Ceiling Heights in Homes and Offices

The modern trend to taller ceilings is a return to tradition.

WITOLD RYBCZYNSKI

CERTAIN DOMESTIC features are taken for granted in today's new home market: granite countertops in kitchens, separate glass-walled showers in bathrooms, walk-in closets in bedrooms. Another feature that has become common in new production houses is the high ceiling. According to the National Building Code, the standard ceiling height is ninety-six inches, or eight feet; for suspended ceilings, the minimum height is ninety inches, or seven and a half feet. But nine- and ten-foot ceilings are now common, not only in living rooms and kitchens, but also in bedrooms. Even taller ceilings are appearing in custom homes. Yet not so

Figure 1: An office of the 1960s

long ago, eight-foot ceilings were the norm. What changed?

The minimal modern ceiling appeared first in the work of one of the pioneers of twentieth-century architecture, the French-Swiss architect Le Corbusier. In 1920, he unveiled the so-called Citrohan house, whose name was a pun on Citroën since it was a prototype for a house that was to be as practical and convenient as a car. The two-story design consisted of a full-height living room, overlooked by a bedroom, which was located in a sort of loft. To reduce the overall height of the house, Le Corbusier made the bedroom as low as possible, about seven and a half feet. The Citrohan house was never built, but in the 1950s Le Corbusier used the double-height living room concept in a series of high-rise apartment houses called *unités d'habitation*. In the *unité d'habitation*, the low ceiling in the kitchen or bedrooms was intended as a counterpoint to the soaring living room.

Another famous architect, Frank Lloyd Wright, used a similar arrangement in the Suntop Homes, built in Ardmore, Pennsylvania in 1939. A loft containing a kitchen with a ceiling that was only about seven feet high overlooked a two-story-high living room. The ceilings in Wright's Prairie-style house were often extremely low, since the architect (who was five feet, five inches tall) accentuated the horizontal lines of his designs. His architecture influenced the appearance of the so-called ranch houses, a staple of 1950s and 1960s production housing, which were generally low to the ground, with ceilings dimensioned accordingly. As houses started to be mass produced, low ceilings became the norm; builders and architects considered ceilings taller than the legal minimum to be wasteful and inefficient. Buyers seemed to agree—even large, custom-designed houses regularly had low ceilings; seven and a half feet was not uncommon. Over time, the more or less universal standard became eight feet, a dimension that resulted from two four-foot-wide drywall sheets being laid horizontally one above the other.

Another influence on ceiling heights was environmental. Before the advent of air-conditioning, taller ceilings made for cooler rooms, as hot air gathers at the top of a tall room. With air-conditioning, this was no longer true. Lower rooms were more convenient—and cheaper—to cool.

Sometime in the 1990s, homebuilders started experimenting with taller ceilings. The historic preservation movement can take some of the credit for this evolution. Previously, when old buildings were "modernized," tall ceilings were usually covered over with a dropped ceiling. When the public started becoming interested in older buildings, there was a heightened appreciation for "interesting" details such as ceiling moldings, coves, and plastered ornament. Dropped ceilings were removed and the old tall ceilings were restored to view. Part of the historic preservation movement was the adaptive reuse of old buildings, especially old industrial buildings, which usually had tall ceilings. Developers discovered that tall ceilings were popular with buyers, and they became as much a feature of "loft living" as open plans, brick walls, and exposed ducts.

Just as historical features such as decorative gables, divided windows, and paneled doors started showing up in new houses, so did taller ceilings. Homebuilders were happy to oblige since tall ceilings didn't add much cost or complexity to the building process—and buyers were willing to pay. At first, taller ceilings were offered as extras, but soon nine feet became the new standard, and drywall manufacturers started producing sheets four and a half feet wide to accommodate the new demand. Incidentally, when the minimum ceiling height in the Netherlands was raised from eight feet to about eight and a half feet in 2003, the reason given was that people were taller, which may be another reason for higher ceilings. The average height of adult males in the Netherlands is slightly more than five feet, eleven inches, taller than most Western countries, including the United States, where the average height of adult males is slightly less than five feet, ten inches.

A similar move to taller ceilings has occurred in office buildings. In 1965, the newest skyscraper in Manhattan was the

Figure 2: An office in the Comcast Building, Philadelphia

CBS Building—Black Rock—designed by Eero Saarinen. The stylish interiors by Florence Knoll Basset were the best that corporate money could buy; modern art hung next to modern furniture (much of it designed by Saarinen and Bassett). The ceilings were eight feet nine inches, which was considered generous, since the norm for office buildings at that time was eight and a half feet. According to architect Graham Wyatt, it was Gerald Hines who, in the late 1970s, decided to make nine-foot ceilings the norm in his office projects. This soon became the industry standard for class A office buildings.

Thirty years later, office ceilings have continued to grow taller. The ceilings of the recently built New York Times Building, for example, are eleven feet high. Since conditioned air is fed from the floor, rather than from the ceiling, the taller height is not a disadvantage to cooling. The new Comcast Center in Philadelphia also has eleven-foot ceilings, and executive floors have thirteen-foot ceilings (Figures 2 and 3). Taller ceilings in office buildings have been driven not only by the prestige associated with taller rooms. The growing popularity of open planning and office cubicles means that large expanses of space are visible, and taller ceilings make these work places more pleasant. According to Robert A. M. Stern, the architect of the Comcast Center, "Taller ceilings also allow light to penetrate deeper into the building, which is important if you are optimizing daylighting." This point is particularly important in office buildings seeking

Figure 3: Seating area and conference room in the Comcast Building, Philadelphia

LEED certification. On the other hand, energy concerns for heating and cooling mandate lower rather than taller ceilings, so it is unlikely that office building ceilings will continue to grow. Rather, they will probably recede somewhat, to reach a median between the old nine-foot standard and the current eleven feet.

Although the general trend in commercial construction has been to higher ceilings, there are situations where lower ceilings persist. One is Washington, D.C. According to the Building Height Act of 1910, buildings in the District cannot be taller than the width of the street plus twenty feet. In practice this means a maximum building height of 130 feet on avenues (160 feet on parts of Pennsylvania Avenue), and ninety feet on residential streets. Since developers want to maximize the carrying capacity of a site, there is pressure to minimize floor-to-floor heights. This is done by keeping ceiling heights relatively low and minimizing structural depth by using thin post-tensioned or prestressed flat concrete slabs. Another situation where the floor-to-floor dimension may be critical is when a building is just under seventy-five feet tall. The Uniform Building Code (UBC) requires special arrangements for elevators and fire protection for buildings that exceed a seventy-five-foot height limit. That means that in order not to trigger the UBC requirements, a six-story office building would have to have ceilings no taller than nine-feet (twelve and a half feet feet floor-to-floor).

