 95%-CI (0.06, 0.20)]. The representation of this interaction in Fig. 2 and the estimated parameters for the fixed effects reveal that, from T0 to T1, means for Attention and Positive Affect for children in the under-stimulation group and Attention for children in the over-stimulation group became lower, while these in the control group remained virtually the same.

The case-to-case mean contrast comparisons reveal that the T0 vs. T1 difference in Attention is significant for both the understimulated [95%-CI (0.59, 2.18)] and the overstimulated [95%-CI (0.48, 2.28)] children ($p_{\text{Tukey}} < 0.001$ in both cases). This is in support of H1a.

As predicted, Positive Affect decreases from T0 to T1 for under-stimulated children [95%-CI (0.28, 0.40), $p_{\text{Tukey}} < 0.001$]. However, there is not a significant decrease in Positive Affect for the over-stimulated children [95%-CI (−0.05, 0.08), $p_{\text{Tukey}} = 0.99$]. Therefore, H1b is partially supported. Interesting, and unexpected, is the marginal increase in Positive Affect for the control group [95%-CI (−0.12, −0.0005), $p_{\text{Tukey}} = 0.047$].

Table 1
Descriptive Statistics [Mean (Standard Deviation)]by Stimulation condition and Point in Time.

Attention and Positive Affect before (T0) and after (T1) Stimulation (Under, Over, Control)

	Attention		Positive Affect	
	T0	T1	T0	T1
Over	26.38 (7.15)	25 (6.78)	3.51 (0.35)	3.49 (0.32)
Under	26.83 (9.32)	25.44 (7.9)	3.51 (0.32)	3.17 (0.35)
Control	26.47 (8.25)	26.74 (8.1)	3.6 (0.38)	3.66 (0.29)

Attention and Positive Affect before (T1) and after (T2) exposure to Natural or Urban scenes

	Nature				Urban			
	Attention		Positive Affect		Attention		Positive Affect	
	T1	T2	T1	T2	T1	T2	T1	T2
Over	24.91 (7.13)	28.91 (8.41)	3.45 (0.39)	3.57 (0.37)	25.1 (6.59)	25.67 (6.29)	3.54 (0.25)	3.60 (0.18)
Under	25.7 (8.08)	27.37 (7.09)	3.22 (0.28)	3.42 (0.25)	25.19 (7.86)	26.7 (9.36)	3.11 (0.41)	3.27 (0.36)
Control	27.04 (8.62)	26.76 (8.31)	3.63 (0.34)	3.61 (0.3)	26.42 (7.69)	27.29 (7.48)	3.70 (0.21)	3.6 0 (0.24)

Preference ratings for Natural or Urban scenes for each Stimulation condition (T2)

	Nature	Urban
Over	3.45 (0.46)	3.07 (0.56)
Under	3.06 (0.45)	2.39 (0.7)
Control	3.44 (0.66)	3.14 (0.64)

Note. The sample size in each cell ranges from 42 (over) to 54 (under).
Note. In Panel (1) the sample size in each cell ranges from 42 (over) to 54 (under) whereas in Panels (2) and (3) the sample size in each cell ranges from 21 (over) to 27 (under).

Table 2
Mixed-effect model results for the analyses of attention and positive affect per stimulation condition.

ANOVA:						
	Attention			Positive Affect		
	F	*p*	η_p^2	*F*	*p*	η_p^2
(Intercept)	1564.52	**< 0.001**		16450.85	**< 0.001**	
Time (T)	24.30	**< 0.001**	0.14	82.72	**< 0.001**	0.36
Stimulation (Stim)	0.15	0.86	0.00	10.50	**< 0.001**	0.12
TimexStim	10.82	**< 0.001**	0.13	109.27	**< 0.001**	0.59

Random effects:				
	(Intercept)	Residual	(Intercept)	Residual
StdDev:	7.90	1.43	0.32	0.10

