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Aesthetic appreciation of architecture in lay people and experts: The impact of spatial features and prefrontal tDCS on liking judgements of interior spaces

Aesthetic appreciation is an inherent and unique trait of our species (Nadal & Skov, 2013). Humans perceive, create, and respond to objects and scenes such as paintings or dance in an aesthetic way, and this interaction is able to affect our psychological states in terms of evoking strong emotions like pleasure in us (Chatterjee, 2011). This human phenomenon is studied traditionally in the field of philosophical aesthetics and empirical aesthetics, frequently with a focus on visual arts (Leder, Belke, Oeberst, and Augustin, 2004). This is not astonishing, since art, at least in its classical form, is largely created to please our senses (Desmet & Hekkert, 2007). Moreover, aesthetic appreciation is not limited to works of art, our environment as a whole can serve as a source of aesthetic experiences (e.g. Carlson, 2002). We engage aesthetically in picturesque sunsets, thunder clouds, deep valleys and many other natural scenes. However, aesthetic appreciation reaches beyond those prototypical examples of aesthetic experiences to our closest surroundings where we live and work: our built environments (Carlson, 2002). Regarding evidence that people in Western cultures spend most of their time per day indoors (e.g. Brasche & Bischof, 2005; Brown, 1983; Klepeis et al., 2001), architectural design becomes a matter of importance for empirical research (Vartanian et al., 2013). For example, Nasar (2008) argued that it is most likely that specific aesthetic qualities of architecture have an immediate beneficial or adverse effect on our sense of well-being. As a consequence, architectural design may influence our subsequent patterns of behaviour in those built environments (Nasar, 2008), and, in the long term, our mental and physical health in general (Evans, 2003). Hence, there is a need to gain knowledge about the principles of aesthetic appreciation of architecture, their underlying neural foundation involved in those processes and, in turn, a need to identify specific determinants in architecture which are able to ‘please our senses’ (Carlson, 2002; Nasar,

2008; Vartanian et al., 2013). Moreover, this knowledge can be used by means of an interdisciplinary dialogue between psychology, neuroscience, and architecture to better plan and design our surroundings in order to comply with the needs of the users of a built environment (Nasar, 2008; Vartanian et al., 2013).

The present thesis aims to further examine the aesthetic appraisal of architecture by studying the impact of specific spatial features of architectural interiors on aesthetic judgements in different groups of people, namely lay people and experts in architecture. Furthermore, previous findings with regard to the neural underpinnings of aesthetic processes in human mind were tested for architectural stimuli. This thesis lies within the tradition of the experimental field of psychological aesthetics, but is also grounded on the field of neuroaesthetics. Therefore, a brief historical background of empirical aesthetics will be presented at the beginning, followed by a description of Leder et al.'s (2004) model of aesthetic experiences that served as framework of the present work. I then will move on to the latest research findings that constituted the primary basis of this work.

A brief historical background of empirical aesthetics

As mentioned above, research on aesthetic appreciation is not new. It has its tradition in the philosophical field of aesthetics (e.g. Cela-Conde, Agnati, Huston, Mora, & Nadal, 2011), but several scientific domains approached with its own methods of investigation (Nadal & Skov, 2015).

In psychology, it was Fechner with his *Vorschule der Ästhetik* (1876) who marked the origin of an empirical psychology of the aesthetics (Jacobsen, 2006). In contrast to the field of aesthetics in philosophy, he argued for an empirical driven research 'from below' that has the objective to gain general principles of the aesthetics based on empirical facts (Jacobsen, 2006; Fechner, 1876). Furthermore, he approached the aesthetics from a mathematical perspective by quantifying the aesthetical value of rectilinear forms with different proportions

(Nasar, 2008). Fechner suggested a preference for rectangles representing the proportion of the 'Golden Section' (Leder, 2013), a theory of proportion that was also continued in the field of architecture by architects such as Le Corbusier with his *Modulor* in the twentieth century (Blake, 1960, cited in Nasar, 2008).

Following Fechner, Birkhoff (1933) defined a mathematical measure of aesthetic quality, a formula to estimate the beauty contained in objects like polygons by means of a ratio of order and complexity. As pointed out by Nasar (2008), Eysenck (1941) suggested a very similar theory but, unlike Birkhoff, he also tested it empirically. Nonetheless, Birkhoff's (1933) mathematical approach had a sustained impact on the advancement of aesthetics in empirical psychology (Bornstein, 1984).

In the same decade, Gestalt psychologists such as Koffka (1935) posited the importance of laws of Gestalt to apprehend works of art (Bornstein, 1984), perceptual principles that also aroused the interest of artists and architects of the *Bauhaus* art school (Behrens, 1998). In Gestalt psychology, as recapitulated by Bornstein (1984), certain elements of the composition (e.g. balance or shape) are suggested to be perceived as aesthetic, and the transmitted information is automatically transformed into meaning and convey specific emotions. Bornstein further exemplified, that particular 'good' Gestalts such as symmetry, for example, were suggested to directly arouse emotions like pleasure. Following these ideas, Arnheim's (1974) work was seminal for psychological aesthetics by applying Gestalt principles to artworks (Bornstein, 1984). Moreover, Arnheim (1977) also extended these principles to the realm of architecture (Nasar, 2008).

After a decline in experimental aesthetics, Berlyne (1970, 1971) reflatated the research with his psychobiological theory of aesthetics (Jacobsen, 2006). He highlighted the relation, which follows the form of an inverted U-shape, between the perceived aesthetic value of a stimulus and so-called 'collative' stimulus characteristics (i.e. complexity, novelty, intensity)

through physiological arousal. That is, a moderate level of physiological arousal has the highest aesthetic value (Bornstein, 1984; Jacobsen, 2006). Following Berlyne's (1960) work, Wohlwill (1968) extended these findings to natural environments, and Rapoport (Rapoport & Kantor, 1967) used them to critique urban design (Nasar, 1968).

These early findings shaped the psychological aesthetics of today, and several other factors such as prototypicality (Hekkert & van Wieringen, 1990) or expertise (Cupchick, 1992) were found to be important predictors of aesthetic judgements (Leder et al., 2004).

However, it was not only psychology on its own that gained knowledge about the principles of aesthetic experiences by empirical research. During the last century, neuroscience joined psychological aesthetics with its own scientific methods, and offered a fertile ground to also gain insights into the neural underpinnings of aesthetic behaviour (Nadal & Skov, 2013). Although scholars have been interested in specifying the neurophysiological substrates of aesthetic appreciation at least since Burke (1757), it was the development of neuroimaging techniques at the end of the twentieth century that allowed to correlate neural activity to aesthetic experiences for the first time (Nadal & Skov, 2015).

Zeki (1999a, 1999b) was the one who introduced the term neuroaesthetics into science. He emphasised parallels between organisational processes of the brain and constituents of art, and argued that theories of aesthetics are incomplete without an understanding of its neural basis (Chatterjee, 2011). In his view, both artists and the central nervous system strive for an understanding of visual information by decomposing attributes such as motion or colour, but only the former utilise, accentuate, and uncover functional distinctions of visual processing in the brain in their works of art (Chatterjee, 2011). In other words, artists are suggested to use certain techniques to arouse our interest by activating neural processes closely related to reward (Nadal & Skov, 2013). This idea was also reflected

by theoretical works of Changeux (1994) and Ramachandran and Hirstein (1999), and marked the development of the field of neuroaesthetics (Nadal & Skov, 2013).

Indeed, experimental neuroaesthetics has experienced a tremendous growth since then (Nadal & Pearce, 2011). Until today, numerous experiments focused on linking aesthetic experiences to neural activity, and indicated a complex interplay of neural circuitries associated with sensory and motor processes (i.e. sensation, perception, motor behaviour), neural systems related to knowledge and meaning (i.e. context, culture, expertise), and emotion and evaluation systems (i.e. wanting and liking, emotion, reward) in the brain (Chatterjee & Vartanian, 2014). In addition, it is important to note that neuroaesthetics of today do not focus on a particular type of objects like artworks (Nadal & Skov, 2015). Rather, the field is concerned with the neural underpinnings of cognitive, emotional, perceptual, and evaluative processes among others that are evoked in a person when he or she interacts with an object in an aesthetic way (Skov & Vartanian, 2009).

A model of aesthetic experiences

A good way to localise the present work within the context of empirical aesthetics was offered by Leder et al. (2004). They developed a model of aesthetic experiences that took previous findings of empirical aesthetics into account. The model offered a frame for subsequent research in empirical aesthetics as well as for the present thesis, especially with regard to one main objective of this work: the examination of the role of expertise in the aesthetic appraisal of architecture. Therefore, the structure of Leder et al.'s (2004) model will be explained in some more detail.

The model describes the cognitive and affective processes involved in aesthetic experiences by means of five stages (see Figure 1). According to Leder et al. (2004), these stages represent different cognitive analyses of the stimulus, all of them accompanied by an additional continuous affective evaluation. Each of these five processing units comprise particular factors that are characteristic for the single stage. In addition, the analysis of the stimulus by means of these influencing factors is suggested to occur simultaneously within each stage (Leder et al., 2004).

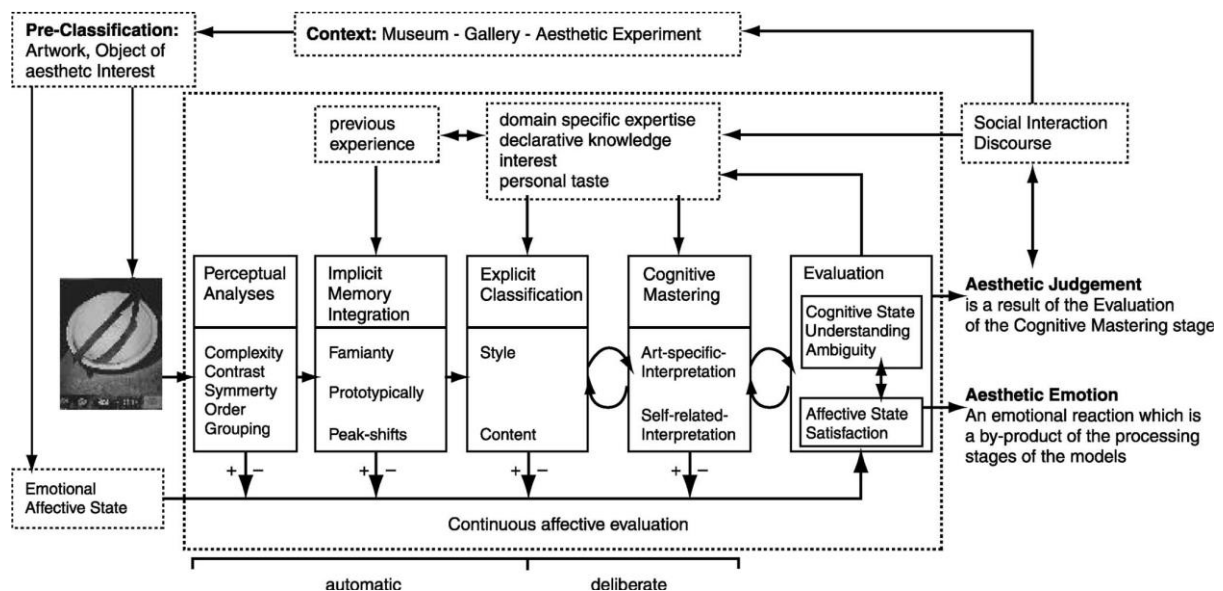


Figure 1. The model of aesthetic experiences by Leder et al. (2004). Retrieved from “A model of aesthetic appreciation and aesthetic judgments,” H. Leder, B. Belke, and A. Oeberst, 2004, *British Journal of Psychology*, 95, p. 492. Copyright 2004 by the British Psychological Society. Reprinted with permission.

An object of aesthetic interest is defined as the input of the model. This object needs to be pre-classified as such by the perceiver to warrant and initiate aesthetic processing (Leder et al., 2004). Contextual features facilitate a pre-classification of an aesthetic object.

For example, the appearance of an object in a museum is described as such a contextual cue (Leder et al., 2004).

The first stage of the model concerns the *perceptual analyses* of the aesthetic object. Visual features like contrast (e.g. Reber, Winkielman, & Schwarz, 1998), visual complexity (e.g. Berlyne, 1970), symmetry (e.g. Locher & Nodine, 1987), and variables described by Gestalt psychologist like order or grouping (e.g. Arnheim, 1954) determine this first processing unit (Leder et al., 2004).