CONCLUSION

Are taller ceilings yet another example of wretched architectural excess? Not necessarily. In fact, it is low ceilings that are the aberration. Throughout the nineteenth century, ceilings in middle-class homes and in office buildings were ten to twelve feet or higher. Ceiling heights followed the architectural rule of thumb: "The larger the room, the taller the ceiling." A banking hall, for example, could easily have a twenty-foot ceiling; a board room was expected to have a taller ceiling than a private office. This was not just a matter of prestige—a tall room looks better-proportioned. The Renaissance architect Andrea Palladio devoted a chapter of his famous treatise *The Four Books on Architecture* to the subject, and included rules to calculate ceiling heights. One rule was to add the length and breadth of a room and divide by two, which means that a room ten feet by twenty feet would have a fifteen-foot ceiling. A simpler rule was to make the room as high as it is broad. This meant that Renaissance rooms were regularly eighteen to twenty feet tall. Modern buildings will never have ceilings this high, but the changes of the last two decades suggest that while extremely tall ceilings may be somewhat reduced to reflect energy concerns, relatively tall ceilings are here to stay.

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The influence of spatial dimensions of virtual environments on attitudes and nonverbal behaviors during social interactions

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A B S T R A C T

Research on physical-world environments has shown that the spatial properties of built worlds are consequential for shaping psychological states and social behavior. However, it has been difficult to empirically test this in natural settings in the physical world. This study uses immersive virtual reality (VR) environments, which have shown to have comparable effects to physical-world environments, to investigate the influence of two spatial dimensions (ceiling height and floor area) on individuals' attitudes and nonverbal behaviors during social interactions. In the present study, groups of three to four physically remote participants wore VR headsets (n = 110) and took part in discussions every week for four weeks in one of four virtual environments that varied in their spatial dimensions (low or high ceilings, small or large floor areas). Results showed that, when in a virtual environment with a high ceiling, participants reported feeling greater perceived restorativeness, awe, and momentary affective well-being, compared to when they were in virtual environments with low ceilings. Participants also paid more social attention (i.e., looked at other group members), when they were in virtual environments with high ceilings. When in a virtual environment with a large floor area, participants reported having a greater sense of awe, compared to environments with small floor areas. Furthermore, when in a large environment with a high ceiling, participants physically moved their heads more slowly and virtually stood further apart from their group members, compared to the other three conditions. We discuss implications for theoretical work on context and behaviors as well as design of social VR environments.

1. Introduction

Virtual reality (VR) is a unique tool that can be used to study psychological and behavioral experiences. Several studies have shown that environments accessed through VR have similar effects on people as environments in the physical world (e.g., Cha et al., 2019; Heydarian et al., 2015; Valtchanov et al., 2010). Furthermore, VR allows researchers to timely, cost-effectively, and flexibly create environments that are otherwise challenging to access or build in the physical world (e.g., Han et al., 2023; Presti et al., 2022). Taken together, VR has been considered a viable tool to easily create environments that can be used for psychological well-being (promoting well-being, Yeo et al., 2020; affecting mood, Jung et al., 2023; reducing stress, Anderson et al., 2017), or train individuals in situations that might be dangerous, impossible, counterproductive, or expensive to create in the physical world (see DICE model, Bailenson, 2018; e.g., Carattin et al., 2012).

There are several gaps within the literature, namely on how the virtual environment influences individuals when they are with others, and consequently, how it shapes the social interactions that take place. Most previous literature focuses on how the virtual environment influences individuals when they are alone. However, social interaction is not only an important part of the human experience, but also one of the most popular and powerful use cases of VR (Lanier & Biocca, 1992). Given its unique affordances, such as spatiality, presence, and embodiment, VR has the unique ability to connect people with themselves, others, and their environments (Lombard & Ditton, 1997). Furthermore, a fundamental premise of the field of social psychology is that the presence of another – actual, implied, or imagined – can influence the feelings and behaviors of individuals (Allport, 1954). As a result, it is critical to understand how virtual environments influence people's experiences when they are alone, but also when they are socially interacting with others.

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Architectural design and the brain: Effects of ceiling height and perceived enclosure on beauty judgments and approach-avoidance decisions

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ABSTRACT

We examined the effects of ceiling height and perceived enclosure—defined as perceived visual and locomotive permeability—on aesthetic judgments and approach-avoidance decisions in architectural design. Furthermore, to gain traction on the mechanisms driving the observed effects, we employed functional magnetic resonance imaging (fMRI) to explore their neural correlates. Rooms with higher ceilings were more likely to be judged as beautiful, and activated structures involved in visuospatial exploration and attention in the dorsal stream. Open rooms were more likely to be judged as beautiful, and activated structures underlying perceived visual motion. Additionally, enclosed rooms were more likely to elicit exit decisions and activated the anterior midcingulate cortex (aMCC)—the region within the cingulate gyrus with direct projections from the amygdala. This suggests that a reduction in perceived visual and locomotive permeability characteristic of enclosed spaces might elicit an emotional reaction that accompanies exit decisions.

1. Introduction

In this study we examined the effects of ceiling height and perceived enclosure on aesthetic judgments and approach-avoidance decisions in architectural design. According to the US National Building Code, the standard ceiling height is eight feet or 2.44 m (Rybczynski, 2009). Nevertheless, it appears that people tend to prefer ceilings that are about two feet (.61 m) higher than this standard. For example, in a series of experiments Baird, Cassidy, and Kurr (1978) demonstrated a single-peak preference function relating ceiling height to preference for rooms—increasing monotonically from 6 feet (1.83 m) to a peak at 10 feet (3.04 m), and decreasing thereafter. Interestingly, the same general function emerged regardless of whether the participants were examining model rooms, or when they stood under adjustable ceilings for a more realistic experience of ceiling height. However, the preferred height of a ceiling also varied as a function of the imagined activity of the occupant within the room. Specifically, participants preferred higher ceilings for the activity of listening than reading, dancing, dining and talking. Nevertheless, despite substantial individual differences in preference and contextual effects, the main effect of ceiling height was robust.

Perhaps even stronger evidence for the desirability of higher ceilings is provided by the willingness of buyers to purchase real

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estate with higher ceilings, despite higher costs involved in its manufacture and maintenance (e.g., heating). For example, although 9-foot ceilings have become increasingly common, the extra cost of adding this single foot to the height of a ceiling is estimated to be about $20,000 for a 4000-square-foot house in the US (Handley, 2011). Indeed, the data from the marketplace show that some people prefer and are willing to pay more for living spaces with taller than standard ceilings, despite increased cost.

Perhaps not surprisingly, attention to ceiling height is not a new phenomenon in architectural design. Considered by many to be the most influential person in the history of architecture, the renaissance architect Palladio (1570/1965) devoted significant portions of his major treatise entitled "*I quattro libri dell'architettura*" (*The four books of architecture*) to rules governing ceiling height. Influenced by the notion of harmony, he listed a series of mathematical proportions and ratios that represented ideal relations among the width, length, and height of rooms. In essence, within Palladio's framework, preference for architectural spaces is a function of perceived proportion.

