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Seeing nature from low to high levels: Mechanisms underlying the restorative effects of viewing nature images

Claudia Menzel^{1*} & Gerhard Reese¹

¹ Social, Environmental and Economic Psychology, University of Koblenz-Landau, Fortstraße 7, 76829 Landau, Germany

* corresponding author: menzel@uni-landau.de; Social, Environmental and Economic Psychology, University of Koblenz-Landau, Fortstraße 7, 76829 Landau, Germany

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Abstract

Nature can benefit human well-being and cognitive function. Merely watching images of nature compared to urban scenes, which differ in many lower-level processed properties, can have such effects. In two studies, we investigated the roles of lower- and higher-level processing on restorative effects evoked by nature and urban-related stimuli. In addition to nature and urban photographs, we used 1) versions that lack spatial information but retain certain image properties including those on regularity (i.e., phase-scrambled images), 2) line drawings that contain spatial information and thus allow for higher-level processing while lacking many diagnostic lower-level processed properties, and 3) words that lack any diagnostic image properties but allow higher cognitive processing and provide a mental image of the environment. We examined restoration after participants viewed either original, phase-scrambled, or line drawing versions of nature and urban images (Study 1), or nature- and urban-related words (Study 2). Although nature and urban scenes differed in several image properties, these did not evoke differences in perceived restoration when presented with phase-scrambled images. However, higher-level processing (i.e., recognizing the environment) led to stronger perceived restoration effects for nature compared to urban stimuli (original images, line drawings, and words). These findings contradict assumptions of nature-specific image properties explaining restorative effects and, therefore, have implications for current theories in the field.

Keywords: restoration; image properties; perceptual fluency; nature; urban; visual processing

23 **1 Introduction**

24 Generally, humans tend to favour natural scenes over urban environments (e.g., Berto,
25 2007; Kaplan, 1987; Sánchez et al., 2016). Nature exposure, compared urban exposure, leads
26 to several physiological and psychological benefits (for reviews see Bowler et al., 2010;
27 Bratman et al., 2012; Corazon et al., 2019; M. Kuo, 2015), as well as a stronger nature
28 connection (e.g., Mayer et al., 2009). Intriguingly, merely watching images of nature compared
29 to urban scenes can result in better cognitive performance and reduced stress, which are
30 considered signs of restoration (Berman et al., 2008; Berto, 2005; Gamble et al., 2014; Hartig
31 et al., 1996; van den Berg et al., 2015; but see also Johnson et al., 2021). However, effects on
32 affect are sometimes smaller for virtual than for real nature experiences (Browning et al., 2020;
33 McMahan & Estes, 2015; Reese et al., 2021). Nevertheless, isolated visual input seems
34 sufficient to elicit at least some restorative effects. Therefore, our primary research question is:
35 *How* can these effects be evoked by merely viewing images? Specifically, the current work
36 aims to systematically investigate the respective roles of lower- (e.g., colour) and higher-level
37 (e.g. recognition of scenes and objects) visual processing on the restorative effects of nature
38 compared to urban environments. We defined restoration broadly as a process in which depleted
39 resources are renewed (i.e., recovering certain states of mood, and attention, but also physical
40 condition; cf. Hartig, 2004, 2017). Resource depletion usually happens through adaptation to
41 external demands in everyday life (Hartig, 2004).

42

43 **1.1 Visual Processing of Nature and Urban Scenes**

44 Scene perception is a rather complex process including dynamic interactions between
45 different processing levels (Groen et al., 2017). Lower-level properties (e.g., colour, luminance,
46 contrast, edge and spatial frequency properties) are generally processed early in the visual

system, but they also modulate later processing stages in brain regions where scenes (and objects) were recognized and identified (i.e., higher-level processing; Epstein & Baker, 2019; Groen et al., 2017). In the following paragraphs, we first introduce several lower-level image properties and their relevance for our research question; then we integrate them with relevant research on higher-level processing.

Natural images share several properties when compared to random ones, such as edges and homogenous areas, which lead to correlated and therefore redundant information (Geisler, 2008; Graham & Field, 2009; Olshausen & Field, 2000). In respective images, this leads to a correlation between pixel distance and values (i.e., closer pixels are more similar than distant ones), and therefore to a specific relationship between the amplitude and spatial frequency in the image (i.e., statistical scale-invariance). This relationship can be measured with the so-called spectral slope (also named Fourier slope or $1/f^\alpha$ characteristics). Presumably due to evolutionary and ontogenetic adaptation to natural environments and therefore certain properties, such redundant information seems to be processed efficiently (Graham & Field, 2009). Images with natural properties (e.g., a certain spectral slope) are preferred and frequently found in aesthetically pleasing datasets (e.g., art), while stimuli with deviating properties were generally disliked and/or induce discomfort (Graham & Redies, 2010; Juricevic et al., 2010; Le et al., 2017; Redies, 2007).

Previous studies showed that images of urban environments differ in several properties from nature images, including the spectral slope (e.g., Braun et al., 2013; Wang & Ogawa, 2015). As indicated above, the spectral slope measures redundant information and represents statistical scale-invariance (i.e., image characteristics remain similar when zooming in and out). Such properties of regularity are assumed to account for the fluent (i.e., easier) processing of natural scenes (Graham & Field, 2009; Joye & van den Berg, 2011). Generally, perceptual fluency is the ease of processing, which leads to positive affect that is being assigned to the stimulus (Reber et al., 2004).

In addition to the spectral slope, other measures are associated with regularity, such as self-similarity and fractal dimension (note that the latter is, however, a measure of complexity). These also often differ between images of nature and urban scenes (Braun et al., 2013). These differences presumably lead to different processing efficiency and energy demands, and therefore might be relevant for different preference and restorative effects when viewing these images (Graham & Field, 2009; Joye & van den Berg, 2011; Reber et al., 2004). Support for the assumed differences in processing between nature and urban images comes also from studies that assessed eye movement and blink rate data when viewing scenes, and the results indicate less effort when looking at nature compared to urban scenes (Berto et al., 2008; Valtchanov & Ellard, 2015). Further studies using neurophysiological or brain activity data provide additional evidence for lower processing demands for more natural sceneries (Grassini et al., 2019; Le et al., 2017; Tang et al., 2017). Even when higher-level processing is eliminated (by scrambling certain image features so that objects and scenes can no longer be recognized), nature-specific lower-level processed properties, including statistical regularity, influence explicitly and implicitly measured preference, but do not seem to be related to restoration or cognitive load (Authors, 2021; Valtchanov & Ellard, 2015; see also Law et al., 2020, for related findings on landscape paintings).

Besides the differences in measures of regularity between nature and urban scenes, edge- and colour-related image properties are associated with ratings of naturalness (Berman et al., 2014; Ibarra et al., 2017; Kardan et al., 2015). One series of studies even revealed that both naturalness and edge properties of urban park photographs seem to causally influence people's thoughts about nature and spirituality (Schertz et al., 2018). In sum, there are various lower-level image properties that seem to be related to preference for certain environments (or levels of naturalness), including measures of regularity, colour, and edge characteristics (Berman et al., 2014; Kardan et al., 2015; Kotabe et al., 2016; Mullin et al., 2017).

Although naturalness and preference ratings are predicted by similar image properties and are usually correlated (Ibarra et al., 2017; Kardan et al., 2015), eliminating higher-level processing diminishes this correlation (Kotabe et al., 2017). Moreover, the positive correlation of naturalness and preference was preserved when words were viewed instead of images (and, thus, scene-diagnostic lower-level properties are not available; Kotabe et al., 2017). Additionally, preference for unaltered images is generally higher than for manipulated ones, in which recognition is more difficult (Tinio & Leder, 2009; Valtchanov & Ellard, 2015). Thus, higher-level processing (i.e., recognition of objects and scenes) seems to play a crucial role for the association between naturalness and preference. Indeed, higher-level properties, such as the amount of water and built objects, more strongly predicted naturalness and preference for scenes and was partly independent of lower-level properties (Ibarra et al., 2017). In fact, several studies identified characteristics of land- and cityscapes that are liked and are associated with restoration, highlighting the importance of higher-level processing (e.g., Abraham et al., 2010; Grahn & Stigsdotter, 2010; F. E. Kuo et al., 1998; Peschardt & Stigsdotter, 2013). In sum, there is evidence that both, lower-level and higher-level properties contribute to preference and potentially restoration effects evoked by nature compared to urban visual experience.

1.2 Theories Explaining Psychological Benefits Evoked by Nature

There are several theories in the field that explain restoration effects based on lower- and/or higher-level processing. The two most influential ones are attention restoration theory (ART; Kaplan, 1995) and stress recovery theory (SRT; Ulrich, 1983; Ulrich et al., 1991). ART proposes that urban environments contribute to the depletion of directed attention, and that it can be restored in nature (Kaplan, 1995). Studies support ART to some extent by demonstrating that nature exposure (compared urban exposure) led to better performance in some attention and working memory tasks, albeit not in all (for meta-analyses see Ohly et al., 2016; Stevenson

et al., 2018). ART claims that natural environments improve attention presumably because they are comprised of characteristics that foster mental restoration by, for example, inducing ‘soft fascination’ and the feeling of ‘being away’ (Kaplan, 1995). The effects of these characteristics (e.g., mountains, lakes, moving leaves; Kaplan, 1995) unfold at rather higher levels of processing, since recognizing them as certain objects seems necessary to, for example, feel being away from daily life.