The *integration of implicit memory* is marked as the second stage (Leder et al., 2004). Here, the analysis of the aesthetic object is affected by familiarity (e.g. Zajonc, 1968), prototypicality of the object within its class (e.g. Hekkert & van Wieringen, 1990), and may be by peak-shift phenomena (Ramachandran & Hirstein, 1999), which are described by Leder et al. (2004) as stronger reactions towards an aesthetic object (e.g. a caricature) that holds exaggerated attributes of its kind. Leder et al. (2004) argued that these first two stages of aesthetic processing are unconscious and automatic, while the following ones are described as usually conscious processes that can be verbalized and occur deliberately.

The third stage of the model is concerned with an *explicit classification* of the aesthetic stimulus, a stage particularly affected by content and style. Moreover, Leder et al. (2004) pointed out that interest, personal taste, and especially knowledge and domain specific expertise may have a strong impact on this level of aesthetic processing. With an increase in knowledge and expertise, the classification by content and style is suggested to differ from those of lay people (Leder et al., 2004). For example, the *American Bar*, situated in the city centre of Vienna, may be classified by a naïve tourist only as one bar among many others to get a drink in the evening, maybe as an aesthetically interesting one. In contrast, an expert in architecture might identify it as one of the early works of modern architecture in Vienna, built by the well-known architect Adolf Loos, whose interior design is characterised by an

ingenious use of mirrors that arouse an additional impression of spatial depth in the visitor (Gemmel, 2005). Such a successful classification of the aesthetic object of interest is suggested to result in a self-rewarding experience and, thus, might be a key aspect for the explanation why humans seek aesthetic experiences (Leder et al., 2004). In addition, the model illustrates that expertise might also affect the implicit analysis of prototypicality in the previous processing stage as well as the subsequent processing level of *cognitive mastering*. Therefore, Leder et al. (2004) argued that research on expertise is one major objective to gain evidence particularly for the third (i.e. *explicit classification*) and fourth processing stage (i.e. *cognitive mastering*) of the model.

The fourth and fifth processing stages (i.e. *cognitive mastering* and *evaluation*) of the model are closely interconnected by a feedback-loop. *Cognitive mastering* concerns the interpretation of the previous aesthetic analyses. Its result is constantly evaluated with regard to the success of reducing ambiguity and the satisfaction with the achieved understanding and the experienced emotional state (Leder et al., 2004). Leder et al. (2004) proposed that aesthetic processing might be redirected to previous levels of the model, if the evaluation was not yet experienced as successful. In addition, they argued that expertise might also play a role in this feedback-loop because of evidence that experts and non-experts differ in terms of the information they use to form an aesthetic judgment (e.g. Winston & Cupchik, 1992). For example, Cupchick (1992) pointed out that aesthetic processing based on style is typical for experts, while the aesthetic judgement of non-experts is more often based on the content of the aesthetic object (Leder et al., 2004).

Moreover, these five cognitive stages of aesthetic processing in the model of Leder et al. (2004) are linked with a consecutively changing affective state. Leder et al. (2004) assumed that each stage of cognitive aesthetic processing is able to influence this affective state in a positive or negative way, depending on the continuous success in cognitively

mastering the aesthetic object. In addition, they supposed that the viewer of an aesthetic object evaluates this affective state and stop aesthetic processing once satisfaction is reached (Leder et al., 2004).

These affective evaluations result in an *aesthetic emotion*, which is defined as one of the outputs of the model (Leder et al., 2004). Similar to the aesthetic evaluations during aesthetic processing, Leder et al. (2004) suggested that the resulting emotion can take a positive form (e.g. pleasure or happiness), but also the opposite in terms of a negative emotion such as displeasure is possible. In contrast, the second outcome of the model, that is an *aesthetic judgement*, may take a more differentiated shape (Leder et al., 2004). Following Cupchik and Laszlo (1992), Leder et al. (2004) proposed that the aesthetic judgement may be based on both cognition and emotion. Moreover, while they suggested that naïve perceivers rely their aesthetic judgement more on emotional factors, experts might rather choose a more cognitive challenging aesthetic evaluation.

Furthermore, it is worth noting that Leder et al.'s (2004) model was developed to elucidate cognitive and affective processes involved in experiences of modern artworks. Nevertheless, Leder et al. (2004) pointed out that the model might also apply for other objects of aesthetic interest. For example, it has been shown that the aesthetic appreciation of industrial design (Hekkert, Snelders, & van Wieringen, 2003) and of car interior design (Leder & Carbon, 2005) underlie similar principles (Leder et al., 2004). Thus, it is likely that aesthetic processing of architectural design is also within the scope of this model. Therefore, it will serve as a framework in the following sections.

The impact of spatial features on aesthetic experiences

At the beginning of this work, it was briefly pointed out why our built environments and especially architectural interiors should be taken into account by empirical aesthetics. In fact, psychology, among other disciplines, is fully aware of the importance of our

environment on human behaviour and well-being. For example, in environmental psychology numerous studies have focused on the effect of natural and built environments on human health in terms of stress reduction and recovery (e.g. Moore, 1981; Laumann, Gärling, & Stormark, 2003; Herzog, Maguire, & Nebel, 2003). Theories like the *Stress Recovery Theory* of Ulrich (1984, 1999) or the *Attention Restoration Theory* of Kaplan and Kaplan (1989) also addressed this topic. Others explored characteristics of and preference for different architectural styles (e.g. Devlin & Nasar, 1989) or discussed the influence of architectural features on memory, spatial perception, and spatial navigation (Sternberg & Wilson, 2006).

However, until today empirical research has not adequately investigated the impact of specific variations of physical features in architecture on behavioural outcomes (Vartanian et al., 2013; Lindal & Hartig, 2013). Even though some evidence exists that linked architectural determinants like building height and variations of facades to preference or perceptions such as the restoration likelihood of a space (Lindal & Hartig, 2013; Stamps, 1999), the research addressed to this issue is rare (Vartanian et al., 2013). Moreover, even less evidence exists regarding the effects of physical features of architectural interiors on aesthetic behaviour.

Nonetheless, an exploratory study was carried out by Vartanian et al. (2013) as an attempt to bridge this gap in research. Specifically, Vartanian et al. (2013) investigated, by means of a functional magnet resonance imaging (fMRI) experiment, how systematic manipulations of the *contour* of interior spaces affect aesthetic behaviour. The general purpose of this study was based on the *habitat theory* of Appleton (1975) according to which humans most appreciate those natural environments whose physical features are perceived as beneficial for their survival, and that was proposed by Hildebrand (1999) to also apply to constructed spaces (Vartanian et al., 2013). In this regard, Vartanian et al. (2013) suggested that the contour of a space might be one of the important physical features that is capable to have an effect on how we judge our built environments aesthetically. As argued by

Vartanian et al. (2013), this assumption was bolstered by findings of early psychological experiments that indicated an effect of the contour of simple stimuli, such as lines, on aesthetic experiences (Lundholm, 1921; Poffenberger & Barrows, 1924; Hevner, 1935). For example, Hevner's (1935) participants associated curved lines with adjectives like graceful or serene, while angles were experienced as vigorous, robust, and more dignified. As pointed out by Vartanian et al. (2013), recent findings confirmed that curved contours are able to evoke pleasant emotions (e.g. Dazkir & Read, 2011). Moreover, a preference was found for various curved stimuli in comparison to rectilinear ones (e.g. Leder & Carbon, 2005; Silvia & Barona, 2009; Leder, Tinio, & Bar, 2011).

Consistent with these findings, Vartanian et al. (2013) found a similar effect for the contour of interior spaces in terms of higher beauty judgements for curved than for rectilinear rooms. In addition, their findings revealed that judgements of the pleasantness of the used stimuli explained almost 60% of the variance of the beauty ratings, indicating that the preference for curvilinear space might be mediated by affective responses towards curvature (Vartanian et al., 2013). On a neural basis, these findings were supported by a higher increase in the neural activity of the anterior cingulate cortex (ACC) when their naïve participants judged the beauty of curved spaces in contrast to rectilinear ones (Vartanian et al., 2013). As emphasised by Vartanian et al. (2013), this brain area has been consistently associated with reward and emotional processing (Kringelbach & Rolls, 2004; Liu, Hairston, Schrier, & Fan, 2011).

Moreover, in a recent published study, Vartanian et al. (2015) investigated the impact of two other spatial features on aesthetic judgements about interior spaces: *ceiling height* and *perceived enclosure*. Even though only a few empirical studies exist concerning the effect of ceiling height on behaviour (e.g. Meyers-Levy & Zhu, 2007), Vartanian et al. (2015) advocated this factor as another potentially important one for the appraisal of built

environments because of its essential role in the history of architectural design (e.g. Palladio, 1570/1965). Furthermore, this suggestion was strengthened by findings of Baird, Cassidy, and Kurr (1978) whose results indicated that a preference for rooms increases monotonically with ceiling height up to a peak of approximately 3 m, followed by a decrease in preference (Vartanian et al., 2015).

Similar to the results of Baird et al. (1978), Vartanian et al. (2015) found that interior spaces with high ceilings were judged as more beautiful by their naïve participants in comparison to rooms with low ceilings. This aesthetic preference for spaces with higher ceilings was accompanied by a neural activation in frontal and parietal brain areas situated in the dorsal stream. These areas have been suggested to be involved in processes of visuospatial attention and exploration (e.g. Cavanna & Trimble, 2006; Kravitz et al., 2011; Wenger et al., 2012) and, thus, might contribute to aesthetic judgements for spaces of these kind (Vartanian et al., 2015).

Besides ceiling height, Vartanian et al. (2015) proposed perceived enclosure of a space as another potentially important factor with regard to the aesthetic appreciation of architectural design. This suggestion, in turn, was influenced by the theory of Stamps (2005) who considered enclosure as the permeability of a space (i.e. the perceived degree of movement through an environment), which comprises two different variations: a visual and a locomotive access to a space. Furthermore, Stamps (2005, 2010) argued, from an evolutionary perspective, that a higher extent in the ability to overlook an environment has a direct advantage for survival in terms of an ability to identify potential risks. Therefore, Stamps (2005, 2010) proposed that an environment with a greater amount of permeability should be preferred aesthetically.

In accordance with this theory, Vartanian et al. (2015) found that open spaces were judged as more beautiful than enclosed ones. Interestingly, the contrast between beauty

judgements of open vs. enclosed spaces was accompanied, among others, by a higher activation in the left middle temporal gyrus (Vartanian et al., 2015). This brain area has been found to be related to abstract representations of visual motion (see Watson, Cardillo, Ianni, & Chatterjee, 2013). Vartanian et al. (2015) therefore proposed that the development of beauty judgements about open spaces might also comprise a processing of motion, which, in turn, might be caused by a perception of a greater amount of visual and locomotive permeability in open rooms in contrast to enclosed ones.

In addition, it is worth mentioning that for beauty judgements of both open rooms and rooms with high ceilings no neural activity was found in regions associated with emotion, affect, reward, and pleasure (Vartanian et al., 2015). As it was argued by Vartanian et al. (2015), this absence of neural activity indicates that, in contrast to beauty judgements about curved spaces (Vartanian et al., 2013), these aesthetic judgements might be developed without a recruitment of brain regions associated with these kind of processes.

Open questions and hypotheses: The impact of expertise on aesthetic judgements about architectural design. Critical to understand how humans appreciate their surroundings is research on the role of expertise in aesthetic processing (Leder et al., 2004). As it was stated out above in reference to the model of aesthetic experiences by Leder et al. (2004), domain-related expertise is suggested to influence the underlying affective and cognitive processes of aesthetic experiences. Specifically, it was pointed out how prior experience and knowledge may impact the way of classifying, interpreting, and evaluating an object of aesthetic interest, and how the results of these processes serve as a basis to form an aesthetic judgement. Moreover, evidence for an effect of expertise on aesthetic experiences was found in numerous psychological experiments (e.g. Winston & Cupchick, 1992; Hekkert & van Wieringen, 1996). Eye-tracking studies, for example, have shown that naïve participants explore artworks using different visual processing strategies in comparison to

experts: While the former focus their attention more on specific elements, the latter ones explore rather the overall composition (Nodine, Locher, & Krupinski, 1993; Vogt & Magnussen, 2007). Furthermore, not only an effect of expertise on aesthetic behaviour and perception was found, but also with regard to the neural underpinnings of these processes (e.g. Bangert et al., 2006). For example, Kirk, Skov, Christensen, and Nygaard (2009) examined differences in the neural activity between experts in architecture and lay people while their participants were making aesthetic judgements about pictures of buildings, and found differences in the neural activity of brain regions related to memory and reward.