Aside from ceiling height, there is also reason to believe that another factor, perceived enclosure, might have an impact on beauty judgments of spaces. Perceived enclosure can be viewed as the perceived degree of movement through space (see Stamps, 2005, 2010; Stamps & Krishnan, 2004). Stamps (2005) argued that the degree of movement through space is more accurately described as *permeability*, which in turn has visual and locomotive variants. For the purpose of the present study we defined *perceived enclosure* as the degree of perceived visual and locomotive permeability. Stamps (2005, 2010) further argued that range of vision has a direct bearing on survival, by enabling the organism to see, hide, and identify threats. Within this evolutionary framework, preference for architectural space is a function of the extent to which it facilitates permeability.[1]

Stamps' (2005, 2010) ideas were influenced by Appleton's (1975) *habitat* and *prospect-refuge* theories, initially postulated in relation to landscapes but since extended to the built environment. According to habitat theory, the judgment of an environment as aesthetically pleasing is a function of its inclusion of features (e.g., shapes, colors, spatial arrangements) indicating its favourability to survival, regardless of whether or not those features are accurate reflectors of greater survivability. In turn, he defined *prospect* as "unimpeded opportunity to see" and *refuge* as "an opportunity to hide" (p. 66), and argued that they constitute intermediate steps in aesthetic appreciation of environments because they affect our perceptions of survivability:

> Habitat theory postulates that aesthetic pleasure in landscape derives from the observer experiencing an environment favourable to the satisfaction of his biological needs. Prospect-refuge theory postulates that, because the ability to see without being seen is an intermediate step in the satisfaction of many of those needs, the capacity of an environment to ensure the achievement of this becomes a more immediate source of aesthetic satisfaction.
>
> Appleton, 1975, p. 66.

For our purposes here, two points are worth emphasizing. First, to Appleton (1975) the ability to 'see without being seen'[2] can lead to aesthetic pleasure. Because prospect (i.e., seeing) and refuge (i.e., not being seen) are by definition the two components of this ability, their realization should contribute positively to aesthetic pleasure. This idea is also captured by Stamps' (2005, 2010) concept of permeability, such that greater permeability should lead to greater aesthetic pleasure for a given environment. Second, this is not to say that the contributions of prospect and refuge to aesthetic pleasure are context invariant. Indeed, there are good reasons to believe that context is an important factor in all manner of judgment and decision making (Goldstein & Weber, 1997), including aesthetics (Brieber, Nadal, Leder, & Rosenberg, 2014). One would therefore expect it to influence the extent to which prospect and refuge contribute to aesthetic pleasure within built environments as well.

To gain further insight into whether ceiling height and perceived enclosure are important variables in architectural design, we conducted an informal survey of 25 interior designers (23 females) during the annual general meeting of the Ontario Interior Designers held in Toronto, ON (March, 2013). The average age of the sample was 50 years ($SD = 8.06$), and all held university or post-graduate degrees. We asked this sample to rate the extent to which ceiling height and openness influence their own design process (0 = *not at all*, 5 = *extremely*). Their average ratings suggested that both ceiling height ($M = 3.56$, $SD = .92$) ($t[24] = 5.78$, $p < .001$, $d = 1.16$) and openness ($M = 3.42$, $SD = .93$) ($t[23] = 4.84$, $p < .001$, $d = .97$) influence the design process considerably (i.e., compared to the midpoint = 2.5). This suggests that interior designers are aware of the importance of these two factors in the design process.

1.1. Beauty judgments and approach-avoidance decisions

Our focus thus far has been on the effects of ceiling height and perceived enclosure on aesthetic assessment of spaces. However, we were also interested in examining the effects of ceiling height and perceived enclosure on decisions to enter or exit those spaces (i.e., approach-avoidance decisions). We were interested in this issue because there are previous data to suggest that people are more likely to opt to be in spaces that they also find beautiful. For example, Ritterfeld and Cupchik (1996) demonstrated that the beauty ratings assigned to photographs of interior spaces are the strongest determinants of the willingness to live in those spaces. Extended to the present study, one would expect that participants would be more likely to opt to approach spaces that they also find more beautiful, because factors that affect beauty judgments (beautiful vs. not beautiful) will affect approach-avoidance decisions (enter vs. exit) in similar ways. However, in the neuroscience of reward there is a well-established distinction in the brain systems responsible for liking versus wanting (Berridge, 1995). This neurological distinction would seem to suggest that the neural basis for judging a given space as beautiful (i.e., liking) might not necessarily correspond with the neural basis for a decision to approach it (i.e., wanting), and that this might manifest itself in different and potentially contradictory responses (e.g., opting not to approach a space that one finds beautiful). Thus, although previous research has shown that one might expect to see a close relation between beauty judgment and approach-avoidance in the context of architectural design (Ritterfeld & Cupchik, 1996), there is also reason to believe that a neural dissociation between liking and wanting (Berridge, 1995) might lead to a differentiation of how ceiling height and perceived enclosure affect beauty judgments and approach-avoidance decisions (see Vartanian et al., 2013).

1.2. Hypotheses

Based on the theoretical and empirical background as well as our own survey of interior designers, the present study was designed

[1] Similar arguments grounding preferences for places in evolutionary adaptations have been made elsewhere (e.g., Hildebrand, 1999; Kaplan, 1987, 1992; Kellert & Wilson, 1993; Nasar, 1988; Sagan & Druyan, 1992).

[2] The term 'see without being seen' was actually coined by Konrad Lorenz but used by Appleton in relation to habitat and prospect-refuge theories.

with the aim of assessing the effects of ceiling height and perceived enclosure on aesthetic judgments and approach-avoidance decisions in the context of architectural interiors. We had four hypotheses regarding the behavioral effects of ceiling height and perceived enclosure. First, we hypothesized that people prefer rooms with high ceilings. Thus, participants would be more likely to judge rooms with higher ceilings as beautiful than rooms with lower ceilings. Confirmation of this hypothesis would constitute a straightforward replication of Baird et al.'s (1978) claim. Second, we hypothesized that people find open rooms beautiful. This hypothesis is based on the idea that open rooms afford a greater degree of perceived visual and locomotive permeability (Stamps, 2005, 2010). Third, we hypothesized that rooms with higher ceilings are more approachable than rooms with lower ceilings. Fourth, we hypothesized that people are more likely to enter open rooms than enclosed rooms. Our third and fourth hypotheses were motivated by the idea that there might exist a functional association between aesthetics and behavior such that factors that affect beauty judgments (beautiful vs. not beautiful) will affect approach-avoidance decisions (enter vs. exit) in similar ways. In this sense, we are likely to enter rooms that we also find beautiful.