In a related line of research, several studies showed that natural compared to urban environments evoke positive affective responses and reduce stress (e.g., Brown et al., 2013; Gladwell et al., 2012; Valtchanov & Ellard, 2010). These studies support the SRT, which suggests that natural environments aid in recovering from stressors via positive affective states (Ulrich, 1983; Ulrich et al., 1991). Ulrich (1983) proposed that higher-level processed visual characteristics, such as the occurrence of water, contribute to the positive affective states evoked by nature. Noteworthy, he also discussed complexity, which can be seen as both a lower- and higher-level processed characteristic, depending on how it is defined (i.e., amount of edges and areas, or number of recognizable objects)¹. Nevertheless, generally, in both ART and SRT higher-level processed characteristics are considered important for preference and restoration (Kaplan, 1995; Ulrich, 1983).

Although studies on ART and SRT provide moderate empirical support, these theories have limitations. For example, they propose relatively specific characteristics, evolutionary origins, and underlying mechanisms that are assumed to lead to restoration. Joye and van den Berg (2011) challenged both theories (esp. SRT) and some of their evolutionary assumptions by proposing a more parsimonious and universal explanation of preference and restoration effects. Their perceptual fluency account (PFA) claims that nature is evaluated as more positive

¹ Ulrich defined it as “the number of independently perceived elements in a scene” (Ulrich, 1983, p. 95). As in our phase-scrambled images neither objects nor edge information remained intact, we did not consider SRT to explain potential restoration effects evoked by phase-scrambled images (*Note*. The figure shows).

and restorative compared to urban environments because the processing of natural environments is more fluent (Joye & van den Berg, 2011). This view is based on findings related to regularity and different processing demands for nature and urban scenes (Joye & van den Berg, 2011). They provide evidence for the influence of lower-level image properties on preference, perception of naturalness, and potentially restoration. Few studies investigated the role of fractal dimension, which is a measure of complexity and for some researchers also for regularity, on landscape preference and restoration (Hagerhall et al., 2008; Hagerhall & Berto, 2008; Taylor, 2006; Taylor et al., 2005). These studies offer some evidence for an influence of fractal dimension on restoration. Although there is empirical support for the PFA, as we mentioned above (e.g., Grassini et al., 2019; Hagerhall et al., 2008; Le et al., 2017; Taylor et al., 2005; Valtchanov & Ellard, 2015), the theory remains largely untested and only little is known on how visual stimulation and processing are linked to restoration.

1.3 Current Research

In the current research, we investigated the independent roles of lower- and higher-level processed properties for restoration through nature compared to urban images. To disentangle the properties, we used several image types as stimuli (Figure 1A; see below for further explanation). Thereby, we used a dichotomous categorization of environments, although we are aware of the limitations of this dichotomization (cf. Staats et al., 2016; Weber & Trojan, 2018). Since our aim was to investigate the underlying mechanisms of effects evoked by such stimulus sets or *in-situ* environments (e.g., Berman et al., 2008; Stevenson et al., 2018; Valtchanov & Ellard, 2015), we focused on these two categories of images. Therefore, our nature category contained natural green and blue environments, and included sceneries of both wild and human-shaped landscapes. In contrast, the urban category contained different scenes of cities, including residence areas, streetscapes, and old city scenes, but no urban green parks.

Our research especially built on the assumptions of the PFA, but also SRT and ART (for an overview of the theories' predictions for our stimulus set, see Figure 1). If the assumptions of the PFA are valid, a presentation of stimuli containing nature-specific properties (esp. related to regularity, available in original and phase-scrambled images [and to some extent also in line drawings]) would evoke restoration effects, namely perceived restoration, increased positive affect, decreased negative affect, and improved cognitive function. Correspondingly, stimuli without such nature-specific properties of regularity (i.e., words) would not evoke restorative effects. In contrast, ART and SRT predict restorative effects when nature-specific higher-level properties (e.g., existence of water or extent) are present; thus, then restorative effects following the presentation of original images, line drawings, and words, but not phase-scrambled images, are expected. We tested these assumptions in two studies and on various facets of restoration (i.e., perceived restoration, working memory, affect, restorativeness ratings of stimuli) and related factors (i.e., preference of stimuli, connection to nature, craving).

Figure 1.

Overview of Stimuli, Their Characteristics, and Predictions From Theories

Note. The figure shows examples of stimuli used in Studies 1 and 2 (A), their comprised visual information (B), and predictions for each stimuli set derived from the theories (C). Original images were from colourbox.de (a stock image database) and cropped to a square format. Gradient in B reflects available information processed at lower- (dark grey) to higher-level (light grey) stages. ART = attention restoration theory. SRT = stress recovery theory. PFA = perceptual fluency account. See main text for further information.

2 Study 1

2.1 Introduction

In a between-subjects design, we investigated restoration outcomes after viewing one of three versions of nature and urban images (Figure 1A and B). Different aspects of restoration

were assessed before and after image presentation. Thereby the differences in restoration between nature and urban stimuli for each image type were most relevant. Using such stimuli in a restoration paradigm allowed us to provide evidence for the validity of key theories in the field and their assumptions (cf. Figure 1C). The original images mainly served as a replication of previous findings and as a baseline for the other image types.

To study lower-level processing independently of higher-level processing, a special type of stimulus (so-called phase-scrambled or phase-randomized images) can be used (for examples, see Figure 1A). In phase-scrambled images, the distribution of spatial frequency and their amplitude (i.e., the amplitude or power spectrum) and thus statistical regularity is kept intact, while the spatial information (i.e., the phase spectrum) is randomized. Therefore, these images are often used in vision science to disentangle lower-level from higher-level processing. In phase-scrambled images, many properties remain similar to original images (e.g., spectral slope, contrast, colour, and orientation characteristics), while spatial information, and therefore object recognition, is impeded. In previous studies, such phase-scrambled nature images compared to urban ones were found to be preferred explicitly and implicitly (Authors, 2021; Valtchanov & Ellard, 2015). We decided to use phase-scrambled images, because they allow us to test a measure of statistical regularity (i.e., spectral slope) independently of higher-level processing, which enables us to investigate assumptions of the PFA. PFA predicts restoration effects evoked by the lower-level properties related to regularity, which would be evident when the presentation of phase-scrambled images elicits a similar effect pattern as original images. Note that the authors of the PFA remained a bit vague on their definition of regularity, as they referred to various studies with different measures of regularity (Joye & van den Berg, 2011).

In addition to lower-level processing, we also investigated the role of higher-level processing by using line drawings based on the original images. In such images, the scene and objects are recognizable, but many of the differences in image properties are removed or altered (especially those on colour and the amplitude spectrum). By using these different versions of

the same source stimuli, we were able to investigate restoration outcomes separately for lower- and higher-level processing, while keeping the same stimulus range and diversity.

Similar to previous studies, we collected data on several facets of restoration, namely affect, perceived restoration, performance in a working memory task, and explicit ratings of restorativeness and liking (e.g., Berman et al., 2008; McMahan & Estes, 2015; Menardo et al., 2019; Stevenson et al., 2018). We expected higher perceived restoration, more positive and less negative affect, as well as better performance in the working memory task after viewing nature compared to urban stimuli. Furthermore, we expected higher liking and restorativeness ratings for nature compared to urban stimuli. For exploratory reasons, we studied further related factors. We included a state measure for connectedness to nature (CTN) to investigate whether current feelings of emotional connection to nature are affected by image presentation as they are for *in-situ* nature experiences (Mayer et al., 2009). Current CTN was also previously identified as a mediator between nature exposure and positive affect (Mayer et al., 2009). Furthermore, we studied craving measures that address the assumed differing energy demands for processing nature and urban images, as was suggested by the PFA and other researchers (cf. Grassini et al., 2019; Joye & van den Berg, 2011). As nature exposure was associated with reduced craving in previous studies (Martin et al., 2019; Wu & Chiou, 2019), we assumed lower food craving after nature compared to urban image exposure.

2.2 Materials and Methods

2.2.1 Participants

Since we were primarily interested in the nature-urban comparison within each image type, a-priori sample size determination was calculated for an ANOVA with a two-level between-subjects factor (nature, urban) and two within-subject measurements (pre, post) using $\alpha = .05$, power = .80, and $f = .25$. This analysis suggested a sample size for each image type of

98 participants. This number exceeds the sample that is needed to detect a medium effect for an aimed interaction in an ANOVA with all six participant groups and two predictors (suggested overall $N = 158$), which is the final analysis we conducted². For it, the factor time was removed by forming difference scores (post *minus* pre). Table 1 shows the final sample size for all conditions.

Participants were recruited via university email lists, social media, and by approaching them on the campus. In total, 313 participants took part in Study 1. Four participants were excluded because of incomplete data or repeated participation. Of the remaining 309 participants, 254 indicated being female, 53 male, and three ‘other’. The age ranged from 18 to 44 years, with a mean of 21.99 ($SD = 3.19$) years. Most participants studied psychology. All participants reported normal or corrected-to-normal vision.

Table 1

Final Sample Size in Each Condition

Image category	Image type		
	Original	Phase-scrambled	Line drawing
Nature	51	59	48
Urban	49	47	55
Σ	100	106	103

2.2.2 Stimuli

We used images representing nature and urban scenes in three versions: original, phase-scrambled, and line drawing (Figure 1A). Based on the original images (list of stimuli can be found in S1 in the Supplemental Material), we created phase-scrambled versions by combining the amplitude spectra of each red-green-blue (RGB) channel with a randomized phase spectrum

² We thank two anonymous reviewers for the suggestion of this alternative analysis.

using Fast Fourier Transform (for more information, see S2 in the Supplemental Material). Line drawings were created based on the dominant gradients in the image using a Gaussian filter and a Sobel edge detector (for more information, see S2 in the Supplemental Material).

