Emotions and the Environment: The Variable Effect of Environmental Complexity on Pleasure and Interest

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

This dissertation establishes a more comprehensive examination of the often discussed environmental complexity effect on emotional response by addressing four specific considerations. First, positive emotional response was considered as composed of many distinct emotions, thus interest was gauged alongside the commonly explored emotion of pleasure. Second, a systematic approach to quantifying environmental complexity was developed where the environment possessed complexity through either the diversity or numerosity of its geometric and featural elements. Third, a cognitive component was introduced to the formation of emotional response, where the bottom-up effect of environmental properties is mediated by subjective, perceived complexity. Fourth, by arguing that emotions are functional, the degree of agreement between subjective emotional responses and navigation behaviour was examined. In Experiments 1.1 and 1.2, complexity was generated by manipulating the numerosity of featural and geometric elements of virtual environments. In Experiments 2.1 and 2.2 complexity was generated by manipulating diversity of featural elements and quantified using information entropy, while Experiment 3.0 employed a similar approach but with real-world environments. Participants rated complexity, interest and pleasure in every experiment, while Experiments 2.1 and 2.2 introduced a virtual reality navigation task and Experiment 3.0 measured behavioural intention using approach-avoidance ratings. Results demonstrated that environmental complexity had a dissociable effect on pleasure and interest; where the effect was positive on interest it was negative on pleasure. Regardless of whether it affected pleasure or interest, the direct effect of environmental complexity on emotion was either partially or fully mediated by perceived complexity. Environmental complexity itself was successfully manipulated using diversity and numerosity of both featural and geometric elements of the environment. Finally, there was a consistent relationship between feelings of displeasure and avoidance behaviour. These novel perspectives suggest that environmental complexity has a variable effect on emotional response, where the exact relationship is dependent both on the emotion probed and factors beyond complexity such as the processing dynamics of environmental features. By arguing for a more nuanced and exhaustive examination of emotional response, this dissertation repositions the research to better assist in the design of more effective, people-centred, built environments.

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Chapter 1 - Introduction: Visual Complexity and Experience of the Environment

The rapid increase of individuals choosing to live in urban centres—predicted to exceed 9.4 billion people by the year 2050 (UN World Population Prospects, 2015)—has the potential to precipitate a serious global issue considering that the urban experience is often negative. Anxiety, depression, stress and overall dissatisfaction are commonly associated with city living (Hood, 2010; Peen, Schoevers, Beekman & Dekker, 2010; Lederbogen et al., 2011). Yet, this does not necessarily have to be the case; it may be possible to design environments that engage, stimulate and result in positive emotions and behaviours. For this to be accomplished it is necessary for us to better understand how the built environment shapes us; thus this dissertation will present five experiments exploring the effects of visual features of the environment on emotion and behaviour. Specifically, by considering the importance of human intrinsic motivation for information gain, the effect of environmental visual complexity on experience will be examined.

Our intrinsic motivation to seek information and learn about our surroundings drives a great deal of our responses towards the environment (Biederman & Vessel, 2006; Kaplan, 1987; Kaplan, Kaplan & Brown, 1989). In this sense, environments that provide rich sources of information, thus meeting our need for information, are preferred to those that are impoverished in information content. From an evolutionary perspective, informative environments are beneficial for an organism's survival, providing possible shelter, sustenance and even warning of danger. Thus, environment preference is adaptive; we experience information complexity positively as it signals increased chance of survival (Kaplan, 1987; Appleyard, 1968). Most frequently, information content is quantified using measures of visual complexity; more visually complex environments carry more information than visually simple environments (Berlyne, 1977; Stamps, 2002; 2003). Generally, complexity of both abstract stimuli (Berlyne, 1970; Day, 1966; 1967), as well as scenes of built environments (Wohlwill, 1968; 1975; Stamps, 2003, 2006; Imamoglu, 2000) exert a significant effect on emotional response.