Fixed effects:						
	Est	*SE*	*p*	*Est*	*SE*	*p*
(Intercept)	26.47	1.15	**< 0.001**	3.60	0.05	**< 0.001**
TimeT1	0.27	0.29	0.36	0.06	0.02	**< 0.001**
StimUnder	0.36	1.58	0.82	−0.09	0.07	0.16
StimOver	−0.09	1.69	0.96	−0.09	0.07	0.19
TimeT1xStimUnder	−1.65	0.40	**< 0.001**	−0.40	0.03	**< 0.001**
TimeT1xStimOver	−1.65	0.43	**< 0.001**	−0.08	0.03	**0.02**

Note. StdDev*:* Standard deviation; *Est*: Estimate; *SE* = Standard error; *df*: degrees of freedom: *df*-Intercept, Time: 1142; *df*-Sti, TimexSti: 2, 142; *df*-Fixed effects: 142. Significant effects are shown in bold.

5.2. Recovery of attention and positive affect after exposure to natural or urban scenes (from T1 to T2)

Attention. Fig. 3a and b provide the group scores for each of the experimental conditions. Considering the possible restorative effects of exposure to natural/urban environments on Attention, Table 3 shows that the three-way interaction Time by Stimulation by Environment is significant ($F(2, 139) = 4.92, p = 0.01$), with a medium effect size [($\eta_p^2 =$ 0.06 with 95%-CI (0.02, 0.12)]. Attention increases from T1 to T2 only for the overstimulated children group that was exposed to natural scenes [95%-CI (−6.58, −1.42)], $p_{Tukey} < 0.001$]. This partially supports H2a. While we had predicted this effect to appear for both over- and under-stimulated groups, increases are not statistically significant for under-stimulated children, neither for natural [95%-CI (−3.94, 0.61), $p_{Tukey} =$ 0.39], nor for urban scenes [95%-CI (−3.79, 0.76)], $p_{Tukey} = 0.54$], while Attention scores remained virtually the same for the control group. The change in scores for Attention in the understimulated group of children does not support alternative hypothesis H3a either, as there is no improvement in Attention after exposure to the urban environment.

Positive Affect. Regarding the possible restorative effect of exposure to natural/urban environments on Positive Affect, Table 3 shows that the three-way interaction Time by Stimulation by Environment for Positive Affect is not significant ($F(2, 139) = 0.21, p = 0.81$). Therefore we explored the Time by Stimulation two-way interaction for Positive Affect ($F(2, 139) = 20.97, p < 0.001$) which had a large effect size [($\eta_p^2 =$ 0.22 with 95%-CI (0.13, 0.29)]. The Time by Environment two-way interaction was not significant ($F(1, 139) = 3.47, p = 0.06$). By combining the two Environment groups (exposed to natural or urban scenes), the power to detect effects increased with the increase in sample size per group. This analysis revealed that indeed both groups (over- and understimulation) increased their mean from T1 to T2 [p_{Tukey} were 0.02 (95%-CI (−0.18, −0.01) and 0.001 (95%-CI (−0.25–0.11), respectively], while the mean for the control group remained the same [95%-CI (−0.02, 0.13)], $p_{Tukey} = 0.27$]. So, exposure to any of the two environments helped recover Positive Affect, for both under- and over-stimulated children. These outcomes do not support H2b that predicted a larger increase in Positive Affect after exposure to natural scenes as compared to urban scenes for both under-and overstimulated subjects. The results do not support alternative hypothesis H3b either, as there is no rise in Positive Affect exclusively for the understimulated group after exposure to urban scenes.