Stimuli were selected based on a pilot study with 104 participants reported elsewhere (Authors, 2021). In the pilot study, the primary image set consisted of original images depicting diverse nature and urban scenes from Germany (100 each), as well as their phase-scrambled and line drawing version. From this larger set, we selected 60 images each for nature and urban environments. Stimuli selection was based on restorativeness ('How restorative is this image for you?'; 5-point scale ranging from 'not at all' to 'entirely'; original images) and recognition ratings ("Do you recognize objects in the image?"; 5-point scale ranging from 'not at all' to 'entirely'; line drawings): We chose images with high (nature) or low (urban) restorativeness ratings, and low (urban) and high (nature) recognizability ratings for line drawings. The latter criterion led to a smaller difference in recognizability ratings for line drawings in the image set used in the current study (cf. Authors, 2021). The selected 60 original images per category differed in their restorativeness ratings, $M_{nature} = 4.33$, $SD_{nature} = 0.87$, $M_{urban} = 1.70$, $SD_{urban} = 0.90$, $t(118) = 37.49$, $p < .001$, $d = 6.85$. Phase-scrambled images did not differ in their ratings on recognizability of objects, $M_{nature} = 1.20$, $SD_{nature} = 0.50$, $M_{urban} = 1.19$, $SD_{urban} = 0.49$, $t(118) = 0.70$, $p = .488$, $d = 0.13$, but line drawings did, $M_{nature} = 3.75$, $SD_{nature} = 0.97$, $M_{urban} = 4.27$, $SD_{urban} = 0.79$, $t(118) = 15.16$, $p < .001$, $d = 2.76$.

Image analyses of the stimulus set used here supported that original and phase-scrambled images differed in colour measures (mean and standard deviation [SD] of hue, mean and SD of saturation), important measures related to the amplitude spectrum (spectral slope, weighted residuals), and most edge measures (edge density, straight and non-straight edge density, anisotropy [not for phase-scrambled images], fractal dimension). For line drawings, most edge measures (edge density, straight and non-straight edge density, fractal dimension, anisotropy, complexity, entropy), mean and SD of brightness, and spectral slope differed between nature

and urban stimuli. See S3 of the Supplemental Material for more information on the differences in image properties between nature and urban stimuli. A detailed description and discussion of image properties derived from the initial set of images can be found elsewhere (Authors, 2021). In short, the results supported previous findings (e.g., Braun et al., 2013) and justified the use of our stimulus set.

2.2.3 Measures

Backwards digit-span task. The backwards digit-span task (BDST) was used to assess cognitive function. It has been implemented in prior studies of attention restoration as a measure of working memory (Ohly et al., 2016; Stevenson et al., 2018). We presented the BDST visually on a computer screen. Similar to Morton and colleagues (2017), participants saw one number at a time at one-of-five locations (centre and in each of the four corners) for 1 s. After each sequence, participants were asked to enter the sequence in reversed order to the computer. Each sequence length was repeated twice (with different numbers) and the test ended after two consecutive errors. Sequences of numbers started with three digits and were extended by one digit at the time with a maximum of nine in total. For the analyses, the difference in length of the last correctly reported sequence before and after image presentation was used.

Positive and negative affect. To assess current affective states, we asked participants to complete the Positive and Negative Affect Scale (PANAS; Breyer & Bluemke, 2016; D. Watson et al., 1988) with a focus on their current feelings. Participants were asked to indicate on a 5-point scale (from ‘not at all’ to ‘extremely’) how well 20 words (e.g., ‘excited’, ‘distressed’) described their current feelings. For the analyses, positive (PA) and negative affect (NA) scores were considered individually. The reliability of each subscale was good (PA for the pre-test: Cronbach’s $\alpha = .86$; NA for the pre-test: Cronbach’s $\alpha = .80$). For each of the analyses, the difference of post- and pre-test was used.

Connectedness to nature. To investigate whether current CTN is affected by viewing images, participants were asked to complete a questionnaire on CTN (Mayer & Frantz, 2004). The German version of the questionnaire previously used by Cervinka and colleagues (2012) was adapted to the current state (CTN-s; Mayer et al., 2009). Participants were asked about their agreement to 13 statements (e.g., ‘Right now I’m feeling a sense of oneness with the natural world around me’) on a 5-point scale (from ‘strongly disagree’ to ‘strongly agree’). The reliability of the scale was good (CTN-s for the pre-test: Cronbach’s $\alpha = .87$). For the analyses, the difference of post- and pre-test was used.

Restoration outcome. We asked participants to indicate their general restorative experiences after viewing the images by completing the restoration outcome scale (ROS; Korpela et al., 2008), which was adapted to viewing images. Participants were asked to indicate how much they agreed to six statements after viewing the images (e.g., ‘I feel restored and relaxed.’) on a 5-point-scale (from ‘strongly disagree’ to ‘strongly agree’). The reliability of the scale was good (Cronbach’s $\alpha = .85$).

Food craving. To study possible energy-consuming effects (cf. Grassini et al., 2019; Joye & van den Berg, 2011; Martin et al., 2019), we chose five items of the general food craving questionnaire state (i.e., items were in German: ‘I’m craving tasty food’, ‘If I ate something, I wouldn’t feel so sluggish and lethargic’, ‘If I ate right now, my stomach wouldn’t feel as empty’, ‘My desire to eat something tasty seems overpowering’, and ‘If I were to eat what I’m desiring, I am sure my mood would improve’; Nijs et al., 2007). The reliability of the scale was good (Cronbach’s $\alpha = .88$). Additionally, we assessed a further measure of craving by offering four small individually-wrapped pieces of chocolate at the end of the experiment, and invited participants to ‘take as many as desired, none, one, two, three, or all four’; we coded how many pieces they took. As food craving depends on hunger, we included reported hours since last meal as a covariate.

Image ratings. As a manipulation check for the phase-scrambled images and to measure potential differences in line drawings, which would be relevant for conclusions on fluent processing, participants rated their recognition of objects ('Do you recognize objects in the image?'), restorative appeal of viewing the image ('How restorative is this image for you?'), and how much they liked the image ('How much do you like this image?') on 5-point-scales (from 'not at all' to 'entirely').

2.2.4 Procedure

Participants were randomly assigned to one of the six conditions (e.g., original nature images or urban line drawings). Up to four participants were tested at individual computers in a quiet laboratory room with closed window blinds and artificial lights. We asked the participants to keep a constant viewing distance of about 60 to 70 cm that corresponded to a visual angle of approximately 11° for the height/length of the images. The monitors, Dell P2214H with full HD 1920×1080 resolution, were calibrated a few days before each period of data collection using a Datacolor Spyder 5 Elite with the respective software (version 5.1). The settings were gamma = 2.2, temperature = 6500 K, and luminance = 120 cd/m^2 .

The procedure of the experiment is depicted in Figure 2. After participants were welcomed, signed their informed consent, and were introduced to the setting, the experiment started with the pre-test of the BDST. Then, we asked them to complete the PANAS and CTN-s questionnaires. This was followed by 10 minutes of image presentation. Sixty images of one subset (e.g., original nature images) were presented for 10 seconds each. We told participants that they should view these images attentively but that they do not need to focus on or memorize anything. After viewing the images, participants were asked to complete a second round of the BDST. Then, we asked them to complete the PANAS, CTN-s, ROS, and food craving questionnaires. Following this, participants rated each image in three blocks on recognizability of objects, restorative appeal of viewing the image, and liking of the image. The order of the

blocks was fixed, while the order of images was randomized in each block. After finishing, we asked the participants to indicate their demographic data and offered the chocolate to them. The study was conducted in accordance to the Declaration of Helsinki and approved by the local ethics committee of the university where the study was planned and conducted (application number: 95_2017).

Figure 2. Procedure of Study 1. Image is from colourbox.de. BDST = backwards digit-span task. PANAS = positive affect negative affect scale. CTN-s = connectedness to nature state. ROS = restoration outcome scale. See main text for further information.

2.3 Results

The analyses presented here are based on 2×3 between-subjects ANOVAs with image category (nature, urban) and image type (original, phase-scrambled, line drawing) for each of the dependent variables (for pre-post measures, differences scores were used). Alternative analyses using ANCOVAs (as suggested elsewhere; Stevenson et al., 2018) revealed similar results³ and can be found in S4 of the Supplemental Material. Descriptive statistics for all measures can be found in Table 2; inferential statistics can be found in Table 3. In line with our assumptions for the a-priori sample size determination, results are presented with unadjusted *p*-values, because our dependent variables measure different constructs and alpha adjustments

³ In addition to the significant results found in our main analyses and reported in the main text, the main effect of image type reached significance for CTN-s (S4 in the Supplemental Material).

lead to reduced power and an increase of Type II errors (Nakagawa, 2004; Perneger, 1998; Sinclair et al., 2013). However, for the sake of transparency and completeness, we included more conservative analyses with Bonferroni-Holm corrected p -values in S5 of the Supplemental Material. Here in the main text, p -values that do not hold significant after this Bonferroni-Holm correction are indicated with “+”.