In view of the consistent evidence for an effect of expertise on aesthetic processing, it becomes clear that there is a need to include research on expertise in studies on the aesthetic appreciation of architecture. Therefore, the first experimental aim of the present thesis was addressed to this issue by following up the research of Vartanian et al. (2013, 2015) in order to examine the impact of architectural determinants on aesthetic judgements in both naïve participants and experts in architecture.

As it has been shown in a similar way by Vartanian et al. (2013), the initial hypothesis was, in the case of non-experts, that curvilinear contours of interior spaces are more likely to elicit higher liking ratings than rectilinear contours. Furthermore, rooms with high ceilings were expected to be more liked by non-experts than rooms with low ceilings because of previous evidence for a similar effect of ceiling height on aesthetic judgements (Baird et al., 1978; Vartanian et al., 2015). Regarding perceived enclosure, it was expected that liking judgements of naïve participants are higher for open interior spaces than for enclosed ones. This hypothesis, in turn, was based on the aforementioned theory of Stamps (2005, 2015) and the empirical evidence of Vartanian et al. (2015), suggesting that spaces with a greater amount of visual and locomotive permeability are preferred aesthetically.

Moreover, it was expected that contour, ceiling height, and perceived enclosure of interior spaces are each significant predictors for the liking judgements of experts in architecture. This hypothesis was formulated non-directional because there is at present no empirical research on how aesthetic judgements of experts in architecture are affected by these spatial features. However, as it was already shown for naïve participants (Vartanian et al., 2013, 2015), it is likely that these architectural determinants are also able to affect aesthetic judgements of participants with a high level of domain-related knowledge and experience. Specifically, I argue that experts in architecture are particularly receptive to these spatial features because of the proposed importance of contour, ceiling height, and perceived enclosure in the field of architecture (Palladio, 1570/1965; Le Corbusier, 1931/1986; Vartanian et al., 2013, 2015).

Aiming to test these hypotheses, two experiments were carried out to investigate separately how aesthetic judgements about interior spaces in non-expert participants (i.e. Experiment 1) as well as in experts in architecture (i.e. Experiment 2) are influenced by variations of contour (curvilinear vs. rectilinear), ceiling height (low ceilings vs. high ceilings), and perceived enclosure (enclosed vs. open). In addition, it was intended to examine whether previous findings of the neural underpinnings of aesthetic appreciation also apply for the aesthetic appraisal of architecture. This second objective of the present work will be discussed in the following.

The role of the left dorsolateral prefrontal cortex in aesthetic experiences

During the last few years, an increasing number of neuroimaging studies were carried out to provide insights into the neural foundation of aesthetic experiences (Nadal & Pearce, 2011). These findings suggest that aesthetic appreciation relies on the neural activity of a complex network of brain regions, rather than a specific area (Nadal & Skov, 2013). In brief, an increase of neural activity was particularly found in low-level cortical regions related to

sensory processing, in cortical and subcortical regions associated with reward and pleasure, as well as in high-level cortical areas involved in top-down processes such as evaluative judgements (see Nadal & Pearce, 2011).

In conjunction with this research, consistent evidence exists for an involvement of the left dorsolateral prefrontal cortex (left DLPFC) in processes of aesthetic appreciation. For example, in a magnetoencephalography (MEG) study of Cela-Conde et al. (2004) it was found that the neural activity in this area was higher when participants judged photographs and artworks as beautiful compared to those they judged as not beautiful. Cela-Conde et al. (2004) therefore proposed that the left DLPFC might be responsible for mediating decisions about the beauty of stimuli. This suggestion was strengthened by evidence of Lengger, Fischmeister, Leder, and Bauer (2007) who found a higher neural activity in this brain area while their participants rated aesthetic qualities of artworks. Moreover, Vessel et al. (2012) likewise demonstrated an increased activity in the left DLPFC when participants viewed aesthetically moving artworks.

Following these findings, the left DLPFC was proposed to be one of the crucial neural correlates of aesthetic appreciation. For example, Cattaneo et al. (2014a) argued from the aforementioned findings that this brain area, which is associated with the executive functions in general, might organise the perception of an aesthetic orientation in terms of directing and maintaining attention towards a visual stimulus. This perspective was based on evidence of Cupchick et al. (2009) who asked their participants to approach artistic stimuli in an 'aesthetic' or in a 'pragmatic' way. Using fMRI, they found that an instructed aesthetic orientation towards an artwork was accompanied by an increased activity in left DLPFC (Cupchick et al., 2009). In accordance with Ridderinkhof et al. (2004), Cupchick et al. (2009) therefore suggested that the left DLPFC might be related to a cognitive top-down control of attention. Moreover, these findings indicate that aesthetic appreciation might not be purely

driven by bottom-up processes facilitated by aesthetic features of the stimuli, rather it comprises a complex interplay between these bottom-up processes and top-down operations of cognitive control (Cupchick et al., 2009).

Nevertheless, these aforementioned electrophysiological and neuroimaging studies only provided evidence for an involvement of the left DLPFC in aesthetic experiences on a correlational basis (Cattaneo et al., 2014a). Cattaneo et al. (2014a), however, used transcranial direct current stimulation (tDCS) to overcome the limitations of reverse inference by directly testing the existence of a *causal* relationship between the left DLPFC and aesthetic appreciation. This kind of non-invasive brain stimulation is suggested to modify the neural activity in the targeted brain area by an induction of weak amounts of direct current (DC) and, thereby, allows to investigate whether the stimulated brain area plays a causal role in a given cognitive process (Miniussi, Harris, & Ruzzoli, 2013). More precisely, brain stimulation with DC is proposed to alter the cortical excitability in the targeted area (Miniussi, Harris, & Ruzzoli, 2013). The duration of this alteration, in turn, is suggested to last for a certain time period beyond the stimulation in dependence of stimulation parameters like the stimulation polarity (cathodal vs. anodal) and the stimulation duration (Miniussi, Harris, & Ruzzoli, 2013). For anodal tDCS, for example, it has been shown that the DC stimulation enhances the cortical excitability in the stimulated area and, thereby, is able to facilitate task executions (e.g. Batsikadze et al., 2013).

By means of this type of brain stimulation (i.e. anodal tDCS), Cattaneo et al. (2014a) asked half of their naïve participants to rate how much they like representational and abstract images before and after a real or a sham stimulation of their left DLPFC. To control that this area is specifically involved in an aesthetic evaluation process and not in any other, the other half of their participants were asked to rate the colourfulness of the images (Cattaneo et al., 2014a). As hypothesised, it was found that anodal tDCS over the left DLPFC resulted

exclusively in higher liking judgements (Cattaneo et al., 2014a). However, Cattaneo et al. (2014a) only found an effect by tDCS for the representational stimuli and not for the abstract ones (Cattaneo et al., 2014a). These findings are in line with the argumentation by Cela-Conde et al. (2011) that the discrepancy of neural activity found in studies of aesthetic appreciation might be caused by the different types of stimuli that were used. From Cela-Conde et al.'s (2011) view, stimuli like abstract geometric patterns used in the study of Jacobsen and Höfel (2003) might rather allow subjective beauty judgements driven by internally generated information. Such self-referential judgements were found to correlate with activity in the frontomedian prefrontal cortex (Northoff & Bermpohl, 2004; Zysset, Huber, Ferstl, & van Cramon, 2002). In contrast, for representational stimuli, which contain more external information on which one can refer, an involvement of the DLPFC is suggested (Cela-Conde et al., 2004; Cela-Conde et al., 2011).

Nonetheless, in a more recent study, Cattaneo et al. (2014b) found that an interference with the neural activity in the left DLPFC, by means of transcranial magnetic stimulation (TMS), caused reduced liking ratings for the kind of art (representational vs. abstract artworks) their participants preferred in general. Therefore, the absence of a tDCS effect for abstract stimuli in the experiment of Cattaneo et al. (2014a) might be only due to the fact that their participants preferred the representational stimuli more than the abstract ones (Cattaneo et al., 2014b).

Taken together, the findings presented in this section suggest that the left DLPFC might play a selective role in processes of aesthetic appreciation in terms of an involvement of this cortical region in a complex interaction between subjective a priori preference on the one hand and external stimuli features on the other hand.

Open questions and hypotheses: The impact of prefrontal tDCS on liking judgements of interior spaces in lay people and experts. In terms of the neurobiological underpinnings of aesthetic appreciation, it was aimed to further examine the role of the left DLPFC in aesthetic processes, especially with regard to the appraisal of architectural interiors. In particular, the focus on this cortical area was chosen because the evidence presented in the previous section indicates that aesthetic judgements about architecture are likely to be within the scope of the left DLPFC. Specifically, an effect of brain stimulation over this brain area was not only found for representational artworks, but also for stimuli very similar to architectural interiors, namely photographs of landscapes and urban scenes (Cattaneo et al., 2014a). Moreover, the results of Cattaneo et al. (2014b) even reveal that the left DLPFC might play a role in aesthetic processes independently of the kind of stimuli that are used. Nonetheless, the suggestion that other representational stimuli of everyday life, such as architectural interiors, are also processed aesthetically by the left DLPFC needs to be tested experimentally.

Thus, the present thesis was additionally addressed to investigate how brain stimulation (i.e. anodal tDCS) over the left DLPFC affects liking judgements about interior spaces in naïve participants. In addition, it was intended to test whether this suggested tDCS effect on aesthetic judgements is also found for experts in architecture. This second objective was based on Cattaneo et al.'s (2014b) findings that a priori preferences of naïve participants are able to mediate effects of brain stimulation over the left DLPFC, suggesting that prior knowledge and experience might have an impact on how brain stimulation over this cortical area affects aesthetic judgements.

In accordance with the findings of Cattaneo et al. (2014a, 2014b), it was hypothesised that real anodal tDCS over the left DLPFC of naïve participants result in an enhanced neural

excitability in this cortical area and, therefore, in higher liking ratings for interior spaces in comparison to a sham tDCS condition.

In contrast, it was expected that real anodal tDCS over the left DLPFC of experts in architecture does not result in differences in liking ratings, neither in comparison to liking ratings after sham tDCS, nor in comparison to liking ratings prior to brain stimulation. Even though Cattaneo et al.'s (2014b) findings indicated that aesthetic judgements of non-experts are affected by brain stimulation in dependence of prior knowledge and experience in terms of general preferences, I argue that a high level of domain-related expert knowledge mediates effects of brain stimulation in a different way. In particular, this assumption is based on findings of Kirk, Harvey, and Montague (2011) who demonstrated that art experts, in comparison to naïve participants, are able to insulate against judgement bias by recruiting cortical areas related to self-censuring and emotion regulation. Following these findings, it is expected that experts in architecture are also able to make use of their domain-specific knowledge in terms of protecting themselves against effects of anodal tDCS over their left DLPFC by means of processes of cognitive control.

To accomplish this further experimental aim, the two aforementioned experiments to examine the impact of spatial architectural features on behavioural outcomes in both lay people (i.e. Experiment 1) and experts in architecture (i.e. Experiment 2) had to be extended in order to allow an additional investigation of the role of the left DLPFC in aesthetic judgements within each group of participants. Specifically, in each experiment, participants were asked to rate how much they like a series of images of architectural interiors prior to and following sham vs. real tDCS over their left DLPFC. To guarantee an optimal tDCS design, sham and real brain stimulation took place in two separated experimental sessions. Because each session consisted of two liking rating tasks, two equivalent stimuli sets were used to avoid effects of familiarisation.

Experiment 1: Non-expert participants

Method

Participants. Twelve lay people in terms of architecture participated in Experiment 1 (7 females, 5 males, $M_{\text{age}} = 29.25$ years, $SD_{\text{age}} = 9.38$, age range: 23-57 years). All were students or participants holding an academic degree, but none of them had any formal or informal training in architecture or in an art-related field. They were all right handed ($M = 99.07$, $SD = 3.21$), as measured with the Edinburgh inventory (Oldfield, 1971), had normal or corrected-to-normal vision and normal colour vision. A written informed consent was obtained from each participant. None of the participants reported a history of neurological, cardiac or psychiatric disease, a history of epilepsy in their families, any current medical disease, usage of psychoactive or analgesic medication prior to the experiment, current pregnancy or metal parts in the body (except dental fillings).

Materials. Two hundred photographs of architectural spaces served as stimuli. The stimuli were identical to the ones used in prior works studying the aesthetic appreciation of architecture (Vartanian et al., 2013, 2015). Each image had been classified with regard to each level of contour (rectilinear vs. curvilinear space), ceiling height (low vs. high space) and enclosure (enclosed vs. open space) of the architectural space (see Vartanian et al., 2013, 2015, for details). As a result, there were 25 images within the following eight conditions: curvilinear low-ceiling open, curvilinear low-ceiling enclosed, curvilinear high-ceiling open, curvilinear high-ceiling enclosed, rectilinear low-ceiling open, rectilinear low-ceiling enclosed, rectilinear high-ceiling open, and rectilinear high-ceiling enclosed. Figure 2 shows an example for each kind of combination.