Additionally, we aimed to explore the mechanisms underlying the potential behavioral effects in terms of their neural correlates by using functional magnetic resonance imaging (fMRI).[3] The advantage of collecting fMRI data is that they enable one to localize regions of the brain where brain activity is modulated in response to manipulations of independent variables—in this case ceiling height and perceived enclosure. In turn, the quality of the inferences one draws from the observation of these activations is proportional to the functional specificity associated with the region under consideration (see Bub, 2000; Poldrack, 2006). Functional specificity (i.e., selectivity) refers to the ability to infer a specific function (e.g., memory) based on the activation of a specific brain region or structure (Vartanian & Mandel, 2011). Ideally, manipulations of the independent variable result in activations in brain regions with high degrees of functional specificity. In such cases, brain activations can aid in inferring mental processes and/or neural mechanisms accompanying the observed behavioral effects.

Our hypotheses about the brain regions underlying the effect of ceiling height were based on the idea that the observation of proportion and ratio in architectural design likely necessitates visuospatial exploration, navigation, and attention. Thus, we reasoned that variations in ceiling height modulates brain networks for visuospatial processing, localized in medial temporal lobe (MTL) structures (Aguirre, Detre, Alsop, & D'Esposito, 1996; Burgess, 2008; Spiers et al., 2001), or the frontal and parietal cortices in the dorsal stream which are connected by axonal tracts that run along the dorsolateral regions of the brain (Mishkin, Ungerleider, & Macko, 1983; Ungerleider & Mishkin, 1982; see also Kravitz, Saleem, Baker, & Mishkin, 2011). In other words, we reasoned that rooms with higher ceilings might be preferred because they facilitate greater levels of visuospatial exploration and attention, in the process activating parts of the MTL and/or the dorsal stream. In addition, rooms with higher ceilings might also be preferred by affecting the feelings of the viewers, related to changes in the activity of brain regions that underlie the experience of affect, emotion, pleasure and reward (see Barrett, Mesquita, Ochsner, & Gross, 2007; Barrett & Wager, 2006; Berridge & Kringelbach, 2009; Chatterjee & Vartanian, 2014; Kringelbach, 2005).

Where in the brain would one expect to observe responsiveness as a function of variation in perceived enclosure? There are a number of different candidate structures. For example, the parahippocampal place area (PPA) responds selectively to places (i.e., spatial enclosures) (Epstein & Kanwisher, 1998). Not only is the PPA involved in scene perception, but its activity while viewing scenes is modulated by level of pleasure (Biederman & Vessel, 2006; Yue, Vessel, & Biederman, 2007). This suggests that the PPA might be sensitive to variation in perceived enclosure in the context of beauty judgment of spaces. Second, previous research has shown that the degree of physical openness depicted in scenes is strongly correlated with ratings of beauty, pleasure, and interestingness (Franz, von der Heyde, & Bülthoff, 2005; see also Kaplan, Kaplan, & Ryan, 1998), suggesting that regions of the brain that underlie the experience of affect, emotion, pleasure and reward might be responsive to openness—the reverse of perceived enclosure (see Barrett et al., 2007; Barrett & Wager, 2006; Berridge & Kringelbach, 2009; Chatterjee & Vartanian, 2014; Kringelbach, 2005). Third, it is also possible that much like high ceilings, open spaces facilitate visuospatial exploration, in the process activating parietal and frontal regions in the dorsal stream (Mishkin et al., 1983; Ungerleider & Mishkin, 1982; see also Kravitz et al., 2011). In fact, to the extent that this exploration is coupled with an intention to approach (or avoid) a space, it would also be accompanied by activation in brain regions implicated in motor imagery and/or planning of voluntary motor movement (Crammond, 1997; Decety, 1996; Dieber et al., 1998; Grush, 2004; Hanakawa, Dimyan, & Hallett, 2008).

We tested our hypotheses by reanalyzing data from a previously published fMRI dataset (Vartanian et al., 2013), conducted originally to investigate the impact of contour (curvilinear vs. rectilinear) on beauty judgments and approach-avoidance decisions. Specifically, in the beauty judgment condition our participants were instructed to indicate whether the space they were exposed to was "beautiful" or "not beautiful" by pressing one of two buttons, whereas in the approach-avoidance condition they were instructed to opt to "enter" or "exit" the space by pressing one of two buttons. Our focus on contour in the original analyses was motivated by a strong body of empirical evidence extending back to the 1920s showing that people prefer curvilinear contour to rectilinear contour in design (Silvia & Barona, 2009). Indeed, we replicated and extended this effect to architectural design in our study, showing that people are more likely to judge curvilinear than rectilinear spaces as beautiful. However, curvilinear spaces were no more likely to elicit approach decisions than rectilinear spaces. In conjunction with a complementary neural dissociation observed between these two processes, we concluded that beauty judgment and approach-avoidance decisions might be underwritten by different sets of considerations and computations.

However, within each level of contour our stimuli were also balanced in terms of ceiling height and perceived enclosure (Fig. 1). For the present report, we shifted the focus from contour to ceiling height and perceived enclosure, enabling us to parse the data anew in order to test the aforementioned four hypotheses, as well as isolating their neural correlates to explore the possible contributions of various mechanisms and processes to the observed effects. It is important to note that unlike the rich empirical and theoretical bases that link curvilinear contour to aesthetic preference (Silvia & Barona, 2009), the evidential base linking ceiling height and perceived enclosure to preference is relatively sparse. As such, our examination of the impact of these two variables on brain and behavior must be considered exploratory rather than confirmatory. Nevertheless, we hope that in conjunction with evidence from

[3] fMRI is not a direct measure of brain activity, but rather a measure of the hemodynamic response (i.e., change in blood flow) in relation to neural activity in the brain. When active, neurons increase their consumption of oxygen. The local response to increased consumption of oxygen is increased blood flow to the region, accompanied by changes in local blood volume and flow. Measuring the variations in the local concentrations of oxyhemoglobin and deoxyhemoglobin molecules accompanying the changes in local blood volume and flow generate a proxy measure for brain activity.