Generally, participants felt more restored (measured by the ROS) after viewing nature compared to urban images, as indicated by a main effect of image category, 95% CI[-3.13, -0.86]. The main effect of image type suggests that viewing original images was more restoring than viewing line drawings, post-hoc $p = .009$, 95% CI[0.44, 3.79], other post-hoc p 's $\geq .10$ (Figure 3). Most importantly, the interaction between image category and type was significant. Viewing nature compared to urban scenes was more restoring for original images, $p < .001$, 95% CI[-6.24, -1.94], and line drawings, $p = .020$, 95% CI[-4.18, -0.36], but not for phase-scrambled images, $p = .69$ (Figure 3). The change in BDST performance was neither affected by category, image type, nor their interaction. The ANOVA for CTN-s revealed a main effect of category, 95% CI[-3.75, -0.53], indicating a more positive change in CTN-s after viewing nature images. Although the main effect of image type and the category $\times$ type interaction was not significant, descriptive statistics suggest that the main effect of category was driven by the original images and line drawings (Figure 3). The ANOVA on the change of positive affect revealed neither a main effect of category nor image type. However, their interaction was significant, indicating that the decrease of positive affect was larger for urban compared to nature line drawings, post hoc $p = .001$, 95% CI[-5.14, -1.31], while there were no differences in change of positive affect for original images, post hoc $p = .197$, or phase-scrambled images, post hoc $p = .277$ (Figure 3). The ANOVA on change of negative affect revealed neither a main effect of category, image type, nor their interaction.

The ANCOVA with hours since the last meal as a covariate revealed that food craving was neither affected by category, image type, nor their interaction. Similarly, the number of

chocolate pieces taken was neither affected by category, image type, nor their interaction, when controlled for hours since last meal.

Viewing nature images was rated as more restorative than urban images. Viewing original images was rated as more restorative than line drawings and phase-scrambled images, both post-hoc p 's $< .001$, 95% CI_{original vs. line drawings}[0.37, 0.69], 95% CI_{original vs. phase-scrambled} [0.82, 0.49]. The interaction between category and type indicated that the differences in restorativeness ratings between nature and urban were only significant for original images, post-hoc $p < .001$, 95% CI[-1.51, -1.02], and line drawings, post-hoc $p < .001$, 95% CI[-1.10, -0.78], but not for phase-scrambled images, post-hoc $p = .690$.

Nature images were liked more than urban images, 95% CI[-0.68, -0.45] (Figure 3). Original images were liked more than line drawings and phase-scrambled images, both post-hoc p 's $< .001$, 95% CI_{original vs. line drawings}[0.38, 0.72], 95% CI_{original vs. phase-scrambled} [0.85, 0.51]. The interaction between category and type indicated that the differences in liking ratings between nature and urban were only significant for original images, post-hoc $p < .001$, 95% CI[-1.20, -0.67], and line drawings, post-hoc $p < .001$, 95% CI[-0.95, -0.63], but not for phase-scrambled images, post-hoc $p = .761$ (Figure 3).

Generally, participants found it easier to recognize objects in nature compared to urban images. Object recognition ratings were highest in original images, closely followed by line drawings, and they were very low for phase-scrambled images, all post-hoc comparisons $p < .001$, 95% CI_{original vs. line drawings}[0.30, 0.48], 95% CI_{phase-scrambled vs. line-drawing}[-1.85, -1.67], 95% CI_{phase-scrambled vs. original}[-2.24, -2.06]. The significant interaction between category and type indicated that the main effect of category was mainly driven by the difference in recognition for original images, post-hoc $p < .001$, while the differences were non-significant for phase-scrambled images, post-hoc $p = .051$, and for line drawings, post-hoc $p = .22$ (Figure 3).

441 **Table 2**

442 *Descriptive Statistics of Measures in Study 1*

Outcome		Original						Phase-scrambled						Line drawing					
		Nature			Urban			Nature			Urban			Nature			Urban		
		<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
ROS		19.31	5.58	6-30	15.22	5.25	7-28	16.41	4.81	6-29	16.79	4.98	7-28	16.29	4.91	7-26	14.02	4.85	6-30
BDST	Pre	5.60	1.14	4-9	5.62	1.29	4-9	5.78	1.11	4-9	5.60	1.22	3-9	5.91	1.31	3-9	5.69	1.07	3-8
	Post	5.90	1.30	4-9	5.92	1.22	4-9	6.17	1.44	3-9	5.91	1.35	3-9	6.31	1.36	3-9	5.70	1.40	3-9
CTN-s	Pre	39.80	8.65	24-61	42.92	9.43	17-59	39.85	10.86	13-62	40.75	7.81	18-59	39.27	10.68	17-54	41.38	10.75	15-59
	Post	43.10	9.63	21-65	42.14	9.65	18-59	39.34	11.80	17-64	40.77	9.56	15-63	39.75	11.18	17-58	38.98	11.85	14-61
PA	Pre	27.82	5.56	17-40	28.18	6.04	16-43	28.22	7.12	14-40	27.13	6.69	16-44	26.63	7.61	14-44	29.49	6.77	16-47
	Post	24.63	7.96	13-43	23.47	7.31	11-38	23.12	7.92	10-40	23.30	7.60	11-41	23.23	7.63	11-45	22.87	7.96	10-39
NA	Pre	13.53	3.54	10-26	13.35	2.98	10-23	14.12	4.08	10-29	14.17	4.03	10-27	13.77	4.33	10-31	13.60	5.40	10-34
	Post	12.39	3.21	10-22	12.92	2.77	10-22	13.86	4.55	10-32	13.15	3.29	10-25	13.40	4.69	10-34	13.53	5.20	10-34
Food craving		12.24	6.18	5-25	12.35	5.53	5-25	13.83	5.82	5-25	11.21	5.31	5-23	13.04	5.40	5-25	12.04	5.48	5-25
Chocolate		1.20	0.78	0-4	1.29	0.76	0-4	1.48	1.06	0-4	1.45	0.80	0-4	1.17	0.64	0-3	1.34	0.76	0-4
Restorativeness rating		3.43	0.67	2.40-4.68	2.17	0.71	1.18-3.45	2.13	0.42	1.13-3.75	2.16	0.44	1.07-3.32	2.74	0.42	1.05-4.58	1.80	0.45	1.00-3.10
Liking rating		3.36	0.72	2.23-4.75	2.42	0.75	1.25-3.72	2.20	0.40	1.00-3.60	2.23	0.48	1.02-3.40	2.74	0.41	1.23-5.00	1.95	0.46	1.00-3.15
Recognizability rating		4.13	0.23	1.87-5.00	3.87	0.26	2.77-4.98	1.90	0.31	1.02-3.10	1.80	0.25	1.00-2.85	3.65	0.35	2.27-4.97	3.57	0.37	1.73-5.00

443 *Note.* ROS = restoration outcome scale. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA = positive affect. NA = negative affect. See main text for further descriptions.

444

445 **Figure 3.**

446 *Results for Study 1 and 2*

447

448 *Note.* Panels show the results for the restoration outcome scale (A), change in positive affect (B), change in connectedness to nature (C), restorateness rating (D), liking rating
 449 (E), and recognizability rating (F) for nature (solid) and urban (open) stimuli presentation for each image type in Study 1 (original, phase-scrambled, line drawing) and Study 2
 450 (words). Vertical lines indicate dissociation between Study 1 and Study 2. Error bars represent standard error.

451

452 **Table 3**
453 *Inferential Statistics (ANOVA) of Measures in Study 1*

	<i>F</i> ratio	df	<i>p</i>	η_p^2
ROS				
Category	11.91	1,303	.001	.04
Type	4.63	2,303	.010 ⁺	.03
Interaction	5.05	2,303	.007	.03
BDST				
Category	0.75	1,269	.386	< .01
Type	0.22	2,269	.802	< .01
Interaction	0.61	2,269	.543	< .01
CTN-s				
Category	6.81	1,303	.010 ⁺	.02
Type	2.51	2,303	.083	.02
Interaction	2.84	2,303	.060	.02
PA				
Category	3.29	1,303	.071	.01
Type	0.90	2,303	.408	.01
Interaction	4.28	2,303	.015 ⁺	.03
NA				
Category	0.05	1,303	.824	< .01
Type	0.84	2,303	.435	.01
Interaction	1.46	2,303	.234	.01
Food craving*				
Category	2.41	1,303	.122	.01
Type	0.25	2,303	.777	< .01
Interaction	0.42	2,303	.660	< .01
Chocolate*				
Category	0.64	1,299	.426	< .01
Type	2.30	2,299	.102	.02
Interaction	0.39	2,299	.678	< .01
Restorativeness rating				
Category	167.54	1,354	< .001	.32
Type	51.28	2,354	< .001	.22
Interaction	48.36	2,354	< .001	.21
Liking rating				
Category	93.95	1,354	< .001	.21
Type	49.92	2,354	< .001	.22

Interaction	26.04	2,354	< .001	.13
Recognizability rating				
Category	22.21	1,354	< .001	.06
Type	1770.39	2,354	< .001	.91
Interaction	3.30	2,354	.038	.02

Note. ROS = restoration outcome scale. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA = positive affect. NA = negative affect. * ANCOVA with last meal as covariate. + not significant after Bonferroni-Holm correction (see S5 in Supplemental Material)

2.4 Discussion

Study 1 assessed restorative effects evoked by viewing nature and urban original, phase-scrambled, and line drawing stimuli. For original images, we replicated higher perceived restoration, as well as higher ratings of liking and restorativeness (e.g., Authors, 2021; Han, 2018; Tinio & Leder, 2009). Furthermore, the data suggested higher CTN-s for viewing nature compared to urban environments (cf. Mayer et al., 2009). This is in line with a recent study using images as well (Pasca et al., 2021). However, we found no environment-related effects on working memory and mood, which contrasts with studies supporting ART and SRT (cf. McMahan & Estes, 2015; Stevenson et al., 2018). The exploratory measures of food craving and chocolate taking yielded no differences between the nature and urban stimuli when we controlled for hours since last meal. Although the overall pattern of increased perceived restoration through nature was supported, the lack of effects on working memory and mood indicates a gap between explicit/self-reported measures (perceived restoration and connectedness, as well as explicit ratings of preference and restorativeness) and more objective or indirect measures of restoration (BDST and PANAS). These findings might have several explanations and reflect general challenges in the literature.