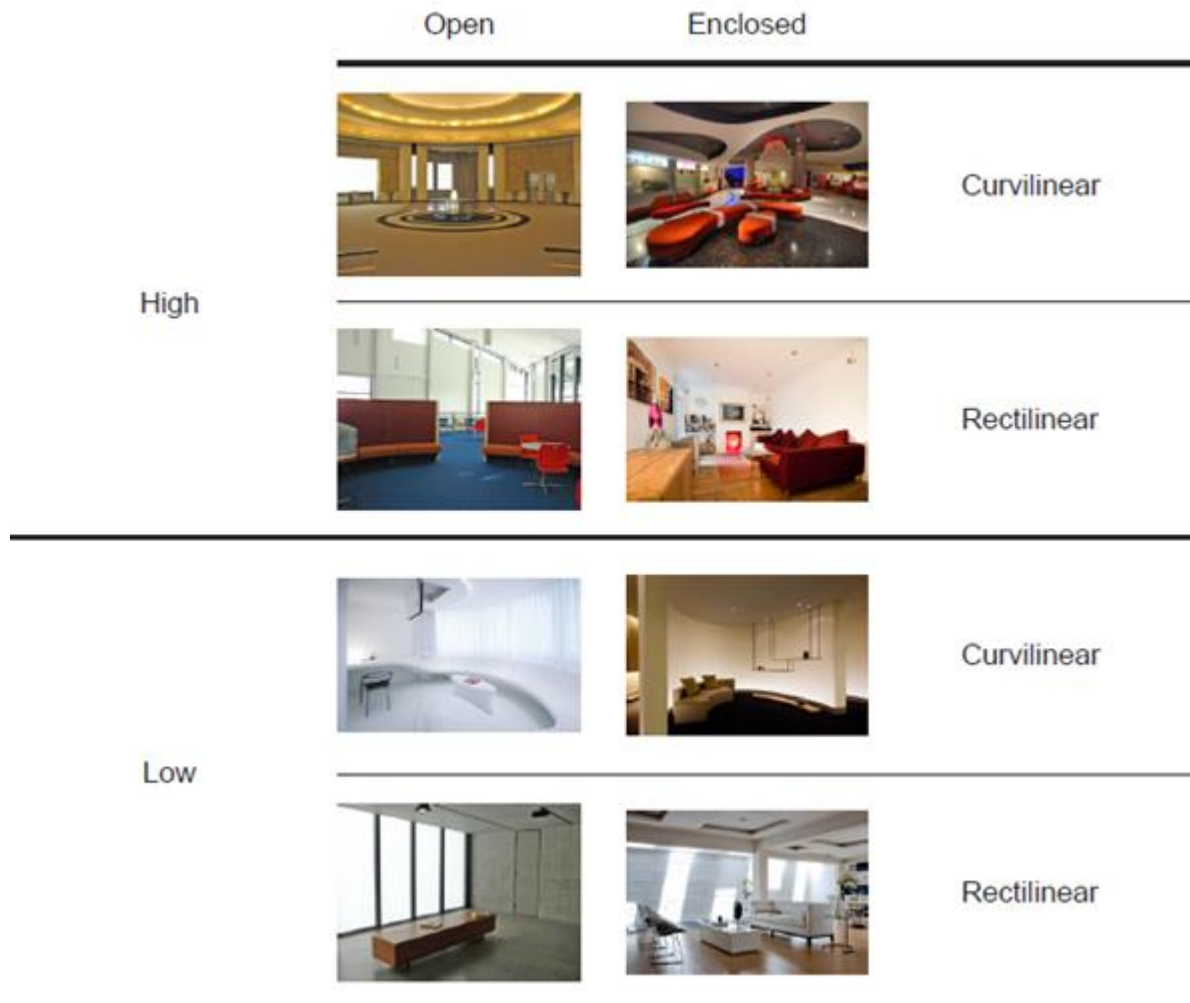


Figure 2. Examples of stimuli of interior spaces used in the experiment for each combination of ceiling height (low vs. high), enclosure (enclosed vs. open), and contour (rectilinear vs. curvilinear). Adapted from “Impact of contour on aesthetic judgments and approach-avoidance decisions in architecture,” by O. Vartanian, G. Navarrete, A. Chatterjee, L. B. Fich, H. Leder, C. Modroño, M. Nadal, N. Rostrup, and M. Skov, 2013, *Proceedings of the National Academy of Sciences*, 110, p. 10447. Reprinted with permission from the authors.

From each condition, one image ($n = 8$ images in total) was randomly selected for practice trials prior to the main rating task itself (see below). The remaining 24 images in each category were divided randomly into two sets of images (Set A and Set B). These two

sets served as stimuli for a pre- and a post-tDCS rating task. Hence, each set contained the same number of images ($n = 96$ images in each stimuli set) from each condition of architectural spaces. All stimuli were adjusted for resolution (i.e. the longer side of each image was standardized to 800 pixels, but the aspect ratio was kept). As in Vartanian et al.'s (2013, 2015) studies, no additional adjustments for luminance, colour etc. were made with regard to ecological validity.

Transcranial direct current stimulation. It was intended to use an experimental design along the lines of Cattaneo et al. (2014a) because of the follow-up purpose of this study to further examine whether the left DLPFC also plays a role in the aesthetic appreciation of architecture. Thus, tDCS was applied through two rubber electrodes (5×7 cm: 35 cm^2) energised by a direct current stimulator (DC-STIMULATOR, neuroConn GmbH, Ilmenau, Germany). As in Cattaneo et al.'s (2014a) procedure, the electrodes were embedded in electrode sponges soaked with physiologic salt solution, but to further minimise the electrical impedance, conductive electrode gel (Electro-Cap International, Eaton, OH, USA) was applied additionally on the inside and outside of the sponges, and the skin underneath the electrodes was cleaned with alcohol. A pair of elastic rubber head straps was used to fix the electrodes. The anodal electrode was positioned over the participants' left DLPFC, while the cathodal electrode was placed over the supraorbital area of the right hemisphere. As it has been shown by Cattaneo et al. (2014a) and several other studies examining the effect of tDCS on cognitive tasks (e.g. Hoy et al., 2013; Leite, Carvalho, Fregni, & Gonçalves, 2011; Metuki, Sela, & Lavidor, 2012), this electrode positioning is able to result in an increase of cortical excitability in the left DLPFC. In the same manner described by Rusjan et al. (2010) and as it has been carried out by Cattaneo et al. (2014a), the position of the left DLPFC on the scalp was localised as the midpoint between F3 and F5 according to the international 10-20 electrode system (Jasper, 1958).

To further follow the recommended procedure (Cattaneo et al., 2014a), each participant took part in one session with real and one session with sham tDCS stimulation. The two sessions took place on two different days with an average separation of 4.7 days (range: 2-15 days). The order of the tDCS sessions (real vs. sham tDCS) was counterbalanced across participants. Hence, one half of the participants started with real tDCS in the first session, followed by sham tDCS in the second session, and, respectively, the other half began with sham tDCS in the first session, followed by real tDCS in second session. Within each session, there were two liking judgement runs as in Cattaneo et al.'s (2014a) procedure: one before and one after tDCS. Furthermore, only one stimuli set (Set A vs. Set B) was used in each rating task as well. The order of the sets was counterbalanced across participants for the first session and was kept for the second session. Hence, one half of the participants rated in both sessions Set A prior to tDCS and Set B afterwards. The order of the stimuli sets for the other half of the participants was the other way around (i.e. Set B before and Set A after tDCS).

Similar to the study of Cattaneo et al. (2014a), each type of stimulation (sham and real tDCS) had a duration of 20 min. For real tDCS, a constant current of 2 mA intensity with 20 s fade-in and 20 s fade-out was applied to the participants. As it has been pointed out by Cattaneo et al. (2014a), a stimulation setting of 2 mA direct current had been shown to be safe and more effective in comparison to 1 mA (e.g. Iyer et al., 2005). In contrast to a so-called 'on-line' tDCS procedure, real tDCS was not applied during the rating tasks. For this kind of stimulation (i.e. an 'off-line' protocol), an enhancement of the cortical excitability by anodal tDCS lasts beyond the duration of the active tDCS stimulation (see Miniussi, Harris, & Ruzzoli, 2013). For sham tDCS stimulation, both electrodes were placed at the same position as for real tDCS stimulation, but the tDCS device induced direct current only for 30 s with 20 s fade-in and 20 s fade-out. To warrant automatic impedance control by the

tDCS device, current pulses (110 μ A for 15 ms) were delivered every 550 ms for the rest of the duration. This sham procedure resulted in an initial tingling or itching sensation by tDCS, but an effective induction of cortical excitability was avoided. Moreover, the tDCS stimulator did not display the kind of stimulation which was used. In contrast to Cattaneo et al. (2014a), the experimenter was not aware of the type of tDCS he was applying. This kind of sham stimulation has been shown to be a successful method for the blinding of both subjects and investigators (Gandiga, Hummel, & Cohen, 2006).

Procedure. Participants were tested individually under quiet room conditions. At the beginning of each session, participants were seated in front of a 24" LED monitor (1920 x 1080 pixels). They were briefed about the experimental procedure and agreed to participate in the experiment by signing a consent form. The computer task and the data collection was executed with E-Prime software (version 2.0, Psychology Software Tools, Inc., Sharpsburg, PA, USA). The task consisted of written instructions and eight practice trials at the beginning, followed by the ratings of either Set A or Set B. Participants were instructed to judge a series of interior spaces in accordance with their initial impression. As in each experimental trial of Cattaneo et al. (2014a), one of the stimuli was presented in the middle of the screen surrounded by a grey (R,G,B: 120,120,120) background, but in the present study participants were asked to rate the stimulus (i.e. 'How much do you like this interior space?') on an 8-point Likert scale at the bottom of the screen. The order of the stimuli presentation was randomised. To further follow the experimental procedure of Cattaneo et al. (2014a), there was no time limit for participants' response. Hence, the image stayed visible until participants expressed their aesthetic judgement by pressing one of the equivalent numbers on the keyboard. Subsequent to response, a blank grey screen was presented for 300 ms as in Cattaneo et al.'s (2014a) experiment, followed by another image of the stimuli set. Figure 3 shows the schematic of an experimental trial.

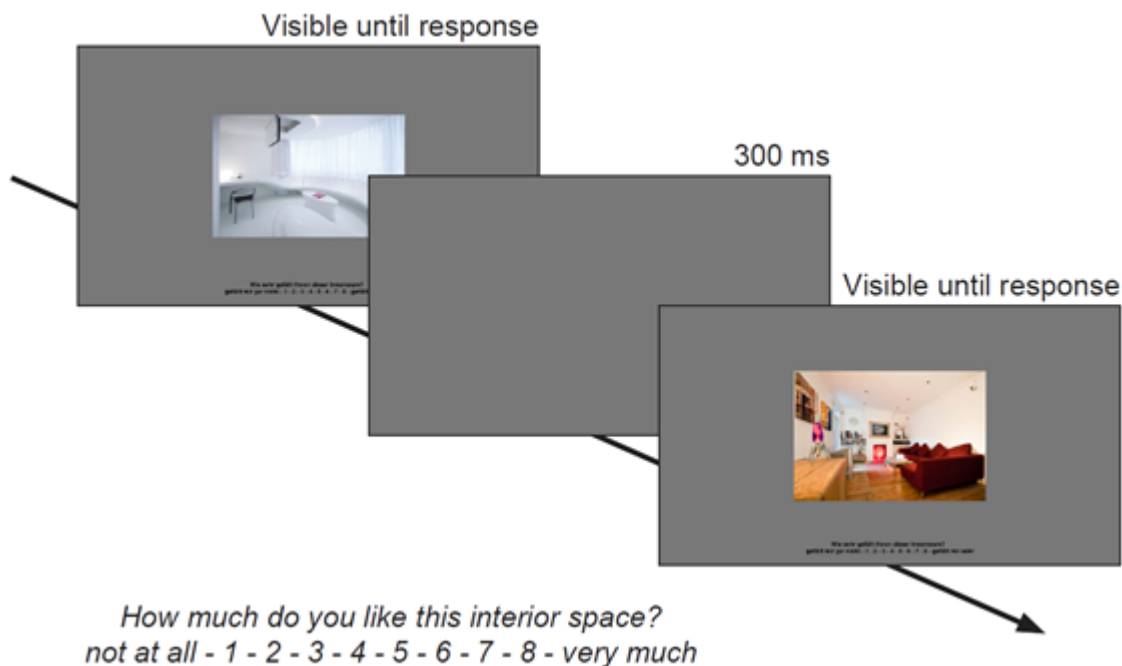


Figure 3. Timeline of an experimental trial. In each trial, participants had to evaluate consecutively how much they liked each stimulus by pressing a number between 1 and 8 (1 = not at all; 8 = very much) on the keyboard.