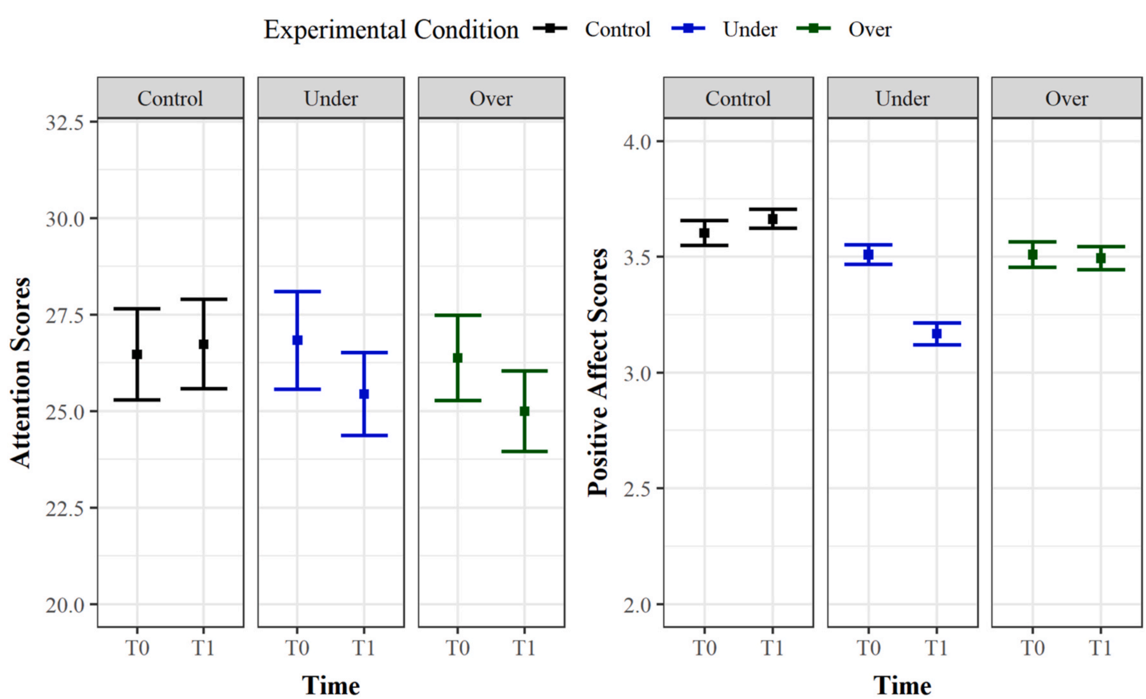

Fig. 2. Time × Stimulation condition interaction for the Attention and Positive Affect scores. The intervals indicate ±1 standard error of the means.