First, the null results for BDST and PANAS may be caused by our particular set of images. In comparison to stimuli used in other studies, ours were relatively diverse, especially the urban images. In fact, they were sourced from a stock image database in which rather

477 beautiful and high-quality images are included. Furthermore, we selected urban areas that
478 include not only streetscapes and industrial areas, as for example in Berman et al. (2008), but
479 also inner city, historic, and residential areas that might be rated as more restorative and
480 beautiful (e.g., Karmanov & Hamel, 2008; Weber & Trojan, 2018). However, note that Study
481 1 and both studies reported in Authors (2021) show that our urban images were (explicitly and
482 implicitly) rated as significantly less restorative than the nature images. The issue of the
483 diversity of urban environments raises the question what characteristics generally lead to the
484 non-positive effects on restoration-related measures (compared to nature stimuli; for a related
485 discussion, see Berto, 2020; Hicks et al., 2020a, 2020b). Similarly, several researchers
486 emphasized considering the diversity of urban environments and showed restorative effects for
487 urban areas as well (Collado & Manrique, 2020; Scopelliti et al., 2019; Staats et al., 2016;
488 Weber & Trojan, 2018).

489 Second, by using a between- rather than a within-subjects design, power might be too low
490 to detect small effects. Although sometimes medium effect sizes were found and overall meta-
491 analyses suggest improved mood and BDST performance, they also showed that effects were
492 on average rather small, especially in lab contexts (McMahan & Estes, 2015; Ohly et al., 2016;
493 Stevenson et al., 2018). Relatedly, a visual presentation of the BDST might have also attenuated
494 the effect, maybe due to addressing visual attention as well (cf. Stevenson et al., 2018). In most
495 other studies, the BDST was verbally implemented (e.g., Berman et al., 2008). Although
496 Morton and colleagues (2017) also presented the BDST visually and found performance
497 differences after nature and urban image presentation depending on manipulated salient identity
498 (when controlled for baseline measurement), other researchers did not replicate better BDST
499 performance in a visual version after nature image presentation (Grassini et al., 2019).

500 Third, the null results—and therefore a discrepancy of our results compared to previous
501 ones—might mirror a general publication bias since studies with significant findings were
502 published more frequently, while those with null-findings are often not shared with the

scientific community. The small number of differences between original nature and urban images in our study limits the interpretability of the other image types' results. Therefore, we focus our main discussion and conclusions on perceived restoration (measured by the ROS) and the subjective ratings of liking and restorativeness, as these findings were most robust, both in the literature (e.g., Menardo et al., 2019) and in the current study.

Phase-scrambled images received lower restorativeness and liking ratings compared to original images. This is consistent with previous findings using implicit measures on valence and stress restoration (Authors, 2021). Although several image properties differed between nature and urban original and phase-scrambled images (see S3 in Supplemental Material; Authors, 2021), we found no differences in perceived restoration (measured by the ROS) nor restorativeness ratings between phase-scrambled nature and urban images. This indicates that the characteristics of the amplitude spectrum (e.g., spectral slope and colour) have no measurable effect on perceived restoration, and is therefore in contrast to the predictions of the PFA.

Although Authors (2021) found differences in implicitly measured associations with valence for nature and urban phase-scrambled images, the current explicit ratings on preference did not corroborate these. Although this is a bit surprising, it is regularly observed that explicitly and implicitly measured evaluations do not correlate or only do so weakly (e.g., Hofmann et al., 2005; Sánchez et al., 2016). Relatedly, Valtchanov and Ellard (2015) reported explicitly and implicitly measured preference for phase-scrambled nature compared to urban images. However, they used a slightly different procedure of image manipulation, their stimulus set was limited (i.e., a total of eight grey-scaled images), and the exact rating terms were different ('pleasant' vs. 'liking' and 'restorativeness'). Our findings, which were based on a much larger number of diverse colour images, indicate that information preserved in the phase-scrambled images do not notably affect affective ratings or perceived restoration. Thus, differences in statistical regularity do not seem to sufficiently explain differences in restoration for original

images, which contradicts the PFA. However, as stated above, our findings for phase-scrambled images are limited regarding the different facets of restoration (i.e., mood and attention) due to similar points discussed above for original images (e.g., visually implemented BDST).

Despite some inconsistency with previous work and the possibility of false negative findings, we believe that the current null results suggest that the lack of spatial information and/or certain other image characteristics (e.g., edge properties) diminishes pronounced perceived restoration effects, and that the amplitude spectrum and colour properties seem to play no or rather minor roles for restoration. This is in line with recent work using landscape paintings and their phase-scrambled counterparts (Law et al., 2020).

Overall, the results indicate that spatial information available in original images and line drawings, which permit higher-level processing (i.e., recognizing objects and the environment), seems to evoke perceived restoration and higher liking ratings for nature compared to urban environments. However, we cannot conclude whether these effects were due solely to the recognition of the environment as nature or urban and its respective associations, or whether they were also influenced by differing edge-related image properties since line drawings of nature and urban environments still vary systematically in some image properties, such as edge characteristics (S3 in the Supplemental Material). Therefore, Study 2 aimed to test the restorative effects evoked by nature- and urban-related words, which lack diagnostic image properties.

3 Study 2

3.1 Introduction

The results of Study 1 indicate that either the recognition of the scene (i.e., higher-level processing) and/or edge-related properties are more relevant for restoration than other lower-level processed properties. Since the line drawings used in Study 1 were based on gradients

within the original image, some image properties still differ between nature and urban images, and, therefore, the effects of lower-level image properties on restoration found for line drawings cannot be entirely ruled out. Therefore, in Study 2, words were used as stimuli to eliminate any diagnostic lower-level properties.

Study 2 was equivalent to Study 1 in procedure and measures, except that words instead of pictures related to nature and urban environments were presented (and therefore we collected no data on recognizability of objects). By using such stimuli, we were able to remove diagnostic lower-level properties while allowing higher-level processing and related associations evoked by the words. Based on the literature and findings of Study 1, which emphasize the importance of higher-level processing, we assumed greater restorative effects (i.e., higher subjective restoration, more positive and less negative affect, better cognitive function, higher current connection to nature, lower craving, as well as higher restorativeness and liking ratings) for nature compared to urban words. This would contradict the assumptions of the PFA, which claims that differences in lower-level properties and processing fluency primarily explain restoration effects.

3.2 Materials and Methods

3.2.1 Participants

Corresponding to Study 1, a-priori sample size determination suggested a total sample size of 98 participants, which was approximated by the final sample (52 in the nature and 44 in the urban words conditions, respectively). Although mathematically the p -value for the interaction of the 2×2 ANOVA with time is equal to the p -value of a t-test using difference scores, the a-priori power analysis for the latter, which we conducted after the review process, indicates a total sample of 128 due to eliminating the within-subjects factor. Sensitivity analysis

for the final analysis with 96 participants revealed a minimum detectable effect size of Cohen's $d = 0.58$.

The recruiting was similar to Study 1, except that we noted in the recruiting information that eligibility was restricted to those who did not previously participate. In total, 101 participants took part. Of them, five participants were excluded because of incomplete data or repeated participation. Of the remaining 96 participants, 77 indicated being female and 19 male. Their age ranged from 18 to 54 years, with a mean of 23.47 ($SD = 5.80$) years (one person did not indicate her age). Most were students from the social sciences.

3.2.2 Stimuli

An initial pool of words was generated by freely associating with the concepts of 'nature' and 'urban', by inferring from the original images (Study 1), by checking the word list provided by Kotabe and colleagues (2017), and by searching synonyms for several words in German dictionaries (www.duden.de, www.corpora.uni-leipzig.de, www.synonyme.woxikon.de). In an online pilot study with 61 participants, 99 words for each category were rated for how well they fit to the respective category of 'nature' and 'urban'. The words with the highest ratings were selected for the study. The final word list consisted of each 60 words (all nouns; e.g., 'lake' or 'flower' for nature and 'tram' or 'church' for urban environments; S6 in the Supplemental Material). Words in the final set did not significantly differ in length, $t(118) = -1.59$, $p = .112$, $d = 0.29$, or frequency, $t(118) = 1.28$, $p = .203$, $d = -0.23$, in the German language (Abteilung Automatische Sprachverarbeitung, Universität Leipzig, 2019). Words were presented in Calibri with a size of 48 pixels whereby the longest word had the same width as the image stimuli in Study 1 (i.e., 11°).