After completion of the pre-tDCS rating task, participants' left DLPFC was localised and electrodes were positioned as described above. Simultaneously with the initialisation of the tDCS stimulation, one of two cartoon movies (i.e. one for each session) was presented on the screen to keep the experimental situation between participants constant. Both cartoons were similar to the ones used in the study of Cattaneo et al. (2014a). The order of their presentation was counterbalanced across participants to avoid confounding effects by the cartoons. After tDCS, electrodes were taken off and the post-tDCS rating task of the remaining stimuli set was performed immediately. One session lasted approximately 60 min.

Results

Behavioural outcomes. Analyses were performed using IBM SPSS Statistics software (version 22, IBM Corporation, Armonk, NY, USA) to examine the effects of

contour, ceiling height, and enclosure in architecture on mean liking scores and mean RT in usual conditions, that is to say, in the absence of brain stimulation of lay people. Therefore, analyses were carried out only by looking at participants' responses to the rating task prior to tDCS in the first experimental session to avoid any confounding effect by tDCS or by task familiarisation due to the repeated measures design.

Liking ratings. The mean liking scores of non-experts for each level of the spatial features are reported in Figure 4.

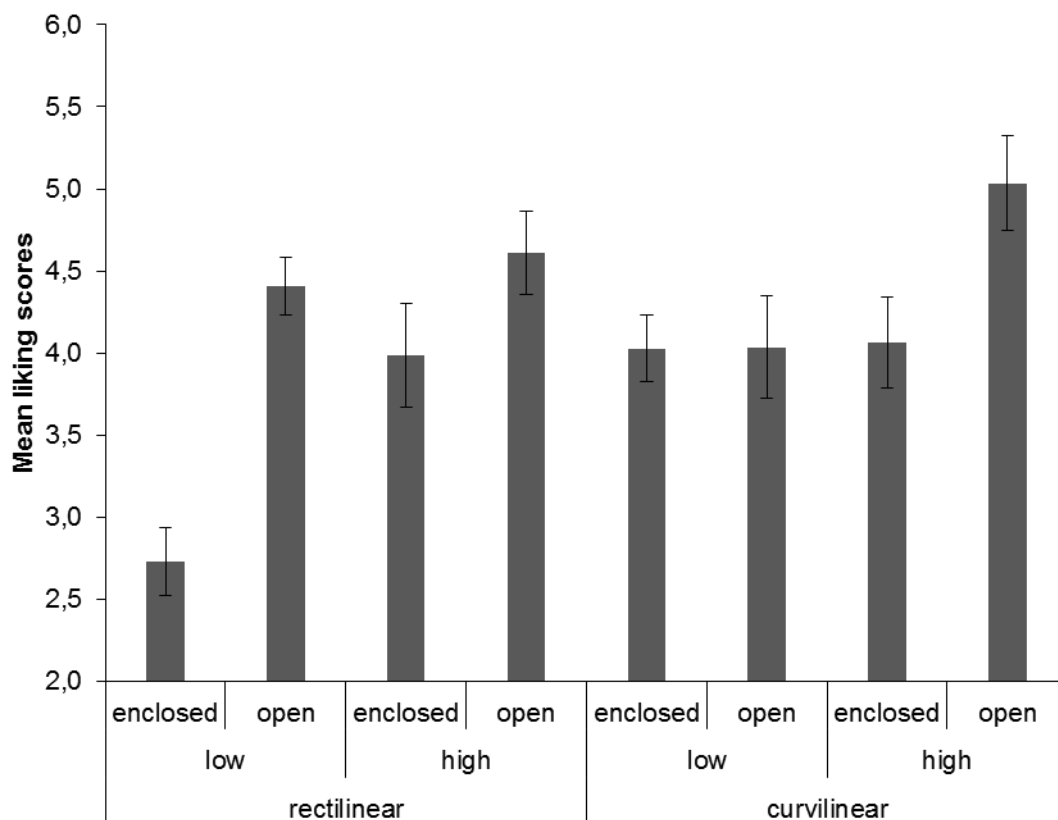


Figure 4. Mean rating scores of non-experts in the pre-tDCS rating task of the first experimental session for each level of contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open). Error bars represent ± 1 SEM.

A repeated measures analysis of variance (ANOVA) with contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open) as within-

subjects factors, and liking ratings as the dependent variable showed a significant main effect of ceiling height, $F(1, 11) = 23.61, p = .001, \eta_p^2 = .68$, a significant main effect of enclosure, $F(1, 11) = 50.50, p < .001, \eta_p^2 = .82$, and a significant two-way interaction contour by enclosure, $F(1, 11) = 17.48, p = .002, \eta_p^2 = .61$. Even more important, the three-way interaction contour by ceiling height by enclosure was also significant, $F(1, 11) = 26.65, p < .001, \eta_p^2 = .71$, suggesting that the effect of at least one spatial factor depended on the levels of the other factors. Neither the main effect of contour, nor any other interaction reached significance (all $ps > .083$).

Additional follow-up dependent t-tests were carried out to break down the significant three-way interaction by testing the effect of each factor separately for each combination of the other two factors (i.e. 12 pairwise comparisons were performed in total). In order to control the familywise error rate, the critical significance level of .050 was Bonferroni corrected for the number of pairwise comparisons to .00417. In addition, adjusted Cohen's d effect sizes for paired samples were calculated in accordance with Dunlop, Cortina, Vaslow, and Burke (1996). Regarding the effect of contour, these analyses revealed that curvilinear contours were significantly liked more ($M = 4.03; SD = .70$) than rectilinear ones ($M = 2.73; SD = .71$), but only when ceiling height was low and rooms were enclosed, $t(11) = -5.49, p < .001, d = -1.85$. Furthermore, the difference between both levels of ceiling height (low ceilings vs. high ceilings) was only found to be significant when contours were rectilinear and rooms were enclosed, $t(11) = -5.64, p < .001, d = -1.25$, indicating higher liking ratings for high ceilings ($M = 3.99; SD = 1.08$) in comparison to low ceilings ($M = 2.73; SD = .71$). In contrast, enclosure affected liking ratings of lay people not only in rooms with low ceilings and rectilinear contours, $t(11) = -13.12, p < .001, d = -2.50$, but also when ceilings were high and contours were curvilinear, $t(11) = -4.05, p = .002, d = -0.99$. In the case of rectilinear rooms with low ceiling, open rooms ($M = 4.41; SD = .60$) were significantly liked more than

enclosed rooms ($M = 2.73$; $SD = .71$). Similarly, open spaces ($M = 5.03$; $SD = 1.01$) were significantly liked more than enclosed ones ($M = 4.06$; $SD = .96$) in curvilinear spaces with high ceilings. In addition, another marginally significant effect of enclosure in the same direction was found for rectilinear rooms with high ceilings, $t(11) = -3.49$, $p = .005$, $d = -.61$, that is to say, open spaces ($M = 4.61$; $SD = .88$) were liked more than enclosed ones ($M = 3.99$; $SD = 1.08$). None of the other pairwise comparisons were significant (all $ps > .020$).

Mean response latencies. Mean RTs of non-experts in each experimental condition of the pre-tDCS rating task of the first session are presented in Figure 5.

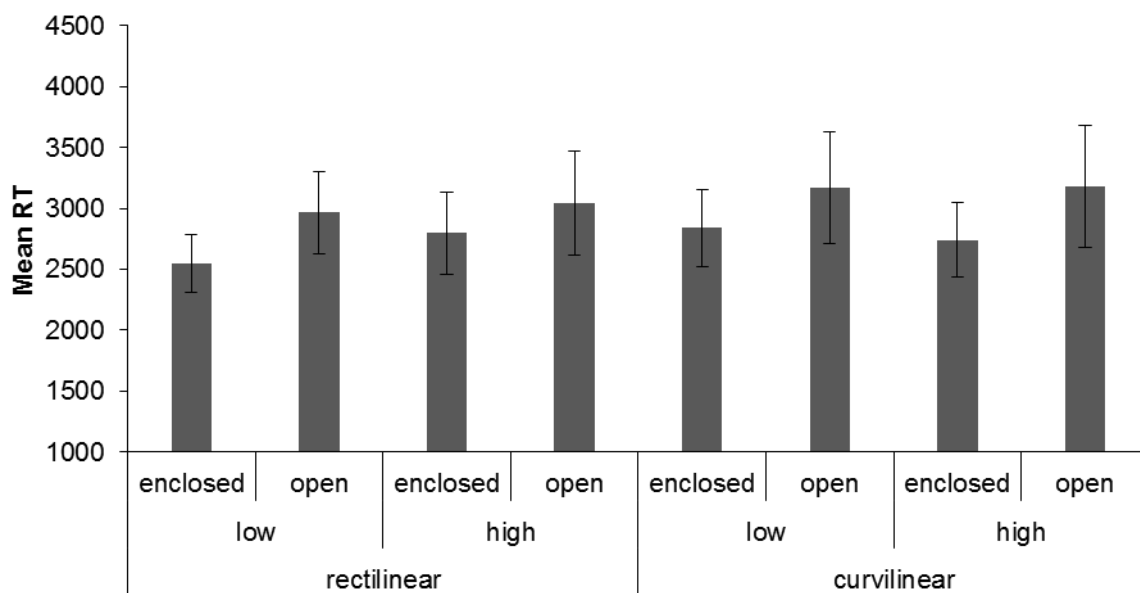


Figure 5. Mean response latencies of non-experts in *ms* for each level of contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open). Error bars represent ± 1 SEM.

To examine the effect of spatial features on response latencies, another repeated measures ANOVA was carried out with contour (rectilinear vs. curvilinear), ceiling height

(low vs. high), and enclosure (enclosed vs. open) as within-subjects factors, and RT as the dependent variable. The analysis revealed a significant main effect of enclosure, $F(1, 11) = 5.90, p = .033, \eta_p^2 = .35$, indicating that lay people took longer to evaluate how much they liked open rooms ($M = 3088.21; SD = 1426.46$) in comparison to enclosed rooms ($M = 2732.22; SD = 998.77$). None of the other main effects or interactions reached statistical significance (all $ps > .104$).

Effects of tDCS stimulation. All non-experts described a slight itching or transient tingling sensation as side effects of tDCS right after the onset of the stimulation, but none of them reported any difference between the sham and the real tDCS condition spontaneously. Statistical analyses were performed on non-experts' mean liking scores and mean RT in all rating tasks (i.e. rating tasks before and after real vs. sham tDCS).

Liking ratings. To analyse the effect of tDCS on liking judgements of lay people, a repeated measures ANOVA was carried out with tDCS time (pre-tDCS vs. post-tDCS) and tDCS type (real tDCS vs. sham tDCS) as within-subjects factors, and liking scores as the dependent variable. Figure 6 shows the mean rating scores of non-experts in the different experimental conditions.

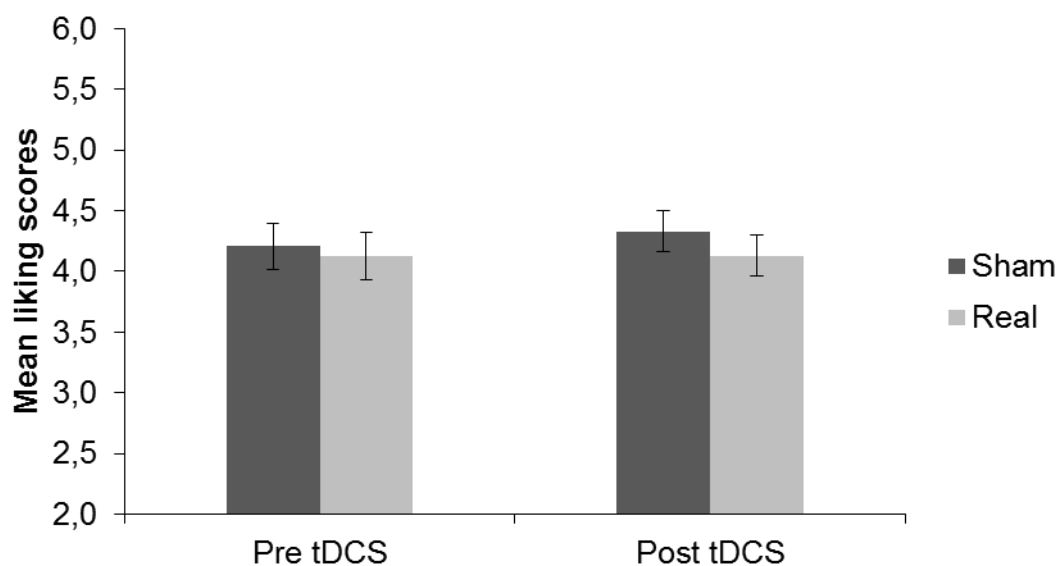


Figure 6. Mean rating scores of non-experts in the liking rating tasks before and after sham vs. real tDCS. Error bars represent ± 1 SEM.