Although the importance of visual complexity in determining emotional response is undisputed, this dissertation will highlight several important limitations within the literature, and by doing so, introduce a more nuanced conceptualization of emotional response resulting from complexity. First, by arguing that positive emotions are composed of more than pleasure alone, this dissertation will examine the variable effect of environmental complexity on interest alongside pleasure. In this way, experience of the environment is positioned as composed of many distinct, yet equally important emotional responses. Second, this dissertation will examine systematically the manner by which the environment may possess and communicate complexity. Third, this dissertation will examine if the effect of objective complexity present within the environment on emotional response is mediated by perceived or appraised complexity. By considering such subjective experiences of complexity, we will align environmental preference literature with current perspectives within emotion research. Fourth, by arguing that emotions are inherently functional we will explore the relationship between subjective emotional response and behaviour within the environment.

1.1. From Stimulus Properties to Emotional Response

Experimental psychologists have long been interested in the relationship between stimulus features and emotional responses. Fechner, one of the fathers of experimental psychology, is often remembered for developing psychophysics, yet he also took research on aesthetics—for so long the domain of philosophers—and grounded it with empirical evidence (Hetrick, 2011; Fechner, 1876). Whereas Fechner examined how stimulus properties shaped aesthetic experience, Gestalt psychologists considered how perceptual organization of visual stimuli shaped aesthetic response (Wertheimer, 1923). Aesthetics under Gestalt psychology was most directly addressed by Arnheim in his *Art and Visual Perception* (1956) and *Film as Art* (1957), where he contrasted the physical medium with internal mental processes, arguing for the importance of the unified whole within aesthetic experience. Recently, Gestalt grouping principles such as proximity, symmetry and closure have been suggested as resulting in fluent perceptual processing which may drive pleasure responses (Moshagen & Thielsch, 2010). Gestalt perspectives altered research on aesthetic experience by highlighting the importance of considering mental processes and the holistic nature of aesthetic experience.

Following such forays into aesthetic experience by Gestalt psychology, Berlyne advanced the field in the 1960's and 70's through the development of his *New Experimental Aesthetics*. Drawn from his earlier work on interest, curiosity and exploratory behaviour, Berlyne positioned experience as resulting either from an individual's need to minimize uncertainty regarding their surroundings or to seek properties which are experienced as intrinsically pleasing (Berlyne, 1970, 1971, 1960; 1954; Cupchik, 1986). Thus, exploratory behaviour is linked to emotional response, where individuals will choose to explore pleasing or interesting stimuli.

Several key points define Berlyne's *New Experimental Aesthetics*. First, positive emotional response results from maintaining intermediate levels of arousal, anything above or below this optimal level is experienced more negatively (Berlyne, 1971). Second, stimuli possess arousal potential as a result of their visual properties—these collative variables are described by uncertainty, novelty or complexity and shape hedonic response by modulating arousal (Berlyne, 1960). Since collative variables shape arousal and moderate levels of arousal are preferred, the relationship between the two is inverted-u in shape, so that positive response results from collative variables which are moderate in uncertainty, novelty or complexity (Berlyne, Ogilvie & Parham, 1968; Berlyne, Craw, Salapatek & Lewis, 1963; Berlyne, 1970). Highly uncertain, novel or complex stimuli are experienced as overly arousing and thus chaotic and unpleasant; on the other hand, redundant, familiar or simple stimuli lead to low levels of arousal and are once again experienced as unpleasant but now boring instead of chaotic (Berlyne, 1971; 1974a). Crucially, such hedonic responses are dynamic and preference for specific collative variables is dependent on one's current arousal level and position on the inverted-u curve. For example, if current arousal level is low, uncertain, novel or complex stimuli will be experienced as pleasant as they increase arousal towards optimal levels. On the other hand, if current arousal level is high, pleasure may result from simple stimuli, as they will result in reduction of arousal back towards moderate, optimal levels. In this way, Berlyne's *New Experimental Aesthetics* is an extension of Hullian drive theory, where responses are dependent on maintenance of an optimal physiological state (Silvia, 2005; Cupchik, 1986).