3.2.3 Procedure

Procedure, design, and materials were equivalent to Study 1. Note, however, that this study was conducted in a different lab on the same campus. Up to five participants were tested simultaneously in the lab at individual computers, with closed window blinds and artificial light. The viewing distance was about 60-70 cm. Stimuli were presented on LG 22MB35 monitors with a full HD 1920×1080 resolution. After collecting the data on the same measures from Study 1 (except for the ratings on recognizability), we additionally asked participants to fill out a questionnaire on their purpose in life (Crumbaugh, 1968), which was used in a related Bachelor thesis. Analysis of this data was, however, not part of the current study. The study was conducted in accordance to the Declaration of Helsinki and approved by the local ethics committee of the university where the study was planned and conducted (application number: 160_2018).

3.3 Results

Descriptive statistics for all measures can be found in Table 4; inferential statistics can be found in Table 5. Alternative analyses suggested elsewhere (Stevenson et al., 2018) revealed the same results and can be found in S4 of the Supplemental Material. As in Study 1, we did not report adjusted *p*-values in the main text. All significant results reported here remained significant after Bonferroni-Holm correction (cf. S5 in the Supplemental Material).

Participants felt more restored after viewing nature compared to urban words, 95% CI[3.38, 7.19] (Table 4; Figure 3). The difference score for the BDST was not different for nature and urban word exposure. A significant difference between the difference scores for CTN-s, 95% CI[2.61, 8.77] indicated that viewing urban words led to a reduction of CTN-s, while viewing nature did not (Figure 3). Similarly, the decrease in positive affect was larger after viewing urban words, 95% CI[1.02, 6.14] (Figure 3). For negative affect, there was no

difference between the word categories. ANCOVAs with hours since last meal as a covariate revealed neither a difference between nature and urban words for food craving, nor number of chocolate pieces taken. Nature words were liked more, 95% CI[1.04, 1.46], and viewing them was rated as being more restorative than viewing urban words, 95% CI[1.30, 1.78] (Figure 3).

Table 4

Descriptive Statistics of Measures in Study 2

Outcome		Nature			Urban		
		<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
ROS		18.31	5.02	6-27	13.02	4.27	6-23
BDST	Pre	5.87	1.45	3-9	5.98	1.52	4-9
	Post	6.04	1.30	4-9	6.35	1.33	4-9
CTN-s	Pre	43.40	9.31	14-61	39.98	10.69	14-58
	Post	44.73	10.00	20-64	35.61	9.96	13-61
PA	Pre	26.85	7.54	10-40	26.59	6.06	18-39
	Post	25.54	7.98	13-43	21.71	7.25	10-37
NA	Pre	14.39	4.54	10-30	14.71	4.84	10-33
	Post	13.02	4.03	10-29	14.55	5.39	10-33
Food craving		13.52	5.54	5-23	12.48	5.63	5-24
Chocolate		0.77	0.65	0-3	0.75	0.58	0-2
Restorativeness		3.18	0.61	2.08-	1.63	0.29	1.13-
rating				4.67			2.45
Liking rating		3.29	0.49	2.22-	2.04	0.47	1.13-
				4.45			3.03

Note. ROS = restoration outcome scale. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA = positive affect. NA = negative affect. See main text for further descriptions.

Table 5

Inferential Statistics (t-Tests) of Measures in Study 1

	<i>t</i>	df	<i>p</i>	Cohen's <i>d</i>
ROS	5.50	94	< .001	1.13
BDST	0.44	84	.661	0.10
CTN-s	3.67	94	< .001	0.75

PA	2.78	94	.007	0.57
NA	1.57	94	.120	0.32
Food craving*	1.44	1, 93	.232	.01
Chocolate*	0.02	1, 93	.891	< .01
Restorativeness rating	11.72	118	< .001	2.14
Liking rating	12.78	118	< .001	2.33

Note. ROS = restoration outcome scale. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA = positive affect. NA = negative affect. * ANCOVA with last meal as covariate (column *t* presents *F* ratio, column Cohen's *d* presents η_p^2)

3.4 Discussion

We used word stimuli to fully control for diagnostic lower-level image properties while evoking mental images of nature and urban environments. Corresponding to the findings for original images in Study 1, nature-related words evoked higher perceived restoration, higher CTN-s, were liked more, and were rated as more restorative than urban-related words. Furthermore, like for line drawings (Study 1), positive affect decreased more after viewing urban- compared to nature-related words. Therefore, the results for words were relatively similar to those for original images and line drawings, in which higher-level information is available—and they were different from the null results from phase-scrambled images. Thus, we conclude that higher-level processing evoked higher perceived restoration—even when no diagnostic lower-level image properties were present. This contradicts the PFA. Rather, these findings are more consistent with ART and SRT, which suggest that certain characteristics, such as water or plants, may lead to feelings of ‘being away’ (ART) and/or positive affective states (SRT). For that, no specific visual input seems necessary: as Ulrich stated, “a feeling response could also be elicited by imagination or a vivid memory of a natural setting” (Ulrich, 1983, p. 90). Note, however, that conclusions on ART and SRT are difficult here as respective measures (BDST and affect) were relatively unaffected in our studies.

4 General Discussion

We investigated the roles of lower- and higher-level processing of nature and urban stimuli and to their effects on restoration-related measures. Image analyses for the stimuli used in Study 1 supported previous findings of diverging lower-level processed image properties for nature and urban scenes (Authors, 2021; Braun et al., 2013; Kardan et al., 2015; Penacchio & Wilkins, 2015). Still, we found no indication that the properties preserved in phase-scrambled images, including those on statistical scale-invariance, contribute to the experimentally tested perceived restorative effects found for original images. Instead, the current studies showed that higher-level processing—identifying of objects and the environment—led to perceived restoration. Noteworthy, for all stimulus types, including original images, nature exposure led to weak or non-significant effects on the other measures (e.g., BDST or PANAS), perhaps due to a lack of a stress-induction. Thus, too little need for restoration, which is seen as important in SRT and ART, might have prevented further restoration effects (cf. Kaplan, 1995; Stevenson et al., 2018; Ulrich et al., 1991). The PANAS and BDST pre-test data support the possibility that the need for cognitive (BDST) and affective (PANAS) restoration may have been too low in our sample. Therefore, we focus on the results of the ROS, which measures perceived restoration, as well as restorativeness and liking ratings, while keeping in mind the limitations related to the BDST, PANAS, CTN-s, and food craving.

Although effects of image properties on preference were previously found in simplified visual stimuli (e.g., greyscale random noise patterns with different spectral slopes; Spehar et al., 2016), a direct comparison of such findings with the current studies has limitations: the differences between our nature and urban photographs are—despite their significance and large effect sizes—often smaller than between the conditions in studies using artificial stimuli (e.g., our average spectral slope difference was 0.21 while conditions in Spehar et al. differed by 0.6 [note that their indicated value was multiplied by two because their calculation was based on

the amplitude spectrum while ours was based on the power spectrum]). Thus, despite significant differences in the absolute values of image properties, our results indicated that the differences in relevant image properties (e.g., spectral slope) between nature and urban stimuli may be too small to have a measurable effect on preference or restoration. Note, however, that relatively small differences in image properties do not necessarily mean that they do not influence perception and evaluation, as for example subtle differences in spectral slope influence aesthetic evaluation of faces (Menzel et al., 2015).

Although the differences in image properties between nature and urban images were—expectedly (cf. Braun et al., 2013)—not large, the null results following phase-scrambled image presentation and their ratings contradict the PFA that “states that unthreatening natural scenes are affectively evaluated more positively than unthreatening urban scenes because our visual system more fluently processes certain aspects of the visual structure of the former than of the latter” (Joye & van den Berg, 2011, p. 266). Although there is no explicitly stated need for restoration in the PFA, its absence might help to explain some of our results. Even so, however, the absence of differences in liking ratings for phase-scrambled images also contradicts the PFA’s underlying assumption that the positive feeling evoked by ease of processing is attributed to the stimulus (Joye & van den Berg, 2011; Reber et al., 2004; Redies, 2007). Thus, even independent of restoration, we found no support for the assumption that nature-urban differences in statistical regularity (measured by the spectral slope) explain preference.

Our results are consistent with a recent study, which revealed beneficial effects after viewing landscape art, but not for their respective phase-scrambled versions (Law et al., 2020). This study did, however, not include a control environment (i.e., paintings of urban scenes), so that one cannot disentangle whether their observed effects are due to recognizing *any* objects, the image as art, and/or the scene as nature. In contrast, our studies allowed us to disentangle the effects of image type (i.e., original, phase-scrambled, line drawing) and category (i.e., nature, urban).

In sum, our results show that the identification of objects and/or a mental image of the environment (induced by the presence of words) led to better perceived restoration after seeing nature- compared to urban-related stimuli. Thus, higher-level processing seems necessary for perceived restoration. Based on these findings, it seems likely that preference for and/or associations with depicted objects or environments led to feelings of restoration, rather than affective responses and/or associations evoked by the processing of lower-level image properties. Similarly, Van Hedger and colleagues (2019) showed that preference for nature sounds depends on higher- rather than lower-level processing: nature sounds were only preferred over urban ones when participants could recognize their source. Similarly, ambiguous sound can evoke restoration when it is assumed to be natural rather than industrial (Haga et al., 2016). Thus, for both vision and sound, lower-level properties alone do not seem to evoke pronounced preference or perceived restoration.