As expected, the ANOVA showed neither a significant main effect of tDCS time ($p = .145$), nor a significant main effect of tDCS type ($p = .225$), indicating no significant differences of liking ratings in the group of non-experts between pre-tDCS and post-tDCS rating scores regardless of the type of tDCS, and no significant differences between sham and real tDCS regardless of the time of the ratings. Crucially, the interaction tDCS time by tDCS type did not reach significance either ($p = .161$), revealing that even though the baseline liking ratings prior to tDCS seemed to be comparable between sham and real tDCS, no significant differences were found between pre-tDCS rating scores and their correspondent post-tDCS rating scores in each tDCS condition (sham vs. real tDCS). In addition, this non-significant interaction also indicated no significant differences between post-tDCS rating scores following real and post-tDCS rating scores following sham tDCS.

Mean response latencies. Mean response latencies of non-experts in each experimental condition are presented in Figure 7.

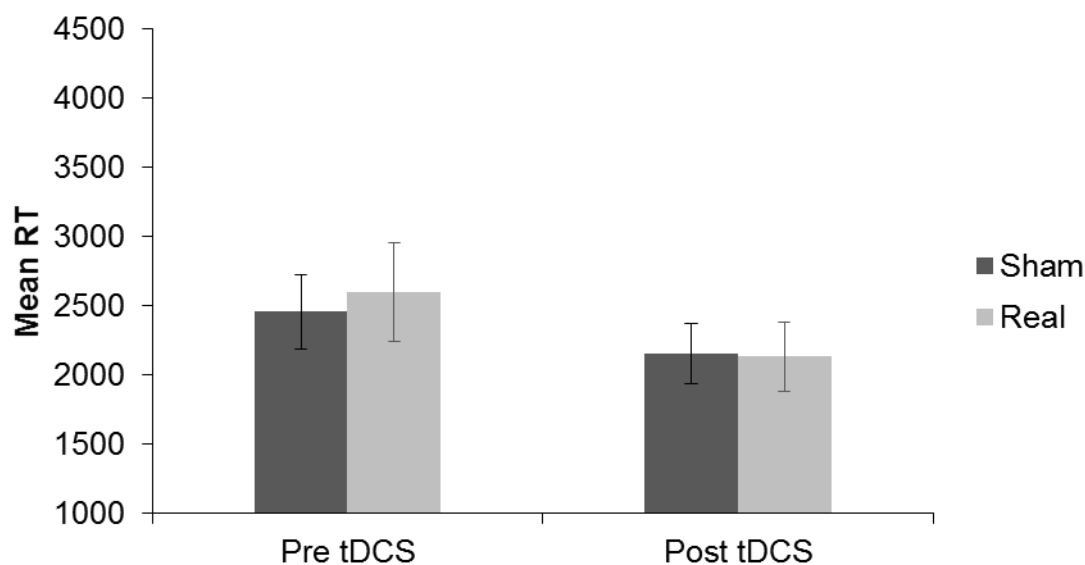


Figure 7. Mean response latencies of non-experts in *ms* in the pre-/post-tDCS rating tasks in each tDCS condition (sham vs. real tDCS). Error bars represent ± 1 SEM.

A repeated measures ANOVA with tDCS time (pre tDCS vs. post tDCS) and tDCS type (real tDCS vs. sham tDCS) as within-subjects factors, and RT as the dependent variable, showed a significant main effect of tDCS time, $F(1, 11) = 8.73, p = .013, \eta_p^2 = .44$, revealing that liking responses of non-experts were faster in the post-tDCS rating tasks ($M = 2143.50; SD = 717.57$) in comparison to the pre-tDCS rating tasks ($M = 2528.31; SD = 974.90$). Neither the main effect of tDCS type, nor the interaction tDCS time by tDCS type reached statistical significance (all $ps > .373$).

Experiment 2: Expert participants

Method

Participants. Twelve experts in architecture (8 females, 4 males) participated in Experiment 2. Participants ranged in age from 24 to 60 years ($M = 30.58, SD = 11.37$), and consisted of 10 students with at least four years of experience in studying architecture, a professional architect with 35 and an interior designer with 23 years of working experience. Eight of the students of architecture worked in a side job or had gained experience in

internships in the field of architecture. In addition, one of these students had a degree in history of art and another one had completed a non-academic apprenticeship in interior design. Two students did not report additional experience in the field of architecture. All participants were right handed ($M = 91.17$, $SD = 8.55$), as measured with a standard questionnaire (Oldfield, 1971), and had normal or corrected-to-normal vision and colour vision. As in Experiment 1, all participants signed an informed consent, and none of them reported a history of neurological, cardiac or psychiatric disease, a family history of epilepsy, a current medical disease, metal parts in the body (except dental fillings), usage of psychoactive or analgesic medication prior to the experiment, or current pregnancy.

Materials and procedure. The stimuli sets and the procedure with regard to tDCS and the computer tasks were similar to the ones used in Experiment 1. The average separation between the two experimental sessions in Experiment 2 was 3.2 days (range: 2-5 days).

Results

Behavioural outcomes. The effects of spatial features on mean liking scores and mean RT of experts were analysed, similarly to Experiment 1, by only looking at the responses to the pre-tDCS rating task of the first experimental session.

Liking ratings. Figure 8 shows the mean liking scores of experts for each level of the spatial factors.

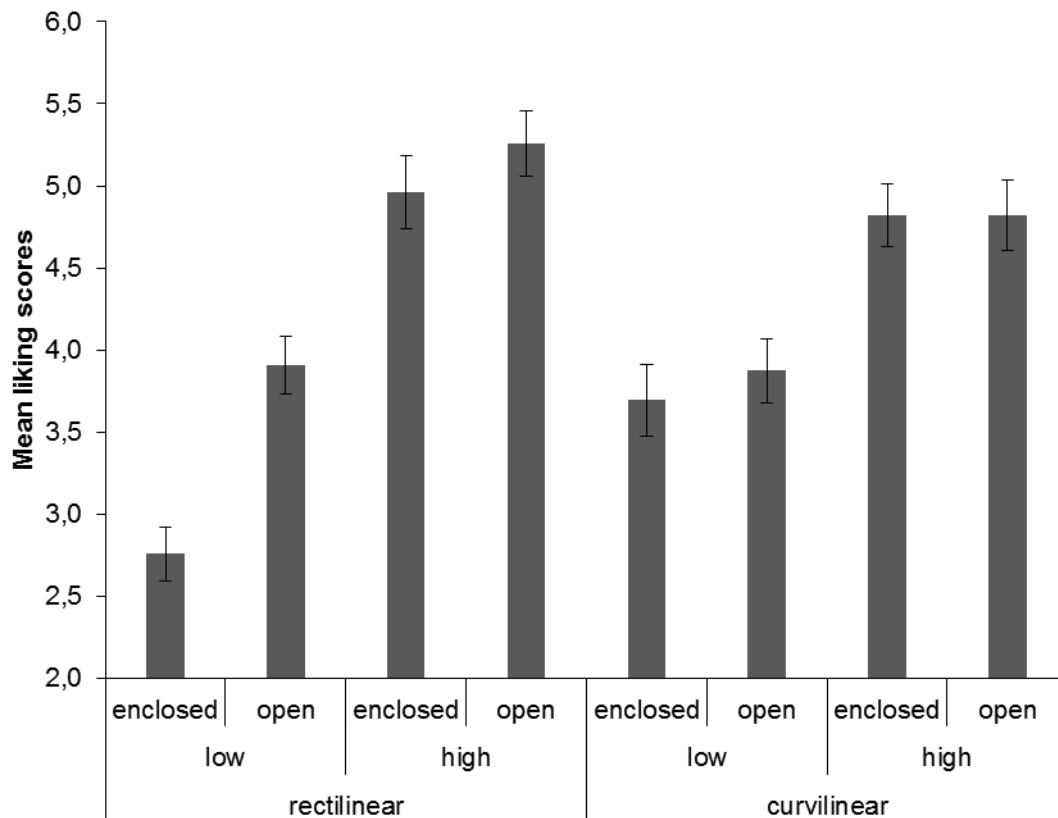


Figure 8. Mean liking scores of experts for each level of contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open). Error bars represent ± 1 SEM.

For experts, a repeated measures ANOVA with contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open) as within-subjects factors, and liking ratings as the dependent variable showed a significant main effect of ceiling height, $F(1, 11) = 58.34, p < .001, \eta_p^2 = .84$, and a significant main effect of enclosure, $F(1, 11) = 5.30, p = .042, \eta_p^2 = .33$. Crucially, the two-way interaction contour by ceiling height, $F(1, 11) = 23.44, p = .001, \eta_p^2 = .68$, the two-way interaction contour by enclosure, $F(1, 11) = 10.78, p = .007, \eta_p^2 = .50$, and the two-way interaction ceiling height by enclosure, $F(1, 11) = 5.63, p = .037, \eta_p^2 = .34$, were all significant, indicating that the effect of at least one of the spatial factors in each two-way interaction differed depending on the level of the

other factor. Neither the main effect of contour, nor the three-way interaction contour by ceiling height by enclosure were significant (all $ps > .151$).

Each two-way interaction was further analysed by carrying out additional follow-up dependent t-tests to examine the effect of each factor separately for each level of the other factor (i.e. 4 pairwise comparisons were performed for each interaction). The type I error rate was controlled for each interaction by using a Bonferroni correction. Thus, effects are reported at an adjusted significance level of .0125. As in Experiment 1, corrected Cohen's d effect sizes for paired samples were calculated as described in Dunlop, Cortina, Vaslow, and Burke (1996). For the two-way interaction contour by height, analyses indicated that curvilinear contours were only significantly liked more ($M = 3.78$; $SD = .58$) than rectilinear ones ($M = 3.33$; $SD = .40$) when ceilings were low, $t(11) = -3.54$, $p = .005$, $d = -0.86$, but not when ceilings were high ($p = .059$). In contrast, high ceilings were significantly liked more ($M = 5.11$; $SD = .61$) than low ceilings ($M = 3.33$; $SD = .40$) when contours were rectilinear, $t(11) = -8.06$, $p < .001$, $d = -3.46$. Similarly, high ceilings were also liked more ($M = 4.82$; $SD = .51$) in comparison to low ceilings ($M = 3.78$; $SD = .58$) when contours were curvilinear, $t(11) = -5.89$, $p < .001$, $d = -1.90$. For the interaction contour by enclosure, it was only found that open rooms were significantly liked more ($M = 4.58$; $SD = .47$) than enclosed rooms ($M = 3.86$; $SD = .49$) when contours were rectilinear, $t(11) = -3.73$, $p = .003$, $d = -1.50$, but none of the other three pairwise comparisons reached statistical significance (all $ps > .042$). Regarding the two-way interaction height by enclosure, analyses showed that open spaces were significantly liked more ($M = 3.89$; $SD = .59$) than enclosed ones ($M = 3.23$; $SD = .56$) when ceilings were low, $t(11) = -3.13$, $p = .010$, $d = -1.16$, but not when ceilings were high ($p = .477$). On the other hand, high ceilings were found to be significantly liked more ($M = 4.89$; $SD = .59$) than low ceilings ($M = 3.23$; $SD = .56$) when spaces were enclosed, $t(11) = -7.91$, $p < .001$, $d = -2.89$. Similarly, high ceilings were also significantly

liked more ($M = 5.04$; $SD = .64$) in comparison to low ceilings ($M = 3.89$; $SD = .59$) when rooms were open, $t(11) = -5.27$, $p < .001$, $d = -1.85$.

Mean response latencies. Mean response latencies of experts in each experimental condition of the rating task prior to tDCS of the first session are reported in Figure 9.