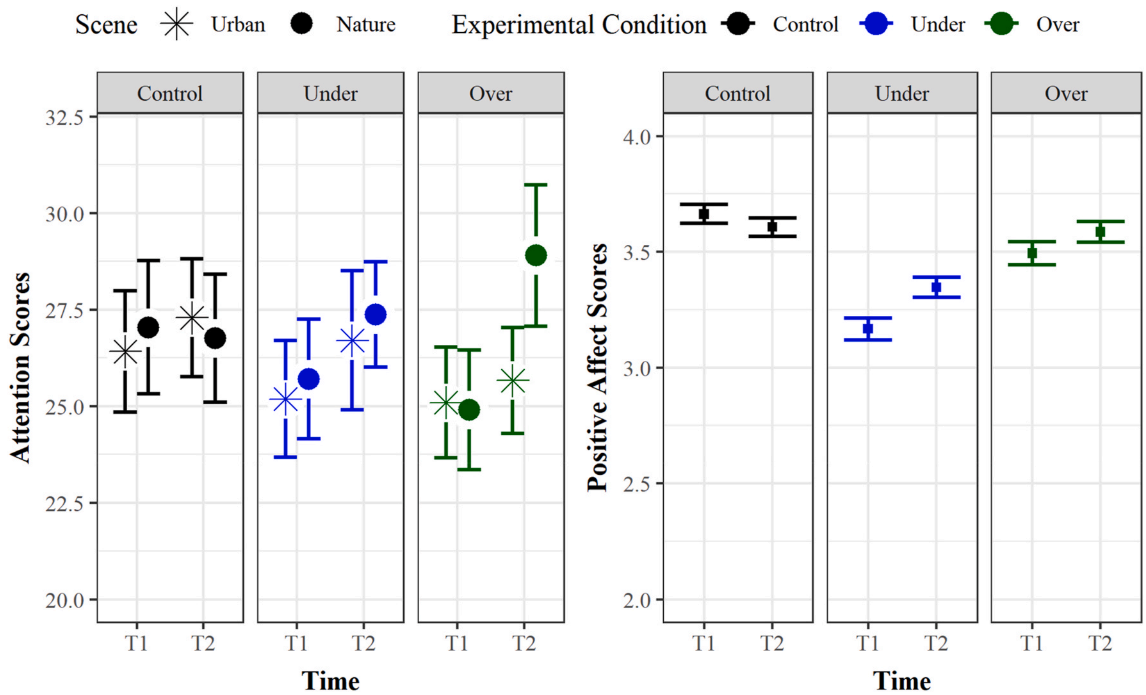

Fig. 3. Time: × Stimulation condition × Environmental condition interaction for Attention (**3a**) and Time x Stimulation condition for Positive Affect (**3b**). The intervals indicate ±1 standard error of the means.

5.3. Preference for a walk in a natural or urban environment after under- or overstimulation

Fig. 4 depicts the means of the preference scores across the experimental design conditions. The analysis shows that the interaction effect of Stimulation by Environment is not significant, $F(2, 139) = 1.38$, $p = .25$. Both main effects are significant and large [$F(2, 139) = 14.66$, $p < 0.001$, $\eta_p^2 = 0.17$ with 95%-CI (0.07, 0.28) and $F(1, 139) = 22.15$, $p < 0.001$, $\eta_p^2 = 0.14$ with 95%-CI (0.05, 0.24), respectively]. As can be seen from the figure, the means for nature are higher than for the urban conditions [95%-CI (−0.65, −0.26), $p_{\text{Tukey}} < 0.001$] and the understimulation group obtains a significantly lower mean than the overstimulation and control group ($p_{\text{Tukey}} < 0.001$ in both cases with 95%-CI (−0.84, −0.28) and 95%-CI (−0.24, −0.82), respectively), the latter two not differing from each other [95%-CI (−0.27, 0.32), $p_{\text{Tukey}} = 0.97$]. An examination of all possible comparisons shows that the only significant differences in terms of preference are the five comparison tests involving the understimulated group of children exposed to urban scenes. The preference mean for understimulated children exposed to urban scenes is significantly lower than all the other means in the plot (p_{Tukey} was between <0.001 and 0.002 with 95%-CIs bounded between −1.55 and −0.18). Finding a main effect of Environment and no interactions formally implies that H4a is supported: All children together (including the control group) prefer the natural environment over the urban environment. However, this is mainly due to the low score of the urban environment reported by understimulated children. And there we see that specific effects are opposed to H4b (i.e., understimulated children prefer urban environments over natural environments), and opposed to H4c (i.e., understimulated children have a higher preference for urban environments than overstimulated children).

6. Discussion

This study makes two novel contributions to existing literature. First, we examined whether understimulation, as well as overstimulation, decreases attentional performance and negatively changes affect. Second, we examined whether

Exposure to visual natural stimuli is restorative for understimulated children, and in comparison with overstimulated ones. In addition, we argued that, while most studies in restoration research (e.g., Berman et al., 2008) conclude that exposure to nature has a stronger restorative potential than exposure to urban environments, this might not necessarily be true for understimulated people. Their craving for stimuli might lead to a better recovery in stimulation-rich urban environments. Hence, we evaluated whether exposure to urban environments is restorative for understimulated children, as compared to exposure to natural environments. To test these hypotheses, we created two experimental conditions: Overstimulation and Understimulation. We also included a control group. Three different aspects of restoration were considered: Attention, Positive Affect, and children's preference for a walk in natural or urban environments.

Our findings show that both over-, and under-stimulated children experienced a decrease in their attentional capability after our manipulation. These results are in line with H1a, stating that both under and over-stimulation situations are taxing for attentional resources. Our findings are in line with previous studies in restoration research showing that overload situations are detrimental to attentional capabilities and task performance (Stevenson et al., 2019). And even more important is that they are also in line with studies indicating that a lack of stimulation can lead to attentional costs and performance errors (Westgate & Steidle, 2020).