Based on prior literature and our current results, it is likely that lower-level processed properties mostly have an indirect effect on restoration. Besides playing a mediating role for higher-level processing, their similarity or fit to the recognized scene may moderate the relationships between higher-level processing, evaluation, and restoration. Similar relationships were suggested recently by others as well (Van Hedger et al., 2019; Schertz & Berman, 2019; Ibarra et al., 2017). For example, certain image properties may amplify activity from lower- to higher-level processing areas or via feedback loops from higher- to lower-level areas after objects are identified. This is supported by previous brain imaging data, which found that brain activity in category-selective regions is affected by image properties (Andrews et al., 2015; Rice et al., 2014; D. M. Watson et al., 2014; see also Groen et al., 2017; and Epstein & Baker, 2019, for reviews on scene perception). Relatedly, within the framework of predictive processing, which suggests a constant and two-way feedback between top-down predictions and bottom-up information to minimize energy (Friston, 2005, 2010), diagnostic lower-level processed image properties may help decreasing the prediction error (esp. when spatial

information is available) and thereby evoke positive emotions (Van De Cruys, 2017). These potential interactions should be addressed in future studies.

Despite the necessity of higher-level processing, our results for line drawings support the notion that lower-level processing plays a mediating or moderating role for restorative effects: perceived restoration was weaker for line drawings, in which many lower-level image properties are missing, compared to original images (Figure 3). Thus, missing properties (e.g., colour, amplitude spectrum properties) seem to influence perceived restoration—although environmental scene categorization in scene-selective brain regions (e.g., parahippocampal place area) is assumed to be similar for photographs and line drawings (Walther et al., 2011). Since our line drawings represent the same source stimuli, the difference in perceived restoration between original photographs and line drawings is unlikely to be due to different mental images of the depicted scene. Additionally or alternatively, the artificiality of modified stimuli (i.e., line drawings) may also contribute to the attenuation in perceived restoration, because such stimuli may evoke lower affective responses (cf. Mould et al., 2012).

Our results for nature-related words evoking perceived restoration and preference effects suggest that properties of the visual input play a minimal role in the beneficial effects of visual nature. Instead, they indicate that associative learning might play a more important role (cf. Egner et al., 2020; Meidenbauer et al., 2019). This somewhat contradicts existing theories, which propose that (visual) characteristics of nature versus urban environments at least partly drive restoration effects (e.g., fluent and efficient processing through lower-level properties humans are evolutionary adapted to [PFA], or properties that allow ‘soft fascination’ [ART]). Although the current studies did not directly test other underlying mechanisms suggested by these theories, our results do not support some of their assumptions (esp. those of the PFA). Despite different image properties, which are associated with scale-invariance and efficient or fluent processing (Graham & Field, 2009), phase-scrambled nature and urban image presentation did not evoke different perceived restoration or ratings on restorativeness and

liking. Instead, when the environment was recognizable, pronounced perceived restoration as well as restorativeness and liking rating were found for nature compared to urban stimuli. Thus, our study provides no support for the PFA's assumption that statistical regularity, which is characteristic for natural scenes, contributes to restorative effects evoked by such scenes.

Although our word lists were relatively diverse, one might argue that nature- and urban-related words differ in valence, but this is also true for image stimuli (cf. Authors, 2021; Sánchez et al., 2016). In fact, differences in valence can be seen as an inherent characteristic of nature and urban stimulus sets (although not all; cf. Collado & Manrique, 2020). The words were considered to evoke similar mental images of the environments as the original stimuli, but without scene-diagnostic visual input. Controlling the valence of nature and urban images *and* words can be a next step for further investigating the role of environment and its processing, independent of valence.

Our results, especially those on words, are consistent with the recently proposed conditioned restoration theory (Egner et al., 2020). This theory assumes that preference and restorative effects of natural and other restorative stimuli is the result of evaluative conditioning processes. As such, restorative and/or positively evaluated activities were linked to and thus associated with certain environments (e.g., nature), so that these environments (and even representations thereof) are learned to be restorative and positive. Thus, one may assume that our participants previously learned associations with nature- and urban-related words but not with phase-scrambled images. Although this explanation is sound, more research is needed to thoroughly test this and the PFA.

Future research may: 1) find more ways to manipulate internal repetition in images and/or fluent processing to experimentally test the PFA further, 2) better disentangle different mechanisms related to preference and restoration, and 3) extend our results on the role of lower-level image properties for affective and restorative evaluations of nature by using more sensitive measures and stress-induction. Similarly, Schertz and Berman (2019) encouraged looking

deeper into the role of lower-level image properties to understand restoration evoked by images. In fact, our current studies cover some of the research questions and methods they proposed—without us being aware of this work before conducting our studies (mid-2017 to early-2019). Our current results contributed to answering them and we support their call for more research on mechanisms and mediators leading to the restorative effects of nature (images). Moreover, future research should include the diverse facets of environmental perception (e.g., observer’s and object’s motion) and interactions with modalities other than vision (e.g., Franco et al., 2017; Heft, 2021), as well as social aspects of restoration (e.g. restoring shared relational resources; Hartig, 2021).

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1140

1 **Supplemental Material**

2

3 S1. Images used in pilot study (Study 1 of Authors, 2021; no indicator) and selected for current Study 1 (*). Images can
4 be accessed on colourbox.de using the noted ID.

category	image ID
nature	10015121, 10015238*, 10015361*, 10053273*, 10091542*, 1025356*, 10441262*, 10485567*, 10508084*, 10710818, 10835093, 10894081*, 10894098*, 10949756, 11007330*, 11231656, 11435318, 11512024, 11512041*, 11618880*, 1207683, 12585176*, 12935962, 13565744*, 13742919*, 13844724*, 17796440*, 18103350, 1948285*, 20212943, 21578564*, 2185835*, 22824806*, 2352894, 2365871*, 2480953*, 2488947*, 2607912, 2608039*, 2608135, 2729142, 2729438, 2760543, 2922966, 3023541*, 3179208*, 3378328*, 3466480*, 3595156, 3788920*, 3788921*, 3802211*, 3846072, 4005221*, 4021164*, 4427411*, 4569194, 4569206, 4583660*, 4657696, 4716064*, 5100417*, 5130886, 5359207*, 5368617*, 5368736, 5368843*, 5369070, 5369508, 5369566*, 5804285*, 6165182, 6165825*, 6255146*, 6261444*, 6381281*, 6382750, 6422149, 6424738, 6425101*, 6425181*, 6591934*, 6669704*, 6783516, 7165486, 7223741, 7531206, 7794939*, 7935139*, 7966162*, 8117048, 8155781, 8192114, 8294139*, 9502254*, 9600960*, 9600968*, 9603897, 9740938*, 9759623
urban	10015182, 1007574*, 1007777*, 10361401, 10378832, 10384378, 10547957*, 10730291*, 1076160, 1076222*, 11322731, 11597067*, 11601356, 11756008*, 11850666*, 11890378, 11975512*, 11999198*, 1208257*, 1208259*, 12123851, 12190299*, 12196268, 12693132, 1290900, 13089236*, 13188561, 13212989, 13334757*, 13640953*, 13640987*, 13641014*, 13641023*, 14272719*, 14272743, 14272772*, 14276706, 14972994, 15324703*, 15747130, 1586138, 15994176, 16306377*, 16844021*, 17346113*, 17574162, 17710049*, 17998745*, 18131360*, 18556902, 18666791, 1922428*, 20995949, 2235448*, 22926446, 22993760*, 22993898, 22993911*, 22993954, 23485686*, 2612104*, 3194143*, 5358369*, 5498772*, 6121632, 6367694*, 6421804*, 6421828*, 6421909*, 6422118, 6430243*, 6430343*, 6430431*, 6446477*, 6535183, 6596422, 6596616, 6906876*, 7134857*, 7153700*, 7153742, 7172760*, 7231339, 7567159*, 7626629*, 7682405*, 7732320*, 7732384*, 7999826, 8094709*, 8128585, 8148463, 8203306*, 8380980*, 854230*, 9515130, 953999*, 9599523, 9629387, 9743295*

5

6

7 S2. Information on the creation of phase-scrambled images and line drawings. The code can be copied and executed in
8 the respective free programs (Octave or ImageJ) to create respective stimuli based on an input folder with square colour
9 jpg-images.

	phase-scrambled images	line drawings
description	By the use of Fast Fourier Transformation, a random phase was created and combined with the amplitude spectrum of each channel of the RGB colour spectrum	First, a Gaussian blur with a sigma of 1 was applied. Second, edges were identified using a Sobel edge detector. Third, a binary image was created. Fourth, in this binary image, pixels were removed from the edges until they are reduced to single-pixel-wide shapes ('Skeletonize' function). Finally, using the 'Dilate' function pixels were added to magnify the lines evenly.
executed in	Octave	ImageJ (code used as macro)
code	<pre>clear; clc; pkg load image idir='inputdictionary'; %enter path to input folder odir='ouputdictionary'; %enter path to output folder cd (idir); %enter folder is set as working directory filenames=dir('*.jpg'); for n = filenames' imname=strcat(idir,n.name) Im = mat2gray(double(imread(imname))); ImSize = size(Im); RandomPhase = angle(fft2(rand(ImSize(1), ImSize(2))))); for layer = 1:ImSize(3) ImFourier(:,:,layer) = fft2(Im(:,:,layer)); Amp(:,:,layer) = abs(ImFourier(:,:,layer)); Phase(:,:,layer) = RandomPhase; ImScrambled(:,:,layer) = ifft2(Amp(:,:,layer).*exp(sqrt(- 1)*(Phase(:,:,layer)))); end ImScrambled = real(ImScrambled); outputname=strcat(odir,n.name); imwrite(ImScrambled,outputname,'jpg'); end</pre>	<pre>run("Gaussian Blur...", "sigma=1"); run("Find Edges"); setOption("BlackBackground", false); run("Make Binary"); run("Skeletonize"); run("Dilate");</pre>