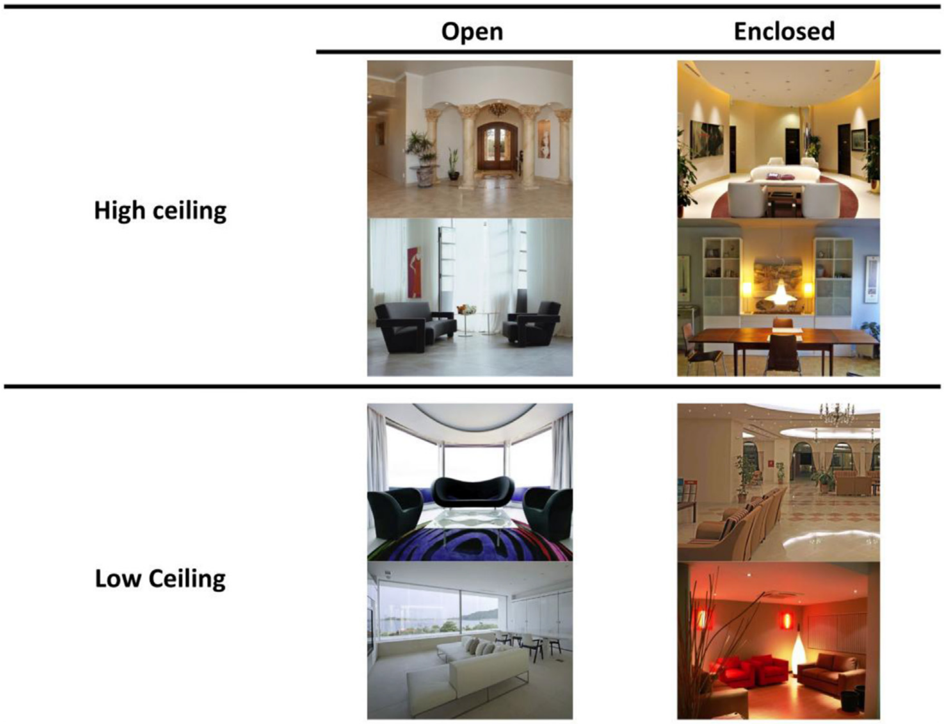

Fig. 1. Examples of stimuli used in the study. *Notes*. Within each of the four conditions we controlled for the number of curvilinear (top) and rectilinear (bottom) spaces (see Method section).

other related studies (e.g., Fich et al., 2014), the data generated in the present study will contribute to the development and refinement of theoretical models of how these two factors influence behavior and related physiological function (see Churchland & Sejnowski, 1992).

2. Material and methods

2.1. Participants

We recruited 18 (12 females, 6 males) neurologically healthy participants ($M = 23.39$ years, $SD = 4.49$) with normal or corrected-to-normal vision. All participants were right handed, as determined by a standard questionnaire ($M = 74.72$, $SD = 19.29$) (Oldfield, 1971).

2.2. Materials

The stimuli for this study consisted of 200 photographs of architectural spaces (Fig. 1). Half of the photographs were used in the beauty judgment run and the other half for the approach-avoidance run. The stimuli were culled from larger architectural image databases available to LBF at the Department of Architecture, Design, and Media Technology in University of Aalborg and to NR at The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture. Half of the spaces had high ceilings and the other half had low ceilings. Similarly, half of the spaces were enclosed and the other half open. This resulted in the following four conditions ($n = 50$ in each condition): open high ceiling, open low ceiling, enclosed high ceiling, and enclosed low ceiling. Across the entire stimulus set half of the rooms were curvilinear and the other half rectilinear; the results for that manipulation were discussed in an earlier publication (Vartanian et al., 2013). LBF and NR reached 100% inter-rater consensus for the inclusion of each image in the final set of 200 images. All images were standardized in terms of size and resolution. Importantly, the stimuli were not controlled in terms of other variables such as light, color, etc. Given the exploratory nature of our study, this was done in large measure to increase the ecological validity of our design. To obtain the stimulus set please contact OV.

2.3. Procedures

Our study consisted of presenting participants in the MR scanner with photographs of interior spaces that varied in ceiling height and perceived enclosure (Fig. 1). This study was presented in two runs—administered in counterbalanced order across participants. In the beauty judgment run participants were instructed to respond “beautiful” or “not beautiful” upon viewing each stimulus. In the approach-avoidance run participants were instructed to respond “enter” or “exit” upon viewing each stimulus, to indicate whether this was a space they would like to enter or leave.

In the course of structural MRI acquisition participants were familiarized with the task via exposure to trials involving beauty judgments and approach-avoidance decisions. The task was presented using E-Prime. Each trial within the runs had identical structure: it began with a fixation point “X” presented for 1000 ms, followed by a stimulus presented for 3000 ms (during which a response was collected), followed by variable inter-trial interval (ITI). The average duration of ITI across all trials was 4000 ms (selected randomly without replacement from a finite bin varying among 3000, 4000, 6000, and 7000 ms).

2.4. fMRI acquisition

A 3-T MR scanner with an 8-channel head coil (Signa Excite HD, 16.0 software, General Electric, Milwaukee, WI) was used to acquire T1 anatomical volume images ($1.0 \times 1.0 \times 1.0$ mm voxels). For functional imaging, $T2^*$-weighted gradient echo spiral-in/out acquisitions were used to produce 35 contiguous 4 mm thick axial slices (repetition time [TR] = 2000 ms; echo time [TE] = 21.4 ms; flip angle [FA] = 90°; field of view [FOV] = 260 mm; 64 × 64 matrix; voxel dimensions = 4 × 4 × 4.0 mm), positioned to cover the whole brain. The first ten volumes were discarded to allow for T1 equilibration effects. The number of volumes acquired was 430 (+10 dummies).

2.5. fMRI analysis

Data were analyzed using Statistical Parametric Mapping (SPM8). Head movement was less than 2 mm in all cases. We implemented slice timing to correct for temporal differences between slices within the same volume, using the first slice within each volume as the reference slice. All functional volumes were spatially realigned to the first volume of the first run. A mean image created from realigned volumes was spatially normalized to the MNI EPI brain template using nonlinear basis functions. The derived spatial transformation was applied to the realigned T2* volumes, and spatially smoothed with an 8 mm full-width at half-maximum (FWHM) isotropic Gaussian kernel. Time series across each voxel were high-pass filtered with a cut-off of 128 s, using cosine functions to remove section-specific low frequency drifts in the BOLD signal. Condition effects at each voxel were estimated according to the general linear model (GLM) and regionally specific effects compared using linear contrasts. The BOLD signal was modeled as a box-car, convolved with a canonical hemodynamic response function. Each contrast produced a statistical parametric map consisting of voxels where the *T*-statistic was significant at $p < .001$. We adopted a combination of voxel-level and cluster-size correction to control against false positives. Specifically, using a random-effects analysis, we reported activations that survived whole-brain voxel-level intensity threshold of $p < .001$, and a minimum cluster size of 10 voxels, uncorrected for multiple comparisons. Previous analyses have demonstrated that this combination adequately controls against false positives for both 2D and 3D volumes (Forman et al., 1995; Lieberman & Cunningham; 2009).