Berlyne and his contemporaries also argued that collative variables effected two distinct response dimensions. The first, an uncertainty dimension, was a result of degree of stimulus information and resulted in feelings of interest and arousal. The other, a hedonic tone dimension, was coded by feelings of pleasure and enjoyment (Normore, 1974; Berlyne, 1974b). Interestingly, collative variables affect these two responses differently. The uncertainty factor, as described by responses of interest, appears to increase monotonically with increases in collative variables (Hare, 1974a; Normore, 1974; Day, 1968) sometimes being asymptotic (Day, 1967). The effect of collative variables on the hedonic tone factor is much less clear, typically appearing to be non-monotonic, and exhibiting either an inverted u-shape (Hare 1974a; Saklofske, 1975; Normore, 1974) or multiple peaks (Day, 1967), while negative or non-significant effects have also been noted (Day, 1968; Eisenman, 1966). The uncertainty factor thus appears to be arousal inducing, increasing positively with collative variables, while the hedonic tone factor appears to seek optimal arousal (Day, 1967; Berlyne, 1974b).

Berlyne argued that stimulus properties affected emotional response through physiological arousal, thus disregarding cognitive processes involved in the formation of emotional response. In contrast, the research of Stephen Kaplan incorporated a cognitive components specifically to environmental preference, by framing preference with respect to how an individual understands and conceptualizes information within the environment (Kaplan, 1979; 1987; Kaplan & Kaplan, 2009). Similar to Berlyne, information content—as a result of visual complexity—is a determinant of preference but, unlike Berlyne, Kaplan (1987) does not argue for an arousal mechanism, instead suggesting that complexity is experienced positively since it allows for the updating and development of a more complete cognitive map of the environment. Thus, objective stimulus properties alone are not enough to describe patterns of experience; instead the cognitive processes that extract meaningful information from complexity are vital (Kaplan, 1987; 1982).

Whether an arousal or cognitive information based perspective is taken, either an inverted-u or positive linear relationship between complexity and emotional response is typical. A variety of methods have been used to generate complexity of both synthetic visual stimuli as well as environments; a summary of this literature will not only highlight that the nature of the relationship is dependent on various environmental properties, but will also pinpoint several important limitations regarding how emotions were conceptualized and measured. Such considerations will allow us to develop a more appropriate examination of the effect environmental complexity plays on emotional response.

1.2. The Effect of Visual Complexity on Preference and Emotional Response

Emotional response is often conceptualized as composed of two dimensions: a pleasure and an arousal dimension (Mehrabian & Russell, 1974a; Russell, 2003; Bakker, Voordt, Vink & Boon, 2014). The pleasure dimension is described by subjective feelings of pleasure, enjoyment and joy while the arousal dimension results in subjective feelings of interest, excitement and curiosity. Pleasure and arousal are both attributed to an object or situation resulting in a number of emotion markers such as physiological response, behaviour and subjective feelings (Russell, 2003). This distinction between pleasure and arousal allows us to summarize the previous research on the effect of environmental complexity on emotional response, while highlighting that the literature has been focused primarily on pleasure based emotions.

1.2.1. The variable effects of synthetic visual stimulus complexity on emotional response.

When considering pleasure response resulting from complexity of synthetic visual stimuli, such as polygons and line stimuli, the effect is highly variable, with positive linear effects (Hare, 1974a; Normore, 1974; Eisenman, 1967) as well as an inverted-u shape functions both exhibited (Berlyne, 1974c; 1974d; Saklofske, 1975; Vitz, 1966). In fact, non-significant effects of polygon complexity on pleasure have been reported (Eisenman, 1966). Results regarding responses on the arousal dimension have been more consistent with positive linear effects observed for a wide variety of visual arrays, polygons and line stimuli (Hare, 1974a; 1974b; Day, 1974; Eisenman, 1966; 1967). Although synthetic stimulus complexity is often discussed as shaping both pleasure and arousal, when it comes to environmental complexity, a summary of the literature will demonstrate several important limitations.