We also found that understimulated children reported lower positive affect after our manipulation than at the baseline, which is in line with previous studies (Eastwood et al., 2012), while no differences were found in the positive affect reported by overstimulated children or by children in the control group. These results partly support H1b. One explanation for the lack of effect of overstimulation on children's positive affect might be that the use of directed attention intensively diminished children's ability to remain focused, but it did not necessarily mean that they disliked the assigned tasks. According to Kaplan (1995, p. 170), *"even a thoroughly enjoyable project is likely to lead to directed attention fatigue"*. Maybe children enjoyed their activities in the overstimulation situation, even if these were attentionally tiring. Another possible explanation is that our overstimulation situation was

Table 3
Mixed-effect model results for the analyses of attention and positive affect after exposure to natural or urban environments.

ANOVA:						
	Attention			Positive Affect		
	F	*p*	η_p^2	F	*p*	η_p^2
(Intercept)	1739.44	< **0.001**		20180.60	< **0.001**	
Time (T)	20.95	< **0.001**	0.13	23.49	< **0.001**	0.13
Stimulation (Stim)	0.13	0.88	0.00	23.13	< **0.001**	0.23
Environment (Env)	0.29	0.59	0.00	0.16	0.69	0.00
TimexStim	3.77	**0.03**	0.05	20.97	< **0.001**	0.22
TimexEnv	1.24	0.27	0.01	3.47	0.06	0.02
StimxEnv	0.11	0.90	0.00	1.52	0.22	0.02
TimexStimxEnv	4.92	**0.01**	0.06	0.21	0.81	0.00
Random effects:						
	(Intercept)	Residual		(Intercept)	Residual	
StdDev:	7.42	2.51		0.28	0.13	
Fixed effects:						
	Est	*SE*	*p*	*Est*	*SE*	*p*
(Intercept)	26.42	1.60	< **0.001**	3.63	0.06	< **0.001**
TimeT2	0.88	0.73	0.23	−0.02	0.04	0.69
StimUnder	−1.23	2.20	0.58	−0.40	0.09	< **0.001**
StimOver	−1.32	2.34	0.57	−0.17	0.09	0.06
EnvNature	0.62	2.24	0.78	0.08	0.09	0.38
TimeT2xStimUnder	0.64	1.00	0.52	0.21	0.05	< **0.001**
TimeT2xStimOver	−0.30	1.06	0.78	0.13	0.06	**0.02**
TimeT2xEnvNature	−1.16	1.02	0.26	−0.08	0.05	0.12
StimUnderxEnvNature	−0.10	3.09	0.97	−0.19	0.12	0.12
StimOvexEnvNature	−0.81	3.30	0.81	0.01	0.13	0.97
TimeT2: StimUnderxEnvNature	1.30	1.40	0.35	0.05	0.07	0.52
TimeT2: StimOverxEnvNature	4.58	1.50	**0.003**	0.03	0.08	0.70

Note. StdDev*:* Standard deviation; *Est*: Estimate; *SE* = Standard error; *df*: degrees of freedom: *df*-Intercept, Time: 1139; *df*-Stim, Time x Stim: 2, 139; *df*-Fixed effects: 139. Significant effects are shown in bold.

not as demanding as we had expected. Other, potentially more demanding situations such as taking an exam might have been taxing on both attention and affect.

Regarding the possible restorative effects of exposure to the two environments, our results showed that children in the overstimulation group recovered their attentional capabilities after exposure to the natural scenes, supporting H2a. This restorative effect was not found for overstimulated children who saw the urban scenes. For understimulated children, the exposure to the natural or the urban environment did not lead to a statistically significant increase of the attentional capabilities, opposed to H2a. The control group also remained unaffected. We found that children in both experimental groups (under- and over-stimulation) reported stronger positive affect after exposure to the environmental scenes, irrespective of category, so likewise for natural and urban scenes. The control group was unaffected. These results are contrary to H2b, which predicted an increase of positive affect after being exposed to natural environments, relative to exposure to urban environments. And regarding preference for a walk after being subjected to over- or understimulating conditions, these are fairly similar for the two environments, the exception being the low preference for urban environments for understimulated participants, contrary to our hypotheses and different from the preferences of the other five groups of children that were all quite similar across conditions.