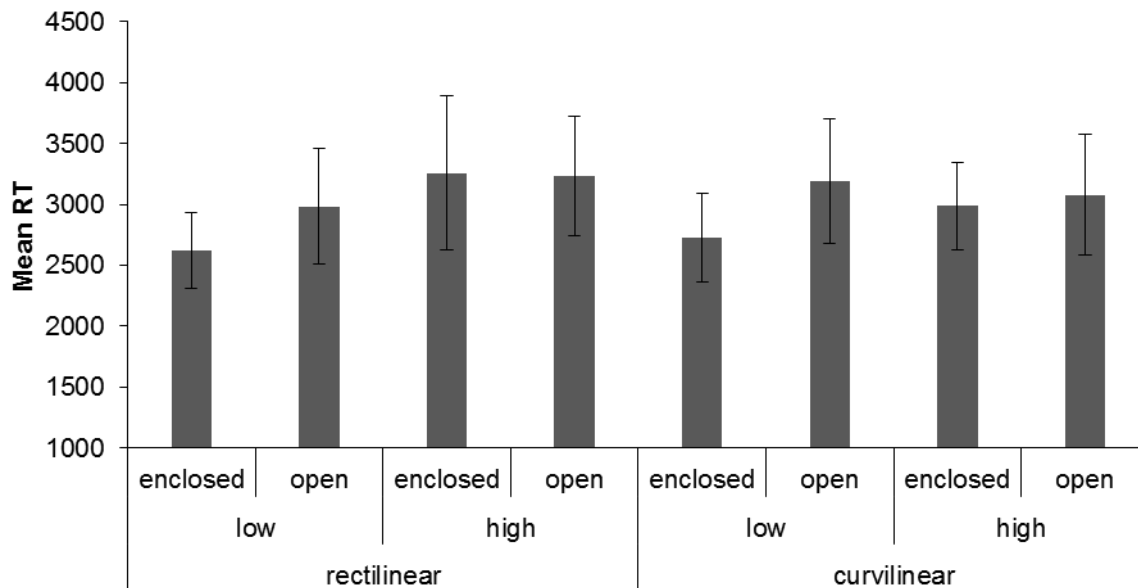


Figure 9. Experts' mean RTs in ms for each level of contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open). Error bars represent ± 1 SEM.

As in Experiment 1, a repeated measures ANOVA with contour (rectilinear vs. curvilinear), ceiling height (low vs. high), and enclosure (enclosed vs. open) as within-subjects factors, and RT as the dependent variable, revealed a significant main effect of enclosure, $F(1, 11) = 5.75$, $p = .035$, $\eta_p^2 = .34$, indicating that the response latencies of experts were also higher for open rooms ($M = 3121.03$; $SD = 1689.72$) in comparison to enclosed rooms ($M = 2898.91$; $SD = 1401.97$). In addition, the interaction height by enclosure was marginally significant, $F(1, 11) = 4.67$, $p = .054$, $\eta_p^2 = .30$. None of the other main effects or interactions reached statistical significance (all $ps > .072$).

Effects of tDCS stimulation. As in Experiment 1, all participants reported slight itching or transient tingling sensations associated with tDCS, but none reported differences between sham and real tDCS spontaneously.

Liking ratings. The effect of tDCS on liking judgements was again analysed with a repeated measures ANOVA with tDCS time (pre-tDCS vs. post-tDCS) and tDCS type (real tDCS vs. sham tDCS) as within-subjects factors, and liking ratings as the dependent variable. The mean liking scores of experts in the different experimental conditions are reported in Figure 10.

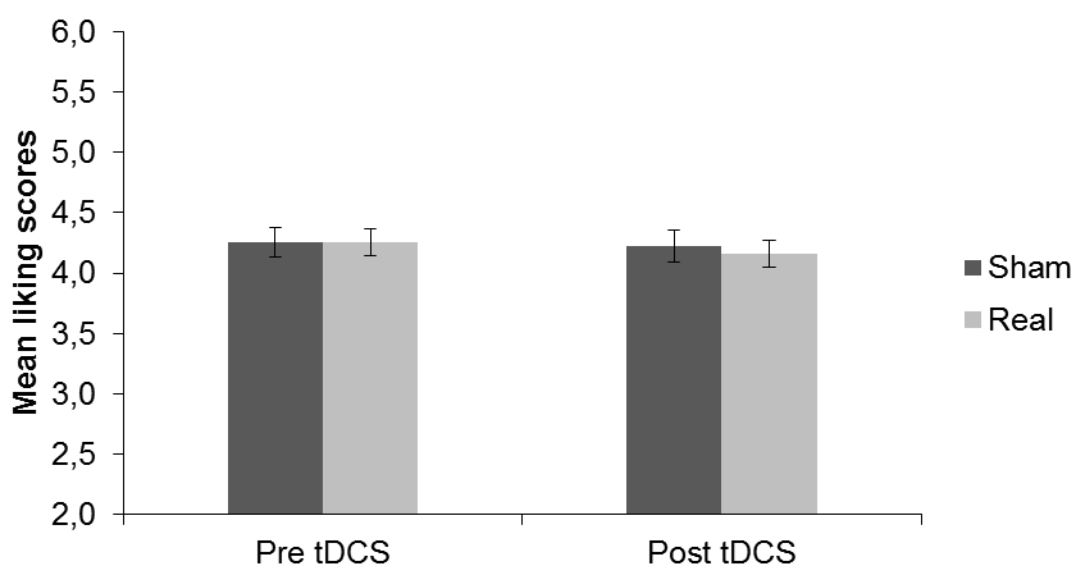


Figure 10. Mean liking scores of experts in the rating tasks previous and after sham vs. real tDCS. Error bars represent ± 1 SEM.

Similar to the findings for non-experts in Experiment 1, the ANOVA revealed neither a significant main effect of tDCS time ($p = .341$), nor a significant main effect of tDCS type ($p = .761$). Moreover, the interaction tDCS time by tDCS type was either not significant ($p = .540$). Thus, the baseline liking ratings prior to tDCS were, again, comparable between both tDCS conditions, but neither significant differences were found between rating scores

prior to and following sham vs. real tDCS, nor between sham vs. real post-tDCS rating scores.

Mean response latencies. The mean RTs of experts in each experimental condition are reported in Figure 11.

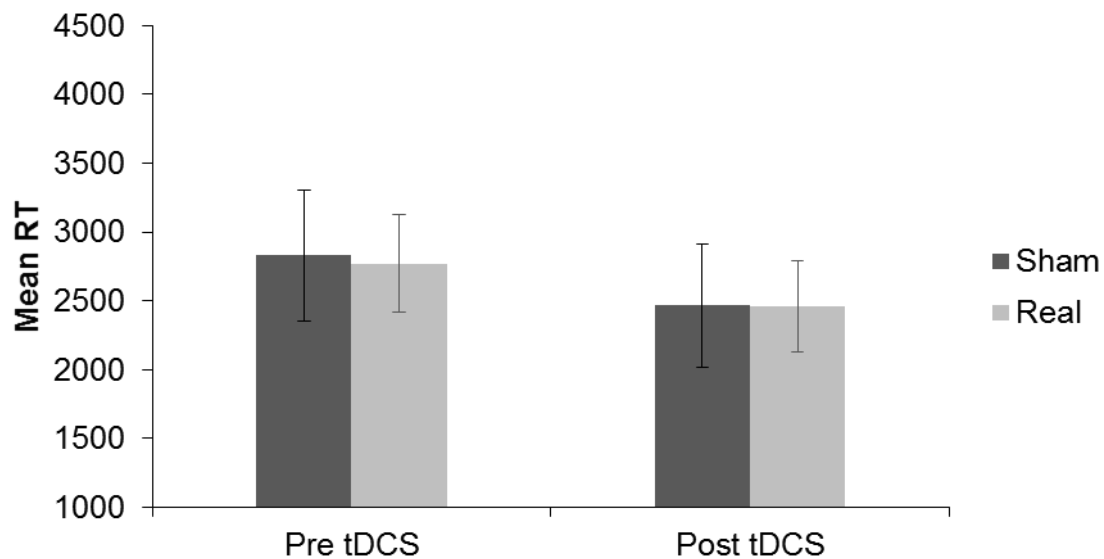


Figure 11. Mean response latencies of experts in *ms* in the rating tasks prior to and following sham vs. real tDCS. Error bars represent ± 1 SEM.

As in Experiment 1, a repeated measures ANOVA with tDCS time (pre tDCS vs. post tDCS) and tDCS type (real tDCS vs. sham tDCS) as within-subjects factors, and RT as the dependent variable, revealed a significant main effect of tDCS time, $F(1, 11) = 17.46$, $p = .002$, $\eta_p^2 = .61$, indicating slower response latencies ($M = 2799.19$; $SD = 1389.26$) in the pre-tDCS rating tasks in comparison to the post-tDCS rating tasks ($M = 2460.48$; $SD = 1264.32$). The main effect of tDCS type and the interaction tDCS time by tDCS type were not significant (all $ps > .847$).

Discussion

The first experimental aim of the present thesis was to examine the effects of the contour, ceiling height and perceived enclosure of architectural stimuli on liking judgements of non-expert participants (i.e. Experiment 1). Regarding the effect of contour, it was hypothesised that curvilinear contours of interiors spaces are more liked by naïve participants than rooms with rectilinear contours. Consistent with previous evidence (e.g. Leder & Carbon, 2005; Silvia & Barona, 2009; Leder, Tinio, & Bar, 2011), curvilinear spaces elicited higher liking ratings in naïve participants than rectilinear ones, but this effect of contour was limited to enclosed spaces with low ceilings. In contrast to a general main effect of contour found by Vartanian et al. (2013), the present results therefore suggest that the impact of contour on aesthetic judgements of naïve participants rather depends on specific levels of other spatial features such as the ceiling height and perceived enclosure of a space. However, this demonstrated complex interplay between the effects of spatial features does not indicate a limitation of previous evidence (Vartanian et al., 2013), the differences between these results are rather caused by the methodical difference that all three spatial factors were examined in the present analysis as independent variables instead of controlling the effects of ceiling height and perceived enclosure.

Moreover, this interdependence of the impacts of spatial features on aesthetic judgements of non-experts was also found for the effect of ceiling height. In particular, the direction of an effect of ceiling height on liking ratings was found to confirm previous evidence that has demonstrated an aesthetic preference for higher ceilings in comparison to lower ones (Baird et al., 1978; Vartanian et al., 2015). Nonetheless, this effect was likewise restricted to one specific type of architectural space (i.e. enclosed rooms with rectilinear contours), revealing that also the effect of ceiling height depended on the levels of the other two spatial factors. As mentioned in a similar way with regard to the effect of contour, the

contrast between these results and a main effect of ceiling height previously found by Vartanian et al. (2015) might be caused by the aforementioned methodical difference between these studies.

In contrast, the effect of perceived enclosure was found to be more independent from the contour and ceiling height of a space. Specifically, open spaces were more liked by non-expert participants than enclosed ones when contours were rectilinear and ceiling height was low, but also when contours were curvilinear and rooms had high ceilings. In addition, a marginally significant effect of perceived enclosure in the same direction was found for rooms with rectilinear contours and high ceilings. Although the effect of perceived enclosure was also limited to specific combinations of the contour and ceiling height of a space, the direction of this effect was, as expected, found to be consistent with previous evidence (Vartanian et al., 2015). Moreover, these findings indicate that perceived enclosure affects liking judgements about architecture in non-experts in a more general way in comparison to the contour and ceiling height of a space.

Overall, the present results of Experiment 1 suggest that indeed all three spatial factors affect aesthetic judgements about architecture in naïve participants. However, in contrast to previous findings (Vartanian et al., 2013, 2015), each effect was only found to be significant for specific spatial arrangements with regard to the levels of the other two factors. Thus, these results did not only confirm the direction of each effect in accordance with previous evidence (Vartanian et al., 2013, 2015), but also extend them by demonstrating that it is rather the specific spatial composition of an interior space, which might be crucial for the aesthetic appraisal of architectural design in lay people.

Furthermore, it is worth noting that the importance of each spatial feature for aesthetic judgements of lay people might be hierarchically arranged. This assumption is based on the different numbers of significant pairwise comparisons found in Experiment 1 in order to test

the effect of each factor separately for each combination of the levels of the other two factors: While ceiling height and contour were found to have an effect on liking judgements only in one specific type of interior space with regard to the two other spatial features, a more general effect was found for perceived enclosure. Interestingly, this suggested higher importance of perceived enclosure might be additionally reflected by the longer response latencies found in naïve participants to judge open in comparison to enclosed spaces. These findings might be bolstered by the aforementioned theory of Stamps (2005, 2010) according to which a greater amount of perceived permeability of a space is aesthetically preferred because of its advantage for survival due to an ability to identify potential risks. Therefore, the longer response latencies for open than for perceived enclosed spaces might be caused by the higher visual permeability of open spaces, which allows a more extensive visual exploration of these spaces. This perceptual exploration of open spaces, in turn, might have caused the higher liking ratings for these kind of spaces in contrast to enclosed ones. However, the present results indicate that, in terms of constructed architectural spaces, this might only be the case for specific spatial arrangements with regard to the contour and ceiling height of a room. Future studies may address this issue by using eye-tracking techniques that allow to investigate how architectural stimuli are visually explored in relation to other variables such as time and aesthetic judgements.