Testing our focal hypotheses consisted of comparing rooms with high ceilings to rooms with low ceilings, and open rooms to enclosed rooms—separately for beauty judgment and approach-avoidance runs. To ensure that (a) both analyses were run based on the same design matrix and (b) explicitly included the variable controlled for in the present study (i.e., contour), within each run we created 16 regressors corresponding to a crossing of 4 variables: contour (rectilinear, curvilinear) × ceiling height (high, low) × openness (open, enclosed) × response (enter/exit or beautiful/not beautiful). Our two focal analyses were conducted by assigning weights of “1” or “−1” to the relevant regressors, involving one-sample *t*-tests. Although incorporated into the design, motor response and ITI were modeled out of the analyses by assigning null weights to their respective regressors.

3. Results

3.1. Behavioral

We analyzed the effects of ceiling height and perceived enclosure, separately on beauty judgments and approach-avoidance decisions. We tested non-directional hypotheses, except when testing for the effect of ceiling height on beauty judgments because of prior data (see Baird et al., 1978). A Wilcoxon Signed Ranks Test demonstrated that ceiling height had a significant effect on beauty judgments, $Z = -1.76$, $p = .039$, $r(Z/\sqrt{N}) = .41$. Specifically, participants were more likely to judge spaces as beautiful if they had high than low ceilings (Fig. 2). In contrast, rooms with higher ceilings were no more likely to be entered than rooms with lower ceilings, $Z = -1.22$, $p = .224$, $r = .29$ (Fig. 2). In turn, perceived enclosure affected both beauty judgments ($Z = -3.27$, $p = .001$, $r = .77$) and approach-avoidance decisions ($Z = -3.51$, $p = .001$, $r = .83$) (Fig. 3). Specifically, participants were more likely to judge spaces as beautiful if they were open than enclosed, and more likely to opt to exit them if they were enclosed than open.

3.2. Neural

In the beauty judgment run, the contrast of high ceilings–low ceilings revealed significant activation in left precuneus (BA 19) ($T = 4.08$, $d(T/\sqrt{N}) = .96$, $x = -36$, $y = -78$, $z = 42$, $k = 17$) and left middle frontal gyrus (BA 6) ($T = 4.02$, $d = .95$, $x = -32$, $y = 18$, $z = 60$, $k = 15$) (Fig. 4). In turn, the open–enclosed contrast revealed significant activation in left middle temporal gyrus (BA 21) ($T = 4.17$, $d = .98$, $x = -52$, $y = -2$, $z = -20$, $k = 21$) and right superior temporal gyrus (BA 22) ($T = 4.11$, $d = .97$, $x = 58$, $y = -14$, $z = -4$, $k = 11$) (Fig. 5). In the approach-avoidance run the contrast of high ceilings–low ceilings did not reveal any significant activation, whereas the enclosed–open contrast revealed significantly greater activation in a large cluster spanning both hemispheres in the anterior midcingulate cortex (aMCC) region of the cingulate gyrus (BA 24) ($T = 6.63$, $d = 1.56$, $x = 10$, $y = 30$, $z = 26$, $k = 774$) (Fig. 6).

4. Discussion

The present study was conducted to explore the effects of ceiling height and perceived enclosure on beauty judgments and approach-avoidance decisions in the context of architecture. As predicted, participants were more likely to judge as beautiful spaces with higher than lower ceilings. In contrast, ceiling height had no effect on approach-avoidance decisions. These findings confirm previous results on the impact of ceiling height on preference for rooms (Baird et al., 1978), and extend them by demonstrating that the effect of ceiling height on beauty judgments is dissociable from its effect on approach-avoidance decisions. However, we cannot exclude that familiarity might have had an effect on

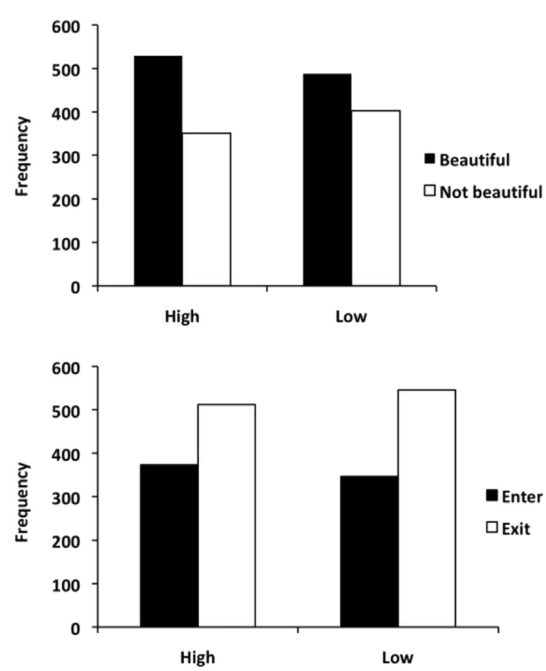

Fig. 2. Effect of ceiling height on beauty judgments and approach-avoidance decisions. *Notes.* The Y-axis represents the sum of responses.

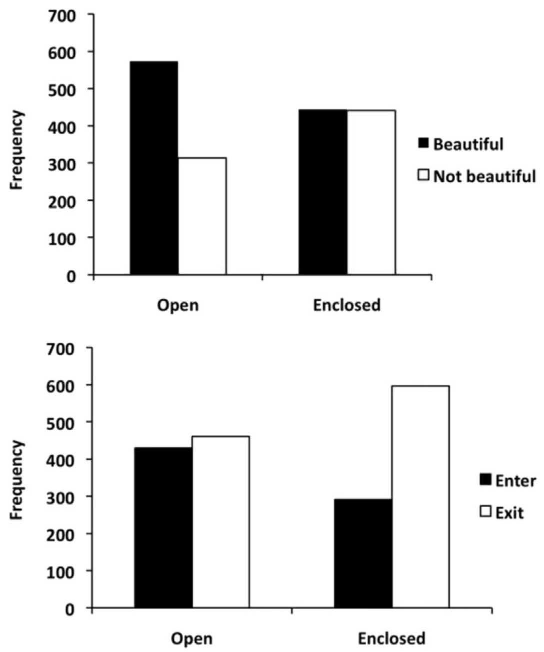

Fig. 3. Effect of perceived enclosure on beauty judgments and approach-avoidance decisions. *Notes*. The Y-axis represents the sum of responses.

beauty judgments and approach-avoidance decisions, given that our participants were likely to have had greater levels of prior exposure to standard ceiling heights in the range of eight feet or 2.44 m (Rybczynski, 2009). This possibility can be tested more directly in future studies.

Interestingly, we found a similar dissociation regarding the effect of contour on beauty judgments and approach-avoidance decisions: whereas participants were more likely to judge curvilinear spaces as beautiful, they were no more likely to decide to enter them compared to rectilinear spaces (Vartanian et al., 2013). These results suggest that the machinery involved in aesthetic judgment might be under the influence of different factors than the machinery involved in approach-avoidance decisions, at least insofar as architectural spaces are concerned.