10

11

12 S3: Mean values of measures for the image set used in Study 1 ($n = 60$ per image category). Results of t -test ($df=118$)
13 comparing nature and urban images. Rows in bold indicate significant difference between nature and urban images.

image type	image property	image category		results of t -test		
		nature	urban	t	p	d
original	spectral slope	-2.22	-2.43	6.71	< .001	1.23
	weighted residuals	3.79*10¹¹	6.46*10¹¹	-7.32	< .001	-1.34
	HSF	0.010	0.010	-0.12	.906	-0.02
	MSF	0.029	0.035	-1.35	.181	-0.25
	LSF	0.961	0.955	0.98	.330	0.18
	self-similarity	0.60	0.57	1.36	.176	0.25
	complexity	12.82	11.48	1.72	.088	0.31
	anisotropy	4.03*10⁻⁴	6.13*10⁻⁴	-9.91	< .001	-1.81
	hue	1.24	-0.13	4.42	< .001	0.81
	saturation	0.46	0.25	8.60	< .001	1.57
	brightness	0.60	0.61	-0.36	.718	-0.07
	SD of hue	1.23	1.53	-3.49	< .001	-0.64
	SD of saturation	0.24	0.19	5.07	< .001	0.93
	SD of brightness	0.25	0.26	-1.75	.083	-0.32
	entropy	7.51	7.50	0.17	.865	0.03
	edge density	0.13	0.10	7.95	< .001	1.45
	straight edge density	0.07	0.12	-7.91	< .001	-1.44
	non-straight edge density	257.45	64.65	17.15	< .001	3.13
	fractal dimension	1.75	1.68	4.36	< .001	0.80
phase-scrambled	spectral slope	-2.24	-2.43	5.56	< .001	1.01
	weighted residuals	3.30*10¹¹	5.59*10¹¹	-7.24	< .001	-1.32
	HSF	0.010	0.010	-0.01	.991	< .01
	MSF	0.028	0.033	-1.27	.208	-0.23
	LSF	0.962	0.960	0.89	.376	0.16
	self-similarity	0.92	0.91	1.53	.129	0.28
	complexity	15.71	16.29	-0.76	.449	-0.14
	anisotropy	1.54*10 ⁻⁴	1.69*10 ⁻⁴	-1.24	.216	-0.23
	hue	1.35	-0.31	5.33	< .001	0.97
	saturation	0.39	0.22	7.63	< .001	1.39
	brightness	0.58	0.59	-0.62	.535	-0.11
	SD of hue	1.00	1.40	-5.02	< .001	-0.92
	SD of saturation	0.25	0.19	5.55	< .001	1.01
	SD of brightness	0.23	0.24	-1.39	.166	-0.25
	entropy	7.72	7.76	-1.52	.131	-0.28
	edge density	0.18	0.16	4.63	< .001	0.85
	straight edge density	0.05	0.06	-2.51	.013	-0.46
	non-straight edge density	481.50	407.63	7.10	< .001	1.30
	fractal dimension	1.96	1.95	3.69	< .001	0.67
line drawing	spectral slope	-1.77	-1.94	10.30	< .001	1.88
	weighted residuals	40.80*10 ¹¹	42.83*10 ¹¹	-1.08	.280	-0.20
	HSF	0.065	0.062	0.50	.617	0.09
	MSF	0.061	0.072	-1.77	.080	-0.32
	LSF	0.874	0.866	0.62	.535	0.11
	self-similarity	0.60	0.59	0.59	.559	0.11
	complexity	36.18	30.04	3.99	< .001	0.73
	anisotropy	10.89*10⁻⁴	11.97*10⁻⁴	-3.26	.001	-0.60
	hue	NA	NA	NA	NA	NA
	saturation	NA	NA	NA	NA	NA
	brightness	0.68	0.74	-3.78	< .001	-0.69
	SD of hue	NA	NA	NA	NA	NA
	SD of saturation	NA	NA	NA	NA	NA
	SD of brightness	0.45	0.43	2.88	.005	0.52
	entropy	2.66	2.38	3.79	< .001	0.69
	edge density	0.12	0.11	3.93	< .001	0.72
	straight edge density	0.04	0.09	-10.35	< .001	-1.89
	non-straight edge density	242.22	82.03	11.02	< .001	2.01
	fractal dimension	1.81	1.76	4.69	< .001	0.86

14 Notes. NA = not available

S4. Results of alternative analyses (i.e., 2x3 [Study 1] or 2x1 [Study 2] ANCOVA on post values controlled for pre-values) for repeated measures variables.

Study 1												Study 2					
category						interaction						category					
type			type			type			type			category			category		
<i>F</i>	df	<i>p</i>	η^2	<i>F</i>	df	<i>p</i>	η^2	<i>F</i>	df	<i>p</i>	η^2	<i>F</i>	df	<i>p</i>	η^2		
BDST	0.64	1, 299	.426	<.01	2.30	2, 299	.102	.02	0.39	2, 299	.678	<.01	0.75	1, 84	.388	.01	
CTN-s	4.94	1, 303	.027	.02	3.16	2, 303	.044	.02	2.54	2, 303	.081	.02	20.24	1, 94	<.001	.18	
PA	2.67	1, 303	.104	.01	0.92	2, 303	.399	.01	3.14	2, 303	.045	.02	9.03	1, 94	.003	.09	
NA	0.02	1, 303	.881	<.01	1.20	2, 303	.303	.01	1.56	2, 303	.211	.01	3.42	1, 94	.068	.04	

Note. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA = positive affect. NA = negative affect.

20 S5. Bonferroni-Holm corrected *p*-values for Study 1 and 2.

	Study 1			Study 2
	category	type	interaction	category
ROS	.004	.073	.049	< .001
BDST	1.000	1.000	1.000	1.000
CTN-s	.057	.497	.299	.002
PA	.354	1.000	.088	.033
NA	1.000	1.000	.936	.481
food craving	.487	1.000	1.000	.698
chocolate	1.000	0.510	1.000	1.000

21 *Note.* ROS = restoration outcome scale. BDST = backwards digit-span task. CTN-s = connectedness to nature state. PA =
22 positive affect. NA = negative affect. See main text for further information.

23

24

category	words
nature	branch (Ast), stream (Bach), tree (Baum), mountain (Berg), highland (Bergland), bee (Biene), leaf (Blatt), blossom (Blüte), pollen (Blütenstaub), flower (Blume), bush (Busch), badger (Dachs), thicket (Dickicht), soil (Erde), fern (Farn), rock (Fels), fish (Fisch), river (Fluss), riverscape (Flusslandschaft), flood (Flut), daisies (Gänseblümchen), mountain range (Gebirge), waters (Gewässer), chirping (Gezwitscher), deer (Hirsch), chestnut (Kastanie), pine (Kiefer), bud (Knospe), leaves (Laub), deciduous tree (Laubbaum), moss (Moos), conifer (Nadelbaum), nest (Nest), plant (Pflanze), flora (Pflanzenwelt), fungus (Pilz), spring (Quelle), rain (Regen), rainbow (Regenbogen), doe (Reh), bark (Rinde), butterfly (Schmetterling), lake (See), woodpecker (Specht), stones (Steine), shrub (Strauch), fir (Tanne), fir needles (Tannennadeln), (animals) Tiere, (fauna) Tierwelt, pond (Tümpel), jungle (Urwald), vegetation (Vegetation), birds (Vögel), forest (Wald), waterfall (Wasserfall), meadow (Wiese), wild boar (Wildschwein), root (Wurzel), twig (Zweig)
urban	traffic light (Ampel), asphalt (Asphalt), car (Auto), train station (Bahnhof), construction site (Baustelle), building (Bauwerk), municipal authority (Behörde), housing block (Block), brakes (Bremsen), bridge (Brücke), pavement (Bürgersteig), bus (Bus), bus station (Busbahnhof), cathedral (Dom), shopping centre (Einkaufszentrum), roadway (Fahrbahn), wheeler (Fahrzeug), airport (Flughafen), alley (Gasse), edifice (Gebäude), sidewalk (Gehweg), shop (Geschäft), harbour (Hafen), tower block (Hochhaus), honking (Hupen), canal (Kanal), church (Kirche), pub (Kneipe), roundabout (Kreisel), crossroad (Kreuzung), culture (Kultur), store (Laden), lantern (Laterne), engine (Motor), motorcycle (Motorrad), parking automat (Parkautomat), parking area (Parkplatz), poster (Plakat), tyres (Reifen), advertising (Reklame), renovation (Sanierung), city train (S-Bahn), siren (Sirene), stadium (Stadion), city council (Stadtverwaltung), street (Straße), street railway (Straßenbahn), street sign (Straßenschild), petrol station (Tankstelle), pidgeon (Taube), taxi (Taxi), tram (Tram), transport (Transport), metro (U-Bahn), vehicle (Vehikel), traffic (Verkehr), apartment (Wohnung), skyscraper (Wolkenkratzer), zebra crossing (Zebrastreifen), centre (Zentrum)