6.1. Reflections regarding theory and options for further research

Overall, we end up with a set of results some of which are in line with expectations while others are clearly not. When we try to understand the outcomes in terms of the theories proposed, it seems that understimulation resembles overstimulation regarding its effects on attention: Children's attention decreases after exposure to each of the two conditions. This is in line with the ideas of Westgate and Steidle (2020), and previously those of Berlyne (1960) and others, supporting the idea that understimulation draws on attention.

In terms of affect, results are equivocal: Understimulation lowers mood, but overstimulation does not. As already mentioned above, Kaplan (1995) suggests that affect does not necessarily have to suffer from a strong demand on attention. The lack of a universal relation suggests that there will be other ways in which affect is sensitive to situations that impact attention. For that, we should take the specific situation in which we investigated our research question into consideration. The experiment was executed in school classes where regular class routines were disrupted. This may have evoked other expectations and concerns that we may not have registered. One potential explanation could be based on the MAC model, briefly described in the Introduction, focusing on meaning. Possibly the overstimulation condition was considered meaningful by the children. That may have led them to consider this a challenging but relevant task, like the control condition but unlike the understimulation condition, which might explain the effects on mood. Admittedly this is a posthoc explanation as we did not consciously design the interventions to differ in meaning. Another potential consequence of our quasi-experimental design, with children nested in (their own) classes, is that effects may not be completely independent of the effects of groups. While the mean scores for the dependent variables were comparable across all classes at the initial measurement point (T0), our study design cannot account for potential interactions between class and independent variables. Of course the elaborate protocol, meticulously followed in all the classes, was supposed to prevent such effects. Ideally, the assignment of children to conditions would have been random but for several reasons, we chose not to do this. In our view assigning children to groups randomly would have disturbed the whole research situation because of the unfamiliarity of such a procedure in a school setting and would have also made approval by children and parents less likely. We therefore maintained the familiar order by leaving children in their own class. Replications with a complete experimental design, in several different contexts and with differential degrees of meaning, assessed beforehand, would be valuable. The importance of replication also concerns the length of the time periods we had for our manipulations: These were short. Both under- and overstimulation will become more serious and potentially problematic when they last much longer, probably impacting attention and affect. Nevertheless, we found effects through our short-term manipulations.

Perhaps the most challenging question is that of the focus on attention or the amount of stimulation as the main explanatory mechanism for recovery through exposure to natural or urban environments. We developed competing hypotheses to address both options and conclude that the classical hypothesis, that natural environments are beneficial for recovery of overstimulation, seems to hold for attention. Recovery of attention after understimulation just did not take place, making it impossible to conclude whether it is the release of the drawing on attention or the simple lack of stimulation that might cause recovery. Therefore, theoretical explanations are unwarranted, awaiting further research.

This inability to draw strong conclusions regarding theory is also manifest in the general effect the exposure to environments had on affect. Apparently, any environment helped to raise affect for the two experimental groups, which was unexpected. Maybe the answer to that question lies in the selection of stimulus material we used to study patterns of recovery. We took great care to select scenes that differed in