In addition, the impact of contour, ceiling height, and perceived enclosure were examined on liking ratings of experts in architecture (i.e. Experiment 2) in order to fulfil the need for research on expertise in studies on aesthetic experiences. As hypothesised, the results of Experiment 2 demonstrated that, indeed, each spatial factor influenced liking ratings of expert participants, but, similar to Experiment 1, a more complex interaction between the effects of contour, ceiling height, and perceived enclosure was found. Specifically, all two-way interactions with regard to the effects of these spatial factors were

significant, indicating that the effect of at least one spatial factor in each interaction depended on the levels of the other spatial factor. In view of these results, the effect of contour was only found to be significant when ceilings were low. Even though no prediction was made with regard to the direction of this effect, the higher liking ratings for curvilinear spaces in comparison to rectilinear ones are consistent with previous evidence investigating the effect of contour on naïve participants' aesthetic judgements (e.g. Leder & Carbon, 2005; Silvia & Barona, 2009; Leder, Tinio, & Bar, 2011; Vartanian et al., 2013). Thus, the present results suggest that also experts in architecture prefer curvilinear spaces in contrast to rectilinear spaces, but this effect may be limited to spaces with low ceiling.

In terms of the effect of perceived enclosure, open spaces were found to elicit higher liking ratings in expert participants than perceived enclosed ones, but this effect was only found when contours were rectilinear or rooms had low ceilings. Although the effect of perceived enclosure was also restricted to specific types of spaces with regard to the ceiling height and contour of a space, it was confirmed that perceived enclosure is able to predict liking ratings about architectural interiors in expert participants. Moreover, the direction of this limited effect was also found to be consistent with previous evidence of Vartanian et al. (2015), who investigated the impact of perceived enclosure on aesthetic judgements of non-expert participants.

In contrast, the effect of ceiling height on liking judgements of experts in architecture was found to be independent from the levels of the other two spatial factors: High ceilings were more liked than low ceilings regardless of whether spaces were curvilinear, rectilinear, or perceived as open or enclosed. Thus, in comparison to the effects of contour and perceived enclosure, ceiling height was found to be the most robust and important source for experts in architecture to form aesthetic judgements about interior spaces. These findings are in accordance with the argumentation of Vartanian et al. (2015) that ceiling height is an

important factor for aesthetic judgements about architectural design because of its essential historical role in the field of architecture (e.g. Palladio, 1570/1965). It is therefore probably not surprising that this spatial factor was found to predict liking judgements of participants with a high level of architecture-related expert knowledge. However, this effect of ceiling height was demonstrated for the first time under experimental conditions.

Furthermore, the results of Experiment 2 suggest that, similar to non-experts, the importance of each spatial feature for aesthetic judgements of expert participants seems to be hierarchically arranged: While the effect of contour was only found to be significant for one specific type of architectural space, perceived enclosure affected liking judgements of experts in a more general way, and an effect of ceiling height was found for all levels of the other two variables. Therefore, the present results additionally indicate that not only ceiling height serves as the most important basis for aesthetic judgements about architectural design in experts in architecture, but also that perceived enclosure and especially the contour of an interior space might be less important for them.

However, it was found that also expert participants took longer to judge open spaces in comparison to enclosed ones. As likewise discussed for a similar effect found in non-expert participants (see above), these longer response latencies might be caused by a more extensive perceptual exploration of open rooms in contrast to enclosed ones. The possibility to visually explore open spaces in a higher extent than enclosed spaces has been suggested to elicit higher aesthetic judgements for these kind of spaces (Stamps, 2005, 2010). The fact that open rooms were more liked than enclosed ones under specific spatial conditions indicate that the aesthetic judgements of experts might be elicited in a similar way, but only when contours are rectilinear or rooms have low ceilings. Nonetheless, the present results suggest that the ceiling height of a space serves as a more important basis for experts in architecture to form aesthetic judgements about interior spaces.

In terms of the neurobiological underpinnings of aesthetic appreciation, the present thesis was addressed to examine whether the left DLPFC also plays a role in processes involved in the aesthetic appraisal of architectural interiors. For naïve participants, it was hypothesised that real anodal tDCS over the left DLPFC result in an enhanced neural excitability in this area, which, in turn, elicit higher liking ratings in comparison to a sham tDCS condition. The results of Experiment 1, however, did not confirm this expected effect of tDCS. Specifically, no differences were found between the post-tDCS liking scores and their correspondent pre-tDCS liking scores in each tDCS condition (real vs. sham tDCS), nor between post-tDCS rating scores following real and post-tDCS rating scores following sham brain stimulation. These results indicate that architectural interiors might not be within the scope of the left DLPFC, although previous findings have demonstrated a significant tDCS effect on aesthetic judgements about representational artworks and stimuli very similar to images of architectural interior spaces, that is to say, photographs of urban scenes and landscapes (Cattaneo et al., 2014a). Moreover, the present results contrast previous findings that the left DLPFC might play a role in aesthetic experiences independently of the specific types of stimuli which are used (Cattaneo et al., 2014b). However, new insights, provided by a recently published review of tDCS studies of Tremblay et al. (2014), indicate that the effect of tDCS on the DLPFC is able to vary in dependence of a wide range of factors such as the experimental task, stimulation parameters and stimulation polarity, intra-individual variations (e.g. the state of the stimulated neural network), and variations between subjects (e.g. shape, size, and fat tissue amount of participants' heads). This variability of confounding variables is suggested to result in a widespread modification of neural activity by tDCS over the DLPFC, which, in turn, is able to affect a variety of different cognitive functions simultaneously (Tremblay et al., 2014). Thus, studies testing causal relationships between a cognitive function and a cortical area by means of similar tDCS protocols are likely to lead to opposite

results (Tremblay et al., 2014). As a consequence, it is therefore arguable that the inconsistency found between the present findings and previous evidence (Cattaneo et al., 2014a, 2014b) might be rather caused by a variability in the effects of tDCS over the left DLPFC, even though a similar experimental design was used as in the study of Cattaneo et al. (2014a). In addition, the results that naïve participants, as well as expert participants in Experiment 2, were faster to judge the stimuli in the post-tDCS rating tasks in comparison to the pre-tDCS rating tasks in both tDCS conditions (real vs. sham tDCS) might only reflect an effect of task familiarisation due to the repeated measures design.

Moreover, the aforementioned limitations of an effect of tDCS might also apply to the present findings of Experiment 2. Although the liking judgements of expert participants about architectural design were not found to be affected by tDCS in accordance to the hypothesis, the absence of a tDCS effect in Experiment 1, coupled with the aforementioned limitations, indicate that the results of Experiment 2 are rather caused by an unintentional or missing effect of brain stimulation. It remains therefore unclear whether experts in architecture make use of their domain-related knowledge and experience in order to insulate against effects of tDCS. As pointed out by Tremblay et al. (2014), deeper neurobiological insights into tDCS effects and refined tDCS protocols, which take the aforementioned restrictions into account, are needed at this time to use tDCS in a more precise way and to interpret contradictory effects between tDCS studies. However, the usage of TMS might be considered as an alternative option in future studies due to the high spatial and temporal precision of this method (Robertson, Théoret, & Pascual-Leone, 2003). Because a causal relationship between aesthetic experiences and the left DLPFC was already demonstrated in a previous TMS study of Cattaneo et al. (2014b), this method of brain stimulation appears additionally promising in order to overcome the limitations of tDCS and to gain further knowledge of the neural underpinnings of the aesthetic appreciation of architecture.

Conclusion

In sum, the present thesis provided further evidence for an effect of spatial features in architectural design on human behaviour. Previous findings were extended by demonstrating that it is the specific spatial composition of an interior space, which might be crucial for the way how lay people as well as experts in architecture appreciate their built environments aesthetically. Moreover, the impact of each spatial feature was additionally found to vary in the extent of being more or less important for each group of participants in order to serve as a basis to form aesthetic judgements about architectural design. These results contribute to research on how systematic variations of architectural features of built environments affect human behaviour. However, further experimentation is needed to gain deeper insights into the principles of the aesthetic appreciation of architecture, especially with regard to the neural foundation of these processes. Furthermore, the examination of an impact of other physical features (colour, light etc.) on the aesthetic appreciation of our built environments might be a fertile ground for future research (Vartanian et al., 2015). As mentioned at the beginning of this work, this knowledge not only has the potential to understand an inherent and unique trait of our species (Nadal & Skov, 2013), it also can be utilised in order to plan and design our closest environments in compliance with our needs as the users of these spaces (Nasar, 2008; Vartanian et al., 2013).

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Abstract

It is a unique trait of humans to appreciate their surroundings aesthetically. This human phenomenon is not only concerned with artworks or natural scenes, it reaches to our closest surroundings where we live and work: our built environments. Although people in Western cultures spend most of their time indoors, little research exists on how specific variations of architectural features affect human behaviour. In terms of the neural underpinnings of aesthetic appreciation, previous findings remain to be tested for the realm of architecture. In order to pursue these research issues, I examined the effect of contour, ceiling height, and perceived enclosure of interior spaces on liking judgements of lay people as well as experts in architecture. To follow up previous evidence for a critical role of the left dorsolateral prefrontal cortex (left DLPFC) in aesthetic judgements, transcranial direct current stimulation (tDCS) was additionally applied to test this relationship for architectural stimuli. Within both groups of participants, an interaction of the effects of spatial features on liking judgements was found. These findings not only suggest that specific spatial compositions are critical for aesthetic judgements about interior spaces, but also that each spatial factor influences likings judgements of experts and non-experts in a different extent. However, no effect of brain stimulation was found on aesthetic judgements of both groups of participants. With regard to recent findings of varying tDCS effects on the DLPFC, the present results suggest that the cortical excitability of this targeted brain area was not affected in the intended way.

Zusammenfassung

Es ist eine einzigartige Eigenschaft von Menschen, die Ästhetik ihrer Umgebung wertzuschätzen. Dieses Phänomen betrifft nicht nur Kunstwerke oder Naturschauspiele, es erstreckt sich bis hin zu unserer nächstgelegenen Umgebung in welcher wir leben und arbeiten: die gebaute Umwelt. Auch wenn Personen westlicher Kulturen ihre meiste Zeit in Innenräumen verbringen, existiert nur wenig Forschung darüber, wie spezifische Variationen architektonischer Merkmale menschliches Verhalten beeinflussen. Darüber hinaus müssen bisherige Forschungsbefunde zur neuronalen Untermauerung ästhetischer Wertschätzung für den Bereich der Architektur noch überprüft werden. Um diesen Forschungsfragen nachzugehen, wurde der Effekt der Kontur, der Raumhöhe und der wahrgenommenen Geschlossenheit von Innenräumen auf Gefallensbewertungen von Laien und Experten der Architektur untersucht. Bisherige Forschungsergebnisse, welche dem linken dorsolateralen präfrontalen Cortex (linker DLPFC) eine wichtige Rolle für ästhetische Bewertungen zuschreiben, wurden zudem aufgegriffen, um diesen Zusammenhang mit Hilfe transkranieller Gleichstromstimulation (tDCS) für architektonische Stimuli zu testen. Innerhalb beider Versuchsgruppen wurden Wechselwirkungen zwischen den Effekten von Raummerkmalen auf Gefallensbewertungen gefunden. Diese Ergebnisse legen nicht nur nahe, dass spezifische Raumkompositionen für ästhetische Bewertungen ausschlaggebend sind, sondern auch, dass sich der Einfluss jedes einzelnen Raummerkmals auf Gefallensbewertungen von Experten und Laien in ihrem Ausmaß unterscheidet. Allerdings wurde kein Effekt der Gleichstromstimulation auf die ästhetischen Bewertungen beider Versuchsgruppen gefunden. In Hinblick auf neuere Erkenntnisse zu variierenden tDCS-Effekten auf den DLPFC, deuten diese Ergebnisse darauf hin, dass die kortikale Exzitabilität dieses Gehirnbereichs nicht in der intendierten Art und Weise beeinflusst wurde.

Curriculum Vitae

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Education

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Work experience / Internships

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