At the neural level, we had hypothesized that because the observation of proportion and ratio in architectural design necessitates visuospatial exploration and attention, we might expect to see greater activation in the neural systems that underlie visuospatial processing in relation to rooms with higher ceilings. Indeed, we observed activation in the left precuneus and the left middle frontal gyrus—two structures with well-established roles in visuospatial processing (for reviews see Cavanna & Trimble, 2006; Kravitz et al., 2011). In fact, there is recent evidence demonstrating that cortical thickness in the left precuneus exhibits neuroplasticity as a function of training on a virtual spatial navigation task in young adults (Wenger et al., 2012), further highlighting the role of this region in visuospatial processing. The present activations are consistent with the idea that rooms with higher ceilings might be preferred over rooms with lower ceilings because they facilitate greater levels of visuospatial exploration, attention, and navigation. However, contrary to our prediction, in the beauty judgment run we did not observe activation in relation to higher ceilings in brain regions that underlie affect, emotion, pleasure and reward. This suggests that the aesthetic preference for high ceilings is likely not driven by this constellation of inter-related processes.

Interestingly, the activations observed in the precuneus and middle frontal gyrus were lateralized to the left hemisphere. This lateralization of function might be explained in terms of the type of spatial relations under consideration. Specifically, Kosslyn et al. (1989) initially suggested a distinction between abstract categorical vs. specific coordinate spatial relations. Consider a case where you must decide whether the space between two walls in a room is sufficient for the placement of a window with specific dimensions. To make this determination accurately you need specific "coordinate representation … in which locations of objects or parts are specified relatively precisely in terms of metric units" (Kosslyn et al., 1989, p. 724). In other words, precise measurement underlies coordinate relations. In contrast, deciding whether a window is situated to the left of the centre of a wall is unaffected by its specific distance (e.g., 10 cm or 20 cm) from the midpoint. Such "categorical representations … capture general properties of the spatial structure without making commitments to the specific topographic properties" (Kosslyn et al., 1989, p. 723). Using a complementary set of fMRI and lesions studies, Amorapanth, Widick, and Chatterjee (2009) demonstrated that the left hemisphere is relatively biased toward processing categorical spatial relations whereas the right hemisphere is relatively biased toward processing coordinate spatial relations. This suggest that in the context of the present study the visuospatial processing of rooms with higher ceilings might have involved a greater focus on general spatial relations rather than specific topographic features.

The possibility that greater visuospatial exploration underwritten by left precuneus and left middle frontal gyrus is related to beauty judgments comes also from data collected following the completion of fMRI scanning, which involved asking participants to view all the stimuli viewed in the scanner once again, rating each stimulus on *beauty* (using a 5-point scale with anchors *very ugly* and *very beautiful*) and on *pleasantness* (also using a 5-point scale with anchors *very unpleasant* and *very pleasant*). As previously reported (Vartanian et al., 2013), a parametric analysis involving 1st order polynomial expansions demonstrated that activation in left

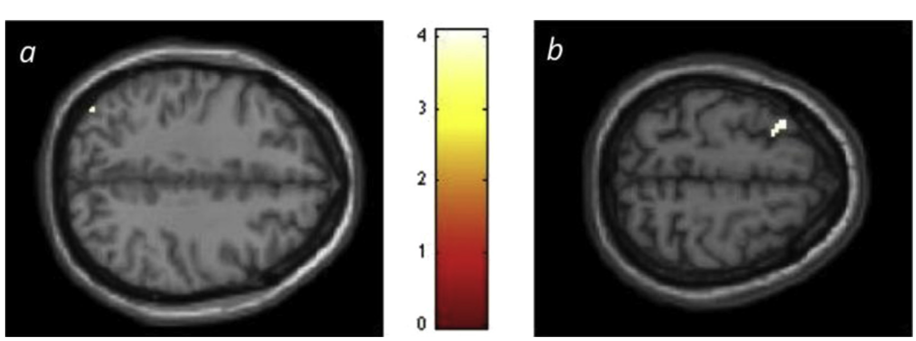

Fig. 4. Higher ceilings activated the precuneus and middle frontal gyrus in beauty judgments. *Notes.* (a) precuneus (located adjacent to the occipital gyrus and superior parietal lobule); (b) middle frontal gyrus. SPM rendered into standard stereotactic space and superimposed on to transverse MRI in standard space. Bar represents magnitude of *T*-score.

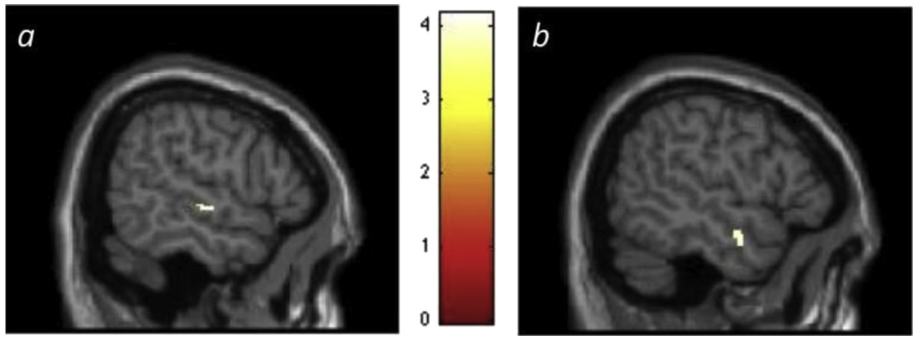

Fig. 5. Open spaces activated the superior and middle temporal gyri in beauty judgments. *Notes*. (a) Superior temporal gyrus; (b) middle temporal gyrus. SPM rendered into standard stereotactic space and superimposed on to sagittal MRI in standard space. Bar represents magnitude of *T*-score.

precuneus and left middle frontal gyrus exhibited a linear relationship with beauty ratings, and that activation in left precuneus also exhibited a linear relationship with *pleasantness*—the valence dimension of the affect circumplex. In combination, these results are consistent with the hypothesis that activation in left precuneus observed in relation to higher ceilings is related to the role of this region in beauty judgment of spaces.

In contrast to ceiling height, perceived enclosure affected both beauty judgments and approach-avoidance decisions: participants were more likely to judge as beautiful open than enclosed spaces, and also more likely to decide to avoid enclosed than open spaces. Interestingly, Stamps (2005) has demonstrated that impressions of enclosure are more strongly influenced by visual permeability than by locomotive permeability, whereas impressions of safety are more strongly influenced by locomotive permeability than by visual permeability. Although we did not distinguish between visual and locomotive permeability in our stimuli, the behavioral results suggest that participants might have attended to different aspects of perceived enclosure (i.e., visual or locomotive) when making choices in the beauty and approach-avoidance conditions. Specifically, impressions of visual and locomotive permeability might have had a greater impact on beauty judgments and approach-avoidance decisions, respectively. Future studies on the effect of perceived enclosure on beauty judgments and approach-avoidance decisions would benefit by distinguishing between stimuli that signal different types of permeability.