1.2.2. The variable effect of environmental complexity on emotional response.

Regarding the effect of environmental complexity on emotional response, Wohlwill (1968) assumed two distinct responses resulting from complexity. The first was a preference response as captured by ratings of pleasure while the second was an interest response captured by behavioural measure of number of exposures selected by participants. The effect of complexity on preference was quadratic—an inverted-u shape relationship was present—suggesting that intermediate levels of complexity were most preferred. On the other hand, the arousal-based emotion of interest showed a positive linear relationship with complexity. Subsequently, Wohlwill (1975) demonstrated a quadratic effect of complexity on liking as described by forced choice selection and a positive linear effect on interest as described by viewing time. Thus, Wohlwill (1968; 1975) demonstrated that complexity had an inverted-u effect on the pleasure dimension and a positive linear effect on the arousal dimension using both verbal as well as behavioural responses. Although providing a foundational examination of the effect of environmental complexity by considering two classes of emotional response, the research by Wohlwill (1968; 1975) is limited because objective measures of complexity were not used, instead the complexity was quantified using subjective responses. Additionally, it is unclear why forced choice and viewing time behaviour were indicative of liking and interest, respectively; it seems equally likely that the opposite or both would be true.

Nasar extended the research on environmental complexity effects on preference by employing naturalistic images of environments (Nasar, 1981; 1984). Although Nasar (1981; 1983; 1984) measured both pleasure and interest, they were summed together to generate a general preference measure that was affected in a positive linear fashion by complexity. Eventually, Nasar (1994, 1988) would abandon such aggregate measures of preference and draw conclusions similar to that of Wohlwill (1968; 1975): that environmental complexity affected pleasure- and arousal-based emotions differentially, with an inverted-u effect on pleasure and a positive linear effect on arousal based emotions. Although drawing on the varied effect of complexity on pleasure and arousal, Nasar (1981, 1994) once again placed emphasis on pleasure by considering preference as deriving primarily from the pleasure dimension, while often failing to discuss the contribution of arousal based emotions such as interest. Additionally, Nasar continued the common practice of relying on subjective measures of complexity as opposed to developing an objective measure.

The lack of objective measures of environmental complexity has been somewhat remedied by recent research where numeric or diversity based measures of complexity are employed; both building shape (such as façade silhouette or façade articulation) and surface elements (such as ornamentation, colour, or façade detail) have been explored. Number of vertices, number of distinct shapes and symmetry resulted in positive effects on preference and pleasure (Heath, Smith & Lim, 2000; Stamps, 1999a; 1999b). Façade articulation, on the other hand, predicted complexity, but its effect on preference was weak (Stamps, 1999b). Generally, complexity has a positive effect on both pleasure (Stamps, 1998b; 1999a; 1999b; 2002) and preference (Herzog & Shier, 2000), while an inverted-u relationship has also been demonstrated rarely (Imamoglu, 2000). In fact, an extensive reanalysis of published results, testing specifically for an inverted-u relationship, failed to find one while showing a clear linear effect. Although a positive linear relationship was found for most types of environments, a negative effect of environment entropy on pleasure was exhibited for sign-scapes, old buildings and residential buildings (Stamps, 2003, 2004). While commendable for measuring objective complexity rigorously, Stamps (2002, 2003 & 2004) once again ignored emotions within the arousal dimension. Although Stamps (2004) went as far as to discuss arousal responses—such as interest—they considered them as synonymous with complexity, ignoring their potential usefulness in describing experience of the environment. Thus, when considering experiments when complexity was objectively measured and its effect on emotional response tested, pleasure based emotions were used almost exclusively, whereas emotions within the arousal dimension, such as interest, were ignored.

1.2.3. Limitations of previous examinations of environmental complexity effects on emotional response.

Thus, the literature can be summarized as possessing two limitations. First, previous research relied heavily on emotional responses within the pleasure dimension, failing to consider arousal based emotions such as interest. Second, many of the experiments relied on subjective measures of complexity, which limits the generalizability of the results and does not lend itself easily to comparison between environments. In the rare instance where pleasure and arousal are both considered, complexity was not quantified objectively.

This overreliance on pleasure as a measure of experience of the environment is problematic since emotional response is complex, comprising of various cognitive components and emotional outcomes, many of which will be experienced positively. For example, curiosity, interest, pleasure and fear are distinct emotions, each of which may be experienced positively, given certain circumstances. Yet most previous work has relied on pleasure response as the primary measure of emotional response and experience.

The second concern—the lack of objective complexity measures—will be remedied by developing a systematic manner by which to quantify environmental complexity, as described in subsequent sections. The first concern—the overreliance on pleasure responses—will be addressed by measuring both pleasure and interest as two distinct, yet equally important positive emotional responses to environmental complexity. By considering interest alongside pleasure we argue that experiences are complex, composed of various cognitive components and emotional outcomes. This more nuanced analysis of emotional response, positing a distinction between pleasure and interest, is supported strongly within the emotion literature, where distinct cognitive structures, functions, physiological components and neurological underpinnings have been noted.

1.3. Objective #1: Distinguishing Between Pleasure and Interest

The literature has, up to this point, discounted the important contribution of arousal based emotions in defining our experience of the environment. Indeed, a large number of emotions, other than pleasure, can describe our preferences and interactions with the environment. Interest may be particularly important as it drives preference, resulting in exploratory behaviour and deeper engagement with stimuli (Wohlwill, 1968; Silvia, 2008; 2010; Stamps, 2010). Thus by discounting responses such as interest, we are missing a complementary and equally important determinant of environment preference and experience. Indeed, within the emotion literature, pleasure and interest are conceptualized as distinct emotions with unique structures, functions and predictors (Russell, 2003; Silvia, 2005; Silvia & Turner, 2006; Smith & Ellsworth, 1985). By considering such differences, it may be possible to develop a more complete understanding of how environmental complexity shapes experience.

The general time course and manifestation of pleasure and interest are argued as being distinct. Pleasure occurs in a ballistic fashion, early in the perceptual process, so that one of the first judgements made by an organism is that of hostility or hospitability (Zajonc, 1980). Thus, pleasure is one of the most basic judgements made regarding a stimulus, forming the basis of more complex emotions and behaviours (Russell, 2003). In contrast, interest is believed to occur later, resulting from cognitive appraisals of arousal, complexity, novelty and coping potential (Silvia, 2005, 2008; Silvia & Turner, 2006; Day, 1967). Experientially, pleasure codes the valence of an event—whether it was positive or negative—while interest codes for the arousal inducing nature of the event—the degree to which it was engaging or stimulating (Russell, 2003; Lang, Bradley & Cuthbert, 1990).

We also see a strong distinction between stimulus features driving pleasure and interest. Pleasure appears to be the result of one of two factors 1) Goal congruence: environments and situations, which are congruent with one's current goal or needs, are experienced as pleasant (Scherer, 1984; Smith & Ellsworth, 1985). And 2) Intrinsic pleasure: visual elements and properties that are processed fluently lead to pleasant experiences (Humphrey, 1972; Reber, Schwarz & Winkielman, 2004; Reber, Winkielman & Schwarz, 1998). This ease of processing perspective is supported by neurological evidence demonstrating that increased neural activation for perception of visual gratings resulted in greater displeasure (Wilkins et al., 2008). This does not necessarily mean that stimuli need to be simple to be processed fluently, instead complex and intricate stimuli can be processed fluently as long as the visual elements are organized in an orderly manner. From this intrinsic pleasure argument, others have suggested that image statistics, which diverge from those statistics found within nature scenes and environments result in discomfort and pleasure (Land, Juricevic, Wilkins & Webster 2010; Valtchanov, 2013). In this evolutionary perspective, pleasure results from how closely aligned visual stimuli are to the function and structure of the perceptual system. Our perceptual systems have evolved to process nature, thus nature is processed more fluently and experienced as pleasing. Interest, on the other hand, results from information content within a stimulus – the more informative or visually complex, the more interesting the stimulus (Day, 1967; Smith & Ellsworth, 1985, Stamps, 2003; 2006). In this way, interest is an information seeking or epistemological emotion, tied strongly to knowledge acquisition (Silvia, 2008).

By considering that emotions are functional and associated with specific behaviours, we see that pleasure and interest are distinct functionally. Simply stated, pleasure leads an organism to avoid discomfort while seeking and maintaining comfort. Comfort and discomfort can be a result of threats within the environment, goal incongruence as caused by the environment or the need to process or perceive the environment easily (Smith & Ellsworth, 1985; Reber, Schwarz & Winkielman, 2004; Reber, Winkielman & Schwarz, 2004). Interest, on the other hand, is an epistemological emotion, resulting in exploratory behaviour driven by the desire for information acquisition (Silvia, 2005; 2008). Thus, interest disregards comfort or discomfort but instead drives exploration for the sole purpose of gaining information about the environment (Turner & Silvia, 2006).

Finally, differences in neural activation and substrates between pleasure and interest have been noted. In a literature review, Posner, Russell and Peterson (2005) compared neural activation between valence and arousal based emotions, pleasure and interest being prime examples of each (Stamps, 2003; 2006; Russell, 2003). Two specific neural circuits were suggested, one underlying valence the other arousal. The valence circuitry consisted of the mesolimbic dopamine system, with activation in the amygdala, prefrontal cortex, hippocampus, as well as the ventral striatum (including the nucleus accumbens and caudate nucleus). Activation of the nucleus accumbens was related directly to activation in the ventral tegmental area. These brain regions are often discussed as being part of the reward system whose activation results in dopamine release and subsequent feelings of pleasure and euphoria (Everitt & Robbins, 2005). Such a dopaminergic mechanism has also been exhibited for environmental preference through activation of the parahippocampal gyrus and ventral striatum (Yue, Vessel, Biederman, 2007). Arousal responses, on the other hand, employed a different grouping of neural regions, showing particularly strong activation from the thalamus to the amygdala and the reticular formation. Activation of the amygdala also showed feed-forward activation to the parietal cortex while thalamic activation resulted in additional activation of the primary sensory cortex, the association cortex and the frontal cortex. Finally, feedback from the reticular formation to the thalamus was argued as leading to increased arousal and activation of primary cortices and association areas. Activation of the reticular formation is especially significant considering its role in preparation for action and engagement with the environment, where damage to the reticular formation results in hypoarousal and coma (Jones, 2003; Heilman, et al., 2003). So whereas pleasure responses resulted in activation of reward circuitry, interest response resulted in activation of the reticular formation, amygdala and thalamus, regions related to preparedness for action. This again highlights that pleasure is related to feelings of euphoria and valence based judgements, while interest is related to arousal resulting from the need to engage with the environment.

The evidence presented above demonstrates that, to a certain degree, pleasure and interest are distinct emotional response. When considering the possible effect of environmental complexity, the importance of the distinction between pleasure and interest becomes apparent. Unfortunately, the majority of environmental psychology research disregards the fact that positive responses are composed of many emotions with distinct structures and predictors, relying predominantly on responses of pleasure. By employing pleasure as the sole response measure, we are missing a large chunk of the experience; in order to understand the effect environmental complexity has on experience, it is vital that we expand our examination of emotional response beyond simple measures of pleasure. Due to its relation to information acquisition and exploration, interest may serve as an important emotion alongside pleasure. Such differences are non-trivial when we consider that pleasure and interest may result in vastly different outcomes and behaviours within an environment. For example, interest will stimulate exploration and information seeking, whereas pleasure may lead an individual to remain within a pleasant environment, thus avoiding possible displeasure caused by changes to one's current location.

1.3.1. The Effect of Environmental Complexity on Pleasure and Interest.

The effect of complexity on interest has been demonstrated as being positive and linear (Normore, 1977; Hare, 1974a; Eisenman, 1966; Day, 1968; Stamps, 2002; Silvia, 2005) while the effect of complexity on pleasure has been less consistent; positive linear (Stamps, 2002; Day, 1968), negative linear (Reber, Schwartz & Winkielman