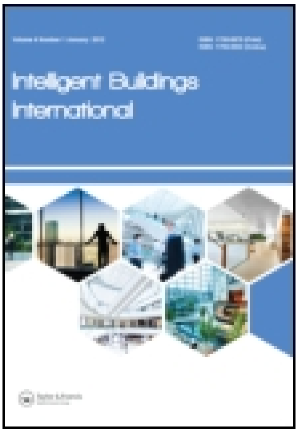

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RESEARCH ARTICLE

Exploration of neural correlates of restorative environment exposure through functional magnetic resonance

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Up until now, neural mechanisms associated with psychological restoration process related to brain activity have not been identified. We explored the neural correlates of restorative environment exposure with functional magnetic resonance imaging while participants viewed photographs with low or high restorative potential (LRP and HRP, respectively). Baseline measurements of self-reported stress before viewing these two categories of environments and post-test measurements were considered as behavioural evidence of psychological restoration. Activation of the middle frontal gyrus, middle and inferior temporal gyrus, insula, inferior parietal lobe, and cuneus was dominant during the view of HRP environments, whereas activation of the superior frontal gyrus, precuneus, parahippocampal gyrus, and posterior cingulate was dominant during LRP viewing ($p < 0.05$). Brain area activations related to involuntary attention were found during the view of HRP environments and brain areas related to directed attention were more active during the view of LRP environments. The results are consistent with the attention restoration theory and suggest that the perception of restorative qualities and a building-integrated vegetation could be considered for architects in order to provide cognitive resources necessary for adequate human functioning.

Keywords: attention; environmental perception; psychological restoration; restorative environments; stress recovery.

Introduction

People spend more than 90% of their lives within buildings. Building design has the potential to cause stress and eventually affect human health (Evans and McCoy 1998). Contrary to this is the concept of restorative environment, which is the one that can aid in recovery from directed attention fatigue (attention restoration theory; Kaplan 1995) and stress (van den Berg, Koole, and van der Wulp 2003). Without sufficient restoration, conditions of resource inadequacy may become chronic, and this can entail negative consequences for effective functioning, wellbeing, and health (Hartig 2007). Restorative elements of design in built environments can help buildings occupants to provide cognitive and affective resources necessary for adequate human functioning. As creators of the built environment, architects need to apply these principles in order to evaluate not only the functionality and form of existing or new environments (Roe 2008), but also the design of healthy environments because of its significance for adaptation and health.

From the perspective of neuroscience, the research in restorative environments exposure will enhance our understanding of the neural systems that subserve the human response to the physical world. Through advances in neuroscience, we are now able to explain the ways in which we

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perceive the world around us and navigate in space and the way our physical environment can affect our cognition, problem-solving ability, and mood. Of relevance in our study is to know how certain particular environmental features (restorative qualities) can enhance some brain-related responses.

Psychological restoration is the result of the recovery from an antecedent deficit (e.g. stress or attentional fatigue) following the exposure to a restorative environment (Kaplan and Talbot 1983). It implies the process of renewing physical, psychological, and social capabilities diminished in ongoing efforts to meet adaptive demands (Hartig 2004).

A psychoevolutionary theory of psychological stress recovery claims that the experience of visually pleasant physical surroundings is thought to reduce stress by eliciting positive emotions, sustaining non-vigilant attention, restricting negative thoughts, and returning physiological arousal to more moderate levels (Ulrich 1983; Ulrich et al. 1991).

Environments that enable and promote these changes can be called restorative and are more likely to be natural rather than built environments (Nikunen and Korpela 2009).

According to attention restoration theory (Kaplan 1995), restorative environments must offer four factors to facilitate the restoration of attention fatigue in a better manner: being away, compatibility, extent, and fascination. Each of these identified restorative components can vary along a broad range depending on the considered scenario. While these components may be rated with a high potential in one scenario they can express the opposite in another. The more restorative qualities a scenario possesses greater the odds that it will be restorative (Kaplan, Bardwell, and Slakter 1993).

Being away refers to a geographical or psychological distance from demanding tasks and the associated ability to escape from distractions.

Compatibility is the factor that associates an individual's needs and desires with what the environment offers.

Extent implies the sense of being somewhere with sufficient scope that one can dwell there for a while, whether or not the physical place is vast (Kaplan 1983).

Similar to the concept of sustained non-vigilant attention (Ulrich et al. 1991) fascination implies a type of involuntary attention that plays a crucial role in attention restoration theory as it provides the opportunity for a depleted attentional system to rest (Kaplan and Kaplan 1989). Based on the distinction proposed by James (1892), attention restoration theory states that the mechanisms of attention are two: Interest (James's involuntary attention) and effort. The kind of attention based on interest is called fascination and it involves patterns difficult not to attend. It refers to a soft, or effortless intrigue in one's surroundings that allows a person to redirect attention from stressful demands. Fascination can be oriented towards particular contents (e.g. animals, people, water, and nature) and/or events (e.g. story telling, gambling, and problem solving), and it can also be engaged in processes of exploring and making sense of an environment (Kaplan 1995). It is characterized along a continuum that ranges from soft to intense. Some natural scenarios such as parks, gardens, and other landscapes are resources for soft type of fascination, whereas intense fascination relates to a series of activities that occur beyond a natural context (e.g. watching TV, shopping, etc.). The latter type of fascination does not promote restoration and reflection (Herzog et al. 1997). Fascination is seen as a source of exogenous visuospatial attention process. This kind of attention can be directed to an object in a bottom-up way (that reflect sensory stimulation), such as in visual pop out driven by perceptual saliency (Itti 2006).