Our results showed that variations in perceived enclosure were accompanied by differences in brain activity. Specifically, during beauty judgments the open–enclosed contrast revealed significant activation in left middle temporal gyrus (BA 21) and right superior temporal gyrus (BA 22) (Fig. 5). Although neuroimaging studies have historically provided some evidence for the involvement of the temporal lobes in visuospatial attention (e.g., Nobre et al., 1997),

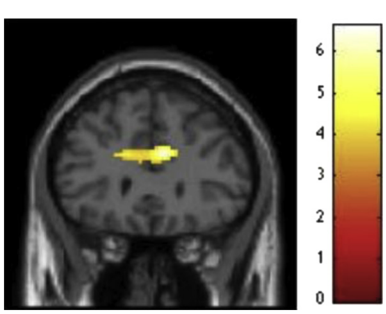

Fig. 6. Enclosed spaces activated the anterior midcingulate cortex (aMCC) region of the cingulate gyrus (BA 24) in approach-avoidance decisions. *Notes*. SPM rendered into standard stereotactic space and superimposed on to coronal MRI in standard space. Bar represents magnitude of *T*-score.

their specific role in the process remains unclear. Shapiro, Hillstrom, and Husain (2002) provided some insight into this by demonstrating that the region that lies between the ventral and dorsal streams—consisting of the superior temporal gyrus and the inferior parietal lobe—contributes to the temporal dynamics of visual processing. Specifically, in the context of the attentional blink paradigm, which is itself a non-spatial task, lesions to this region led to more prolonged deployment of visuotemporal attention compared to lesions exclusively to the superior parietal lobe—-which forms part of the dorsal stream. This suggests that the temporal dynamics of visual processing might be influenced differently by open vs. enclosed spaces, although additional behavioral studies including eye-tracking methodologies are required to test this hypothesis directly.

Further insight into the possible role of the lateral temporal lobes in processing open spaces is provided by a recent meta-analysis of neuroimaging studies which identified the left lateral temporal cortex in the conceptual processing of actions (Watson, Cardillo, Ianni, & Chatterjee, 2013). This finding suggests a role for this region in processing abstract representations derived from visual motion information. To the extent that open spaces, compared to enclosed spaces, embody perceived notions of visual and locomotive permeability, the involvement of left middle temporal gyrus (BA 21) might be related to a greater representation of perceived visual motion in open rooms. Importantly, here too we did not observe activation in relation to higher ceilings in brain regions that underlie affect, emotion, pleasure and reward, suggesting that aesthetic preference for open spaces is likely not driven by this constellation of inter-related processes.

Interestingly, enclosed rooms were more likely to elicit avoidance decisions, and they were associated with robust activation in the cingulate gyrus in the approach-avoidance run. Although this part of the cingulate gyrus has been linked to a large host of cognitive and emotional processes, Vogt's (2005) analysis of 23 neuroimaging studies showing peak activations within the cingulate gyrus demonstrated that the specific region activated in the present study is associated with processing fear. Not only does aMCC receive direct input from the amygdala (Vogt & Pandya, 1987)—a key region for representation of fear in the brain (Whalen et al., 1998)—but no other cingulate region receives similar high and direct projections from the amygdala. This observation raises the possibility that part of the reason for opting to exit enclosed spaces might be related to the experience of fear, consistent with Appleton's (1975) and Stamps' (2005, 2010) hypothesis that range of vision has a bearing on survival, and that restrictions therein might lead to the experience of negative emotions.

In support of this interpretation, Fich et al. (2014) recently demonstrated that participants exhibit greater reactivity to stress when placed in an enclosed rather than an open room. Specifically, the researchers used a virtual reality version of the Trier Social Stress Test (TSST) to induce stress. The standard TSST protocol induces stress by having the participant perform a series of stressful tasks (e.g., giving a presentation) in front of a committee. The advantage of using a virtual reality version of TSST consisted of the ability to manipulate physical features of the room in systematic ways. The manipulation involved assessing participants either under the "open" room condition characterized by large openings that offered a potential for escape, or a "closed" room that did not offer this potential. In addition, the researchers measured saliva and heart rate variability—two robust measures of the human physiological stress response. The results showed that compared to participants in the open condition, participants in the enclosed condition exhibited greater cortisol reactivity to the stress condition and continued to show greater levels of cortisol at recovery. As such, this experiment demonstrated that compared to open spaces, enclosed spaces can increase one's vulnerability to stress, possibly by not offering the potential for escape.

4.1. Limitations

The following limitations should be taken into consideration while evaluating the results of the present study. First, our stimuli were not controlled in terms of various factors (e.g., light, color, etc.). Given the exploratory nature of our study, this was done in large measure to increase the ecological validity of our design. However, future studies should seek to generate stimuli that control for these factors. Second, we did not manipulate the context under which beauty judgments and approach-avoidance data were collected. Given the well-established effect of context on judgment and decision making (Brieber et al., 2014; Goldstein & Weber, 1997), caution should be exercised in generalizing our findings to other contexts. Third, the fact that our data were collected in the fMRI scanner might have impacted our results. Specifically, it is possible that opting to participate in an experiment that takes place within a confined space might have inadvertently resulted in the recruitment of participants that experience an attenuated negative response to perceptually enclosed environments. Fourth, we could not exclude the possibility that familiarity might have had an effect on beauty judgments and approach-avoidance decisions with respect to ceiling height, given that our participants were likely to have had greater levels of prior exposure to standard ceiling heights in the range of eight feet or 2.44 m (Rybczynski, 2009). This possibility can be tested more directly in future studies. Fifth, given the exploratory nature of our study, follow-up work could ideally focus on testing more precise hypotheses following a power analysis using the present data.

5. Conclusion

The evidence presented here contributes to a body of empirical knowledge suggesting that our evaluation of architectural spaces is influenced by variations in their physical features, and that these effects involve specific and dissociable structures in the brain. Specifically, it appears that our aesthetic preference for rooms with higher ceilings is coupled with activation in parietal and frontal structures located in the dorsal stream that support visuospatial exploration and attention, suggesting that aspects of spatial cognition might contribute to the computation of aesthetic preference for these spaces. There is also tentative evidence to suggest that the involvement of the temporal lobes during beauty judgment in relation to open spaces might be related to their roles in the temporal dynamics of vision or abstract motion representation, although those possibilities await direct testing. Finally, not only did enclosed spaces elicit greater avoidance decisions, they also activated the aMCC—a region receiving direct input from the amygdala and involved in fear processing. This observation raises the possibility that a reduction in perceived visual and locomotive permeability might elicit a negative emotional reaction and a corresponding decision to exit spaces.

Conflict of interest

The authors declare no conflict of interest.

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