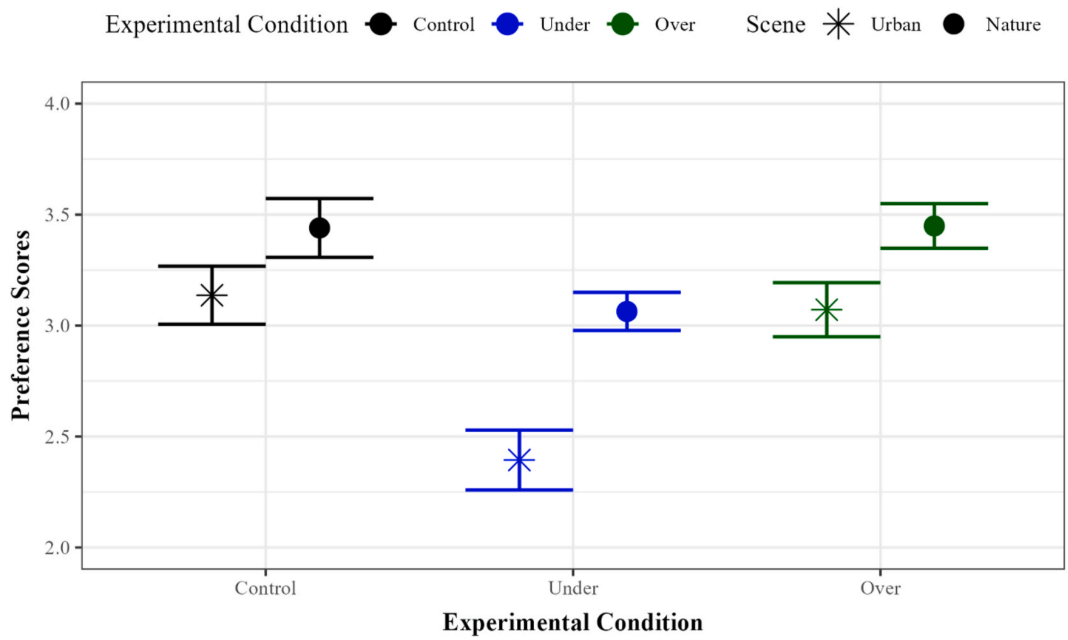

Fig. 4. Stimulation condition × Environmental condition interaction for the Preference scores. The intervals indicate ±1 standard error of the means.

category, urban or natural, but were similar and rather high in preference, as assessed beforehand in the pilot study. This is rarely done (exceptions are Collado & Manrique, 2020; Meidenbauer et al., 2020) and should have avoided the general preference for natural over urban scenes that is often reported. This makes the results in our view more representative of potential effects due to the category of environment. The results on affect seem to underlie the general appreciation for the two sets of environments. However, this is hard to reconcile with the general effect on environmental preference for a walk we found in the main study: The lower preference for the urban environments for all six groups. The specific effect of the understimulated group having the lowest preference scores is remarkable. It is noteworthy that, for children of similar age (i.e., 10–11 years), preferences for urban scenes were slightly higher in a previous study (Meidenbauer et al., 2019), while we found rather similar results across groups, except for the understimulated group. Given the differences between Meidenbauer et al.' (2019) study and ours, the results are difficult to compare. It is again an issue of further research to find out what causes this low preference for urban environments. It cannot be explained by the effect on attention, but we might speculate that behavioral options for children, especially understimulated children, are less salient in the urban environment. This could be in line with Wolhwill's ideas (1974) on the different categories of stimulation – sensory/cognitive, social, and behavioral-that can be distinguished. Children may rate behavioral, and in particular play and exploration opportunities, as richer in natural environments. In future research it might be good to initially match natural and urban environments not so much on beauty but indeed on these play and exploration opportunities children find attractive.

To conclude, our experiment showed that understimulation entails a need of restoration, resembling overstimulation in several ways. We encourage researchers to more closely examine the factors and psychological processes that lead to understimulation as well as those able to help people recover. According to our findings, visual exposure to natural scenes helps overstimulated children restore their attentional capabilities. At the same time, watching beautiful natural and urban scenes, even for a short period of time, can help lift children's positive affect. Given these results, the inclusion of short visual interventions in situations in which children's resources have been diminished, such as during school hours, might help them replenish their attentional and emotional capabilities.

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Author contributions

Henk Staats: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. Silvia Collado: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. Miguel A. Sorrel: Data curation, Formal analysis, Validation, Writing – review & editing

Declaration of competing interest

The authors declare they have no conflict of interest.

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