In contrast, directed attention (James's voluntary attention) describes attention that requires effort and is susceptible to fatigue. The operation involves a mechanism that inhibits the distractions on which directed attention depends (Kaplan 1995). This kind of attention does not arise out of environmental patterns, but of our volition, intentions, and purposes (Kaplan and Kaplan 1989).

Actually, most typical living circumstances favour voluntary attention resulting in attention fatigue (Berto et al. 2010). This fatigue is the manifestation of the accumulative effects of everyday life, multiple distractions that have to be consciously inhibited through voluntary attention in order to function efficiently. Directing attention in a voluntary way according to our goals and intentions is referred to as top-down or endogenous attentional orienting (Mulckhuyse and Theeuwes 2010).

Psychological, neuropsychological, and physiological evidence suggest the existence of two partially segregated networks of brain areas that carry out different attentional (processing) functions (Corbetta and Shulman 2002). One system, which includes parts of the intraparietal cortex and superior frontal cortex, is involved in preparing and applying goal-directed (top-down, controlled attentional mechanism) selection for stimuli and responses. The other system, which includes the temporoparietal cortex and inferior frontal cortex, and is largely lateralized to the right hemisphere, is specialized for the detection of behaviourally relevant stimuli (bottom-up, perceptual mechanism) (Corbetta and Shulman 2002; Fink et al. 1997). 'Top-down' or 'bottom-up' regulation of attentional processes represents conceptual principles rather than referring to anatomical systems (such as ascending and descending projections; Sarter, Givens, and Bruno 2001). In most situations, top-down and bottom-up processes interact to optimize attentional performance (Egeth and Yantis 1997). Endogenous attention orienting is relatively slow to develop, whereas exogenous attention orienting is fast and occurs within 100 ms (Egeth and Yantis 1997). Of interest for the present research is to validate how attention restoration might be reflected in brain activity, taking into account the bottom-up or top-down regulation of attentional processes presumably related with fascination and directed attention.

Most research on psychological restoration employs inferred or subjective measures that convey emotional, cognitive, and behavioural dimensions. Studies that consider physiological variables related to psychological restoration appeared in specialized literature at the end of the last century (Ulrich et al. 1991). Although psychological restoration has been considered an important factor in the promotion of mental health, and environmental research related to this subject may be broadening (Hartig 2001), there is no scientific evidence documenting the cerebral structures involved or the psychophysiological processes underlying this restoration in a clear and systematic manner. Even though there are studies that document brain wave activity (electroencephalogram) resulting from natural and urban environment exposures (Chang et al. 2008; Ulrich 1981), the neural mechanisms associated with brain activity related to the psychological restoration process have not been identified. We propose using functional magnetic resonance imaging (fMRI) to study the neural correlates of psychological restoration processes.

Neuroimaging techniques such as fMRI allow the identification of neural centres related to brain activity. The fMRI is based on the idea that blood carrying oxygen (oxygenated) behaves differently in a magnetic field than blood that has already released its oxygen to the cells. In other words, oxygen-rich haemoglobin in blood and de-oxygenated haemoglobin in blood have a different magnetic susceptibility and therefore give rise to different MR signals. Scientists know that more active areas of the brain receive more oxygenated haemoglobin in the blood. The fMRI picks up this increased blood flow to pinpoint greater neural activity. The measurement of increased blood flow, resulting in a local increase of oxygenated haemoglobin is called the blood-oxygen-level-dependent (BOLD) signal (Logothetis and Wandell 2004) which can be used to construct maps of brain activity that underlie the neural mechanisms of mental activity (Jezzard, Matthews, and Smith 2001). An fMRI study measures the regional flow of blood to the brain with a precision of a few millimetres, allowing scientists to identify regions that are using significant amounts of oxygen – a measure of neural activity (Biederman and Vessel 2006).

fMRI is a neuroimaging non-invasive technique, with high spatial resolution that enables demonstration of entire network brain areas engaged in specific activities. Other tools like electroencephalography offer poor spatial resolution. Positron emission tomography is invasive since it exposes the subject to gamma radiation. Yet fMRI also has its disadvantages, it can only capture a clear image if the person being scanned stays completely still. Another potential limitation is the detection of neuronal mass activity and not activity of specific neuronal units (Logothetis 2008).

fMRI studies allow the identification of neural centres related to perception (Ishai, Ungerleider, and Haxby 2000), selective attention (Chung et al. 2000), visual–spatial attention (Mayer et al. 2004), emotional valence to pleasant, unpleasant, and neutral visual stimuli (Paradiso et al. 1999), tranquillity (Hunter et al. 2010), self-reflection (Johnson et al. 2002), topographical, spatial, and episodic memory processes (Mellet et al. 2010), stress (Lederbogen et al. 2011), and mental fatigue (Cook et al. 2007), all important mechanisms relevant to a restorative experience.

There are several neuroscientific assessments that show the role carried out by the central nervous system in processing of affective and cognitive responses towards the physical environment. fMRI experiments can employ visual images to study the brain's response to them, as well as induced mental states and specific emotions. Recent investigations of neural bases of environmental preference highlight the activation of brain areas that mediate contextual associations of the environment and its link to pleasure (Yue, Vessel, and Biederman 2007). Studies about neuroaesthetics document the neural correlates of beauty perception, including the admiration or rejection of certain landscapes and contexts (Kawabata and Zeki 2004). Moreover, there are studies about the visual processing of environmental scenes and influences that underlie the visual perception of constructed scenarios (Henderson, Larson, and Zhu 2007). Recently, Kim et al. (2010), without taking into account environmental restoration qualities, have studied the human brain activation in response to visual stimulation with rural and urban scenery pictures. Their findings link the brain responses to passive view of rural settings in neuroanatomical areas related with positive emotions (e.g. globus pallidus) and negative emotions and memory processing related with urban views (e.g. amigdala, hippocampus, and parahippocampal gyrus). The authors refer that most of the brain activations in rural and urban views overlapped and that the comparative study of brain activities in response to rural and urban scenic viewing showed only a 0.5% difference.

In the present research, we explore the behavioural response and neural correlates of passive exposure to two environments with different restorative potentials (both natural and urban) considering an experimental paradigm of psychological restoration. The paradigm referred includes: (1) the antecedent condition from which a person might restore (e.g. stress condition); (2) the environment which the person enters during the time available for restoration; and (3) the outcomes that reflect on actual or potential changes in resources and/or components of the experience which mediate those changes (Hartig 2011). In an fMRI scanner environment we first exposed all our participants to a stressful situation (need for restoration and deficit induction through a stressful movie) and then introduced them to a exposure of one type of environment with different restorative potential (low restorative potential (LRP) or high restorative potential (HRP); see Figure 1 for examples of the two environmental categories) in a blocked fMRI design of the experiment (see Figure 2). Baseline measures of stress (T1, self-reported), pre-test (T2, after viewing stressful movie, before viewing LRP or HRP), and post-test measure (T3, after viewing the restorative images) were considered as behavioural evidences of psychological restoration. It is expected that HRP environments have a greater influence on psychological restoration (recovery of an antecedent deficit; e.g. stress, Kaplan and Talbot 1983) in comparison to low potential ones, in which case the influence is expected to be null or non-significant.

According to the attention restoration theory (Kaplan 1995) we hypothesize that, in our experiment, during the restorative environment presentation following the stressful condition,

(a)

(b)

Figure 1. A natural environment with HRP (a) and built environment without nature with LRP (b).

activation of brain areas is related to involuntary, bottom-up, exogenous attention in the HRP exposure, while in the LRP condition, the activation of cortical areas is related to direct, endogenous, top-down attention.

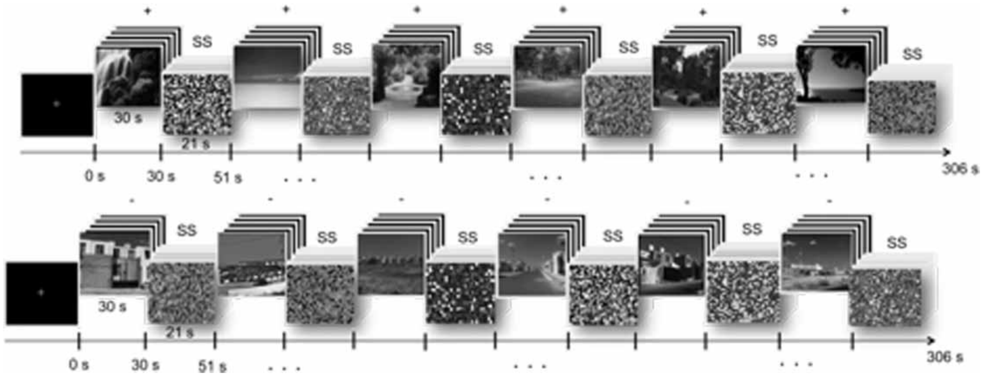

Figure 2. Schematic representation of the experimental design for one fMRI session.
Notes: (+) High restorative images and (−) low restorative images. Each block (+ or −) lasted 30 seconds and each stimulus was presented for 6 seconds. SS = Scrambled pictures. Images of built and natural landscapes alternated with highly scrambled versions. Each SS block lasted 21 seconds and each stimulus was presented for 3 seconds.

Results

Behavioural results

A series of 2 (environment: HRP, LRP) $\times$ 2 (time T1, T2) analyses of variance (ANOVAs) with repeated measures revealed that the average rating on the stress measure was significantly higher after viewing the frightening movie (T2) than during baseline measurement (T1), all p's < 0.001 (see Table 1). These results indicate that the stress-induction manipulation was successful. Independent sample t-test comparing the LRP and the HRP groups showed that at T1 the HRP and LRP groups did not differ ($t(22) = -0.45$, $p = 0.65$), even after watching the stressful video, at T2 ($t(22) = -1.22$, $p = 0.23$), indicating that these groups were comparable with respect to their perceived stress before and after watching the stressful video. Participants in the HRP group exhibit a tendency to obtain lower scores of perceived stress after viewing the restorative stimulus. On the other hand, perceived stress was similar to LRP in T2 and T3 (see Table 1), suggesting a null process of stress recovery for this group. Notwithstanding the foregoing, a series of 2 (environment: HRP, LRP) $\times$ 2 (time T2, T3) ANOVAs with repeated measures on the second factor show only marginally significant effects in T2 and T3, as indicated by the time $\times$ group interaction $F\ (1, 22) = 3.62$, $p = 0.07$.

fMRI results

Figure 3 shows a general view of the areas more active in HRP than in LRP (a) and LRP than in HRP (b). Figure 3 highlights a greater distribution of activations for LRP environments, whereas

Table 1. Perceived stress as a function of restorative exposure and time of measurement.

		HRP			LRP		
		T1	T2	T3	T1	T2	T3
Perceived stress	*M*	1.68	2.28	1.82	1.63	1.95	1.95
	SD	0.30	0.74	0.51	0.43	0.53	0.46

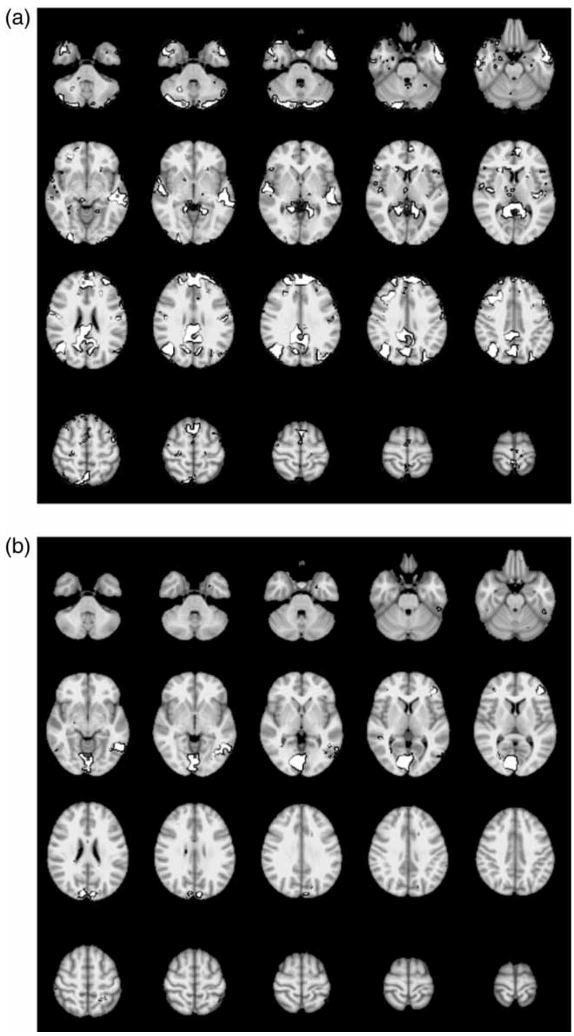

Figure 3. A series of BOLD fMR images for brain areas activated following visual stimulation with still pictures of HRP vs. LRP views (a) and LRP vs. HRP views (b) in 24 volunteers. For group analysis of HRP and LRP groups, differential activation maps, which correspond to the contact of HRP vs. LRP and LRP vs. HRP, were obtained from the two-sample *t*-test. Significant activation maps for these contrasts were identified by a whole-brain analysis with a statistical threshold of $p < 0.05$.
Notes: The BOLD (blood oxygenation level dependent) method is based on the state of oxygenation of the haemoglobin (Ogawa et al. 1990). This molecule has different magnetic properties depending on the concentration of O2; when it is fully saturated with oxygen (oxyhaemoglobin) it behaves as a diamagnetic substance, while when some oxygen atoms have been removed (deoxyhaemoglobin) it becomes paramagnetic. Within any particular imaging voxel (representing a small part of the brain) the proportion of deoxyhaemoglobin relative to oxyhaemoglobin dictates how the MR signal will behave in a BOLD image: areas with high concentration of oxyhaemoglobin give a higher signal, which reflect brain activity (a brighter image in zone e.g. the enhanced white areas of the brain slices) than areas with low concentration.

in the case of HRP environments there is a remaining minor activation. Table 2 then summarizes these results. Figure 4 shows specific anatomical location of these activations. The list of brain regions may at first seem overwhelming, so we devote the next section to a review of results from cognitive neuroscience that will help us interpret the role of these key regions.

Table 2. Differential brain activities between HRP and LRP groups.

		HRP vs. LRP						LRP vs. HRP					
				MNI coordinates						MNI coordinates			
	Region of activation	BA	L/R	*x*	*y*	*z*	Z^a	BA	L/R	*x*	*y*	*z*	Z^a
Frontal lobe	MFG	46	L	−40	42	8	2.5						
	SFG							9	L	30	52	30	3.5
								9	R	4	58	32	3.0
								8	R	6	38	54	2.3
Temporal lobe	MTG	22	R	48	40	4	0.0						
	ITG	37	L	−58	−56	−8	2.3						
	Insula	13	R	40	0	−2	2.0						
Parietal lobe	IPL	40	R	58	−28	38	2.0						
	Precuneus							19	R	40	−74	32	2.79
	Precuneus							39	L	−44	−74	32	2.21
Occipital lobe	Cuneus	19	R	10	−88	22	3.42						
	Cuneus	19	L	−40	−80	26	3.45						
Limbic system	PG							30	R	12	−42	2	1.9
	PC							29	R	10	−46	12	1.9

Notes: MNI = Montreal Neurological Institute, BA = brodmann area, L/R = left/right hemisphere, MFG = middle frontal gyrus, SFG = superior frontal gyrus, MTG = middle temporal gyrus, ITG = inferior temporal gyrus, IPL = inferior parietal lobe, PG = parahippocampal gyrus, PC = posterior cingulate.
[a]The activated brain regions were determined by group *t* tests with a threshold corresponding to a statistical significance level of $p < 0.05$.

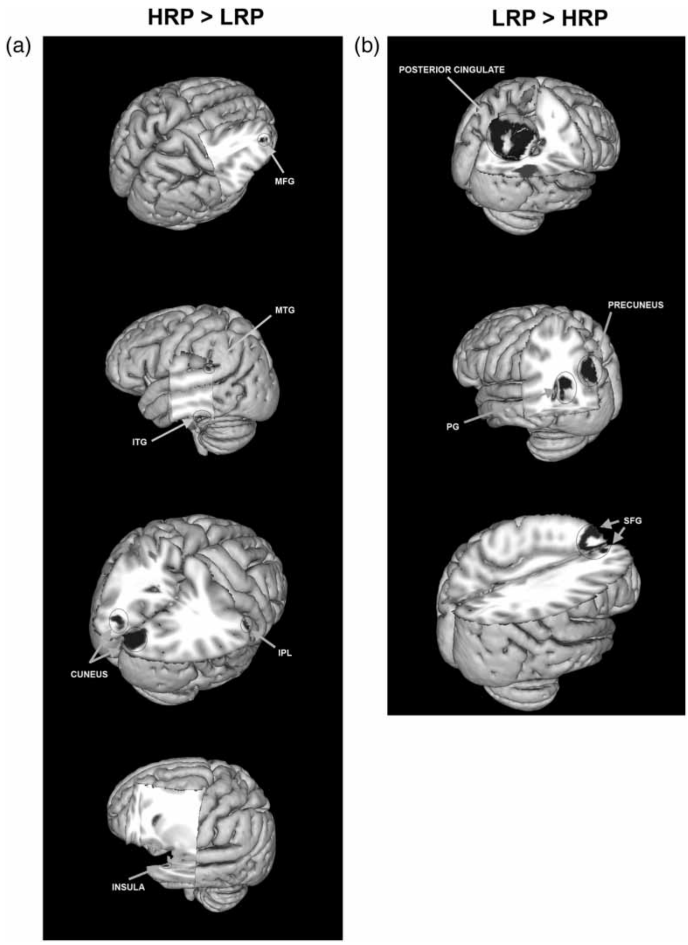

Figure 4. Overview of regions activated during visual stimulation in the two groups. Brain activation areas are in black. MFG= middle frontal gyrus, MTG= middle temporal gyrus, ITG=inferior temporal gyrus, IPL= inferior parietal lobe, IPL= inferior parietal lobe, PG= parahippocampal gyrus, and SFG= superior frontal gyrus.

In the next section, we will look in more detail at cognitive correlates of the brain regions highlighted in Table 2 and review the literature that suggests why those areas might be differentially active in HRP and LRP.

Brain activations in perspective

Spontaneous activity in the primary visual area involves memory-related mental imagery processes and/or the mechanism of replaying previous information for visual memory consolidation (Wang et al. 2008).

During HRP scenery the left middle frontal gyrus, right middle temporal gyrus, left inferior temporal gyrus, right insula, right inferior parietal lobe, and cuneus (bilaterally) were predominantly activated as compared with LRP viewing.

The frontal lobes are thought to regulate posterior cortical activity by exerting control over the sensory and integrative functions of the posterior regions of the brain (Tucker and Derryberry

1992). Also, frontal lobe activation is correlated with novelty-seeking behaviour (Dafner et al. 2000). An important collative property, novelty, is related to spontaneous attention control (Berlyne 1960). Middle frontal gyrus is prominently engaged in storing of spatial information (Leung, Gore, and Goldman-Rakic 2002), dominance of inhibitory control (Garavan, Ross, and Stein 1999), and focusing attention (Clapp et al. 2011). The activation of the dorsolateral prefrontal cortex is consistent with studies in neuroaesthetics. In these studies, the assessment of images labelled as 'beautiful' evokes higher activity in the mentioned area (Cela-Conde et al. 2004). The temporal lobe represents the memory storehouse for visual representation of complex stimuli (Miyashita 1988). The middle and inferior temporal gyri are involved in cognitive processes, including semantic memory, language, visual perception, and multimodal sensory integration (Martin et al. 1996). Right insula cortex activity is enhanced by awareness of emotionally charged stimuli. Insular cortex is activated by visceral stimulation (Aziz, Schnitzler, and Enck 2000), pain (Peyron et al. 2002), and emotional processing (Phillips et al. 1998). The parietal lobes in the brain integrate sensory information and determine object positions in space and are associated with approach-related behaviours (exploration behaviour) (Foster et al. 2008). The inferior parietal lobe, Brodmann Area 40, is thought to be involved in spatial attention, establishing maps of extra personal space and multimodal sensory integration (Lynch 1980). Two components of the emotional processing (activation and affection) contribute consistently to visual cortex activations. Motivationally significant pictures produced greater activation of the visual cortex (e.g. cuneus) compared with neutral images (Bradley et al. 2003).

During LRP scenery viewing the brain areas – left and right superior frontal gyrus (Brodmann area 9/8 respectively), precuneus (right and left), right parahippocampal gyrus, and posterior cingulate – were predominantly activated as compared with HRP viewing.

Right superior frontal gyrus plays an important role in emotional cognitive processes related to an approximation-avoidance emotion (Paradiso et al. 1999), working memory (Rajah, Languay, and Grady 2011), and activation in visual stimuli recognition tasks (Maguire, Frith, and Cipolotti 2001). The precuneus tends to activate in visual attention processes and relates to episodic memory (Fletcher et al. 1995). In our study, the precuneus activation shows a tendency to higher view concentration on LRP vs. HRP scenes. Precuneus activation can relate to familiarity degree that people have in constructed environments. This is consistent with studies regarding visual familiarity and neural responses present in precuneus activation (Gobbini and Haxby 2006). fMRI studies indicate that the parahippocampal gyrus becomes highly active when human subjects view passively topographical scenery such as images of landscapes, cityscapes, or rooms (e.g. images of 'places') (Epstein 2005). The human right hippocampal region is critically involved in retrieving information that links object to place (Owen et al. 1996). Our results are consistent with scenery observation involved in processing the geometric structure of built environments (Epstein 2005). The posterior cingulate carries out an important role in the organization of flexible behaviour as a response to a constantly changing environment (Pearson et al. 2011).

Discussion

Previous work has shown that environments with HRP (e.g. natural environments) engendered more positive emotional self-reports (Hartig et al. 1996, 1997) and a stress recovery (Ulrich 1983; Ulrich et al. 1991). Therefore, recovery of an antecedent deficit resulting from a visual experience of HRP images was expected, in contrast with the LRP experience. In the present study, perceived situational stress did not improve significantly from T2 (after viewing stressful movie, before viewing the restorative settings) to T3 (after seeing the restorative images) for the HRP group as was expected. Our results show a non-significant trend in the predicted direction and partially reflect a process of recovery from stress in the HRP group. Within these results it is important to consider some methodological and technical implications. For example, the scanner environment and its psychological side effects (Harris, Cumming, and Menzies 2004) could act as limitations for a stress recovery process. On the other hand, perhaps our sample size ($n = 24$) could affect the statistical significance (Sieguel and Castellan, 1995).

Our findings from the contrast of HRP vs. LRP suggest that three brain regions may be particularly relevant to explain some psychological restoration process: the left middle frontal gyrus, insula, and cuneus. According to the attention restoration theory, involuntary attention is a spontaneous, effortless, inhibitory response to interesting stimuli. All the positive restorative stimuli presented here were classified as interesting and stimulating (Martínez-Soto, Gonzales-Santos, and Barrios 2012) and were associated with brain activations in the frontal areas and could be explained as stimuli fascination. The insula activation has been documented in emotional experiences involved in contemplative practices (Lazar et al., 2005), and has been found to be active during the presentation of natural scenic views (Kim et al. 2010). An increase in cuneus activation is associated with the affect and activation valence of the profile obtained in HRP environments (Martínez-Soto, Gonzales-Santos, and Barrios 2012).

On the other hand, the role of the posterior cingulate in the experience of built LRP environments is noteworthy. A higher cingulate activity is present in stimulating scenarios of endogenous attention (Pearson et al. 2011). It has implications in the perception of constructed scenarios such as the ones that require a constant adaptation dynamic due to the socio-environmental demands of daily life in urban scenarios. Encounters with low restorative urban environments place higher demands on information processing resources and entail a higher adaptation effort (Stainbrook 1968).

We hypothesize the activation of brain areas related to involuntary, bottom-up, exogenous attention in HRP exposure, while in the LRP condition the activation of cortical areas is related to direct, endogenous, top-down attention. Our findings suggest that endogenous, top-down, directed attention is more active during viewing of LRP vs. HRP environments. This is evidenced by the activation of right hemispheric prefrontal and parietal regions, which have been found to be regions of relevance in sustained attention performance (Pardo, Fox, and Raichle 1991). Similarly, as previously referred, a higher cingulate activity is present in stimulating scenarios of endogenous attention, such as built low-restorative environments. Unlike natural environments, urban environments contain bottom-up stimulation (e.g. car horns) which capture attention dramatically and additionally require directed attention to overcome that stimulation (e.g. avoiding traffic, ignoring advertising, etc.), making urban environments less restorative (Berman, Jonides, and Kaplan 2008).

Exogenous, bottom-up, involuntary attention is often associated with activation of a right lateralized ventral fronto-parietal network with core regions of ventral frontal cortex (inferior frontal gyrus) and temporoparietal junction (inferior parietal lobule and superior temporal gyrus) (Corbetta and Shulman 2002). Our data support the role of the inferior parietal lobule as an area involved in the ventral attention network that is active in reoriented attention towards salient stimuli (Buschman and Miller 2007; Mayer et al. 2004; Peelen, Heslenfeld, and Theeuwes 2004). Also, a higher activation of the middle frontal gyrus during viewing of HRP environments is suggestive of a exogenous involuntary stimulus-driven attention (Snyder and Chatterjee 2006). Exogenous attention – the more automatic, stimulus-driven component of spatial attention – is oriented more rapidly (is fast and occurs within 100 ms), is less susceptible to interference, and does not place demands on cognitive resources which endogenous attention does (Cheal and Lyon 1991). These qualities could perhaps be the break that allows the rest of directed attention and conceivably promotes attentional restoration.

As mentioned in the Results section, restorative environments with LRP showed greater brain activations distribution in contrast to high-potential restorative environments (see Figure 3). This range of variability could be explained in terms of effort and efficacy of stimulus processing and rapid, selective, and content-specific processing of biologically relevant stimuli with high adaptive and evolutionary significance (Appleton 1975; Anokhin et al. 2006; Delorme, Richard, and Fabre-Thorpe 1999).

A higher number of activated areas responding to environments with LRP suggests greater effort in processing information (Kaplan 1995). Neurophysiologically, attention can be described as increase of activity in a particular brain area involved in the processing of stimuli (Rees and Lavie 2001). This coincides with the fact that urban environments tend to generate greater demands on information processing resources and require more effort to adapt (Stainbrook 1968) and thereby possibly greater diversification in the response of brain activity. On the opposite side, the focus is not only associated with increased activation, but also can occur along a decrease in activity in other brain regions (Loose et al. 2003). That is, enhances brain activity in regions that render the selected stimulus (e.g. primary visual cortex) and decreases activation in regions not associated with the processing of such stimulus (e.g. primary auditory cortex). Under an evolutionary perspective, a lower activation distribution in the case of HRP environments could be linked to the fact that the natural contents can be processed relatively easily and efficiently because the brain and sensory systems have developed in natural environments (Wohlwill 1983).

Studies of fMRI employ various types of experimental designs, most of which fall into one of two categories: (1) block design (as the one presented here, where a block contains a series of stimulus that are presented during a discrete epoch of time) and (2) event-related design (types of trials are interleaved and each trial is modelled separately as an ‘event’). Further studies in the neural correlates of restorative environments exposure could consider the use of event-related paradigm which minimizes habituation and boredom (Buckner et al. 1998), which in some way can be a limiting factor in the analysis of neural activity because stimulus repetition results in net reduction of neural activity (Biederman and Vessel 2006).

The fMRI techniques, such as resting state (Morcom and Fletcher 2007), could be useful for studying the post-restorative brain state which could be similar to the studies of post-stress brain state (van Marle et al. 2010). In these studies, post-restorative network changes in the brain could be explored. Resting activity might be keeping the brain’s connections running when they are not in use. Or it could be helping to prime the brain to respond to future stimuli, or to maintain relationships between areas that often work together to perform tasks. It may even consolidate memories or information absorbed during normal (or in this case, restorative process) activity (Smith 2012).

Most of the restorative environments studied here are natural, which means considering the influence of vegetal elements in the design of built settings. However, recent studies refer to the importance of built scenarios whose architectural qualities (Lindal and Hartig 2013) may have to be considered in future studies of neural correlates of psychological restoration. The design of built setting with nature must be taken into account in order to ameliorate several environmental stressors (noise, traffic, crowding, and air pollution) that affect everyday living conditions of most urban communities (Martínez-Soto 2010). Other architectural dimensions linked to stress that should be considered in the design of built spaces are lack of stimulation, the perception of highly ambiguous spaces, misaffordances (when we are unable to readily discern the functional properties of a space; Heft 1997), and uncontrollable environmental conditions (Evans and McCoy, 1998).

An overview of the neural correlates of restorative environments exposure shows the activation of brain areas related with different complex mental functions. These include brain areas related with attentional process (bottom up and top down), multimodal sensory integration, episodic memory, topographic orientation, and brain areas related with emotion processing. These are cognitive neuroscience findings, whose aims are understanding complex mental functions such as perception, memory, language, and emotion (Gazzaniga, Ivry, and Magnum 2008).

fMRI is a tool used by a growing number of scientists who seek to investigate the brain mechanisms underlying psychological phenomena (Cacioppo and Decety 2009). Considerable advances in the fMRI technique during the last decade have made fMRI data more precise and reliable. Compared with the traditional questionnaire methods of psychological evaluation, fMRI is far more objective. This technique allows for more objective measures of psychological processes because it can be used to investigate psychological tasks to which people have little or no verbal access (Aue, Lavelle, and Cacioppo 2009).

The present research is pioneering in implementing an experimental paradigm of psychological restoration using fMRI and is a methodological contribution from neuroscience to the study of restorative environments. The neuroscience research in restorative environments means better understanding of the neural basis of environmental transactions that promote human wellbeing. This understanding contributes to evidence-based design to look at the biological bases of human needs, relevant to all built settings and all people (Edelstein 2008). From this point of view the study of the neural correlates of restorative environment exposure represents a contribution to 'neuro architecture' which proposes a new discipline that unites neuroscience with the experience of built environments (Edelstein and Marks 2007).

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Appendix

Methods

Participants

Twenty-eight healthy, right-handed, voluntary male participants were recruited after all responded to an informed written consent. All were mid-to-high socioeconomic level with age averaging 36.18 years (SD 12.46) and a scholarity mean of 16.55 years. All procedures were institutional review board approved. Four were eliminated due to: clinical problems (2), claustrophobia (1), and problems with data transfer (1). None had significant neurological or psychiatric history and all answered the SCL 90 symptoms list and the Edinburgh Inventory computerized versions (González-Santos et al. 2007; Oldfield, 1971). Twelve participants were assigned to the HRP group (36.83 $\pm$ 11.52 y.o.a.) and 12 to the LRP group (36.00 $\pm$ 13.23 y.o.a.).

Design

An experimental study was conducted with two independent between-subject variables HRP or LRP groups, while perceived stress was measured three times as within-subject variable (T1, T2, and T3). Perceived stress was tested immediately after all subjects were positioned in the scanner to obtain a baseline level (T1), after exposure to stressful video (T2), and after restorative images viewing (T3). The stressful video was introduced to cause an emotive and cognitive deficit (Brand, Versput, and Oving 1997) to quantify a restorative effect. The participants were randomly assigned to the two between-subject groups.

Stimuli and paradigm

Prior to entering the scanner, subjects received thorough instructions about the scanning procedure and the tasks to perform stress dimension listing (Stress and Activation Adjectives Checklist; King, Burrows, and Stanley 1983; Martínez-Soto, Gonzales-Santos, and Barrios 2012) to rate precisely that moment's emotional state. The stress sub-scale is a measure of perceived situational stress consisting of nine adjectives (e.g. annoying, worried) with a response format of four options (from yes with certainty to not at all).

Once positioned inside the scanner all subjects answered a randomized version of the Stress and Activation Adjectives Checklist to estimate a baseline measure (T1). All list presentations and responses were programmed with Java and interfaced with a magnetic resonance compatible response grip (NNL, Nordic Neurolab, Bergen, Norway).

Prior to the restorative environment presentation all subjects were exposed to a deficit induction, using 4.54 minutes of fragments from the documentary 'Faces of Death, #1' (Brand, Versput, and Oving 1997). Participants were instructed to carefully watch the video and feel free to stop the video if the images were disturbing them. After the video presentation (T2) all subjects answered for a second time the Stress and Activation Adjectives Checklist.

Finally, a restorative environment stimuli paradigm using fMRI was executed. This run followed a blocked design presentation controlled by E-prime (Psychology Software Tools, Inc.) and synchronized with the MR scanner (NNL Synchronization box, Bergen, NR). All restorative environment stimuli were taken from a previous study (Martínez-Soto, Gonzales-Santos, and Barrios 2012) and consisted of photographs rated with the Mexican revised scale of Environmental Restoration Perception (Martínez-Soto and Montero y López-Lena, 2010). The categories were: LRP (built settings without nature, $n = 14$; score average ≤ 3.5, scale 0–9) and HRP environments (natural scenes, $n = 21$ and some built urban environments with nature, $n = 4$; score average ≥ 6.5, scale 0–9). According to our design, each group was exposed only to LRP or HRP condition. The restorative stimuli were distributed in six blocks of restorative environments and six blocks of highly scrambled versions or neutral images of built and natural landscapes without any obvious conventional meaning. Each block had five randomized images and each image presentation lasted six seconds. The scrambled versions had seven randomized images with 3 seconds of duration per image. The HRP block and LRP block were alternated with blocks of scrambled versions (see Figure 2). Each high or low restorative block began with the presentation of a screen and instructions: 'Here you will see a series of photographs, which you must observe freely. Avoid storing and judging any detail. This presentation is not a memory task nor should any work be performed related to the particular content of the photographs'. After the instructions, a fixation point appeared (1000 ms) on a grey background followed by the block design for 306 seconds. At the end of the fMRI run, all subjects answered the Stress and

Activation Adjectives Checklist list again (T3). All the visual stimuli were projected using a magnetic resonance compatible Nordic NeuroLab's Visual System (NNL, Bergen, NR). HRP and LRP images were adjusted to the same resolution and none contained close views of humans (Cela-Conde et al. 2004).

fMRI data acquisition

All MR imaging were performed in a G.E. 3.0T Discovery MR750 with a 32-channel head coil. Anatomical 3D high-resolution T1 images were acquired for each subject. Functional images were collected using an EPI – blood oxygen level-dependent sequence, 102 volumes, TR/TE = 3000 ms/40 ms, over 38 slices 4-mm thick, with a 64×64 matrix, resulting in a $4 \times 4 \times 4$ mm^3 isometric voxel.

Behavioural data analyses

To ascertain whether perceived stress for HRP and LRP groups was similar at the baseline, and after watching a stressful video, an independent sample *t*-test comparing the LRP and HRP groups at T1 and T2 was reported. Repeated-measures analysis of variance (RM-ANOVA) was used to assess the effects of HRP and LRP groups, measuring time point and the interactions for the interventions T1–T2 and T2–T3.

fMRI data analyses

All the functional images will be transferred to an off-line analysis station and processed with FSL (FSL V4.1.9, fMRI Oxford University, Smith et al. 2004).

Brain activation in LRP environments exposure

The brain regions associated with LRP scenery viewing included the superior frontal gyrus (left, *z*-score, 3.05), cuneus (left, *z*-score, 3.30; right, *z*-score, 2.93), cingulate posterior (right, *z*-score, 4.69; left, *z*-score, 3.52), parahippocampal gyrus (left, *z*-score, 4.33; right, *z*-score, 4.52), lingual gyrus (right, *z*-score, 4.52), fusiform gyrus (left, *z*-score, 4.25), and precuneus (rigth, *z*-score, 4.18).

Brain activation in HRP environments exposure

Active brain areas in HRP views are parahippocampal gyrus (left, *z*-score, 3.71; right, *z*-score, 3.46), fusiform gyrus (left, *z*-score, 3.92; right, z-score, 4.32), lingual gyrus (left, *z*-score, 3.94), inferior temporal gyrus (right, *z*-score, 3.61; left, *z*-score, 3.19), precuneus (right, *z*-score, 3.90; left, *z*-score, 3.87), middle frontal gyrus (left, *z*-score, 2.50), and culmen (left, *z*-score, 4.24; right, *z*-score, 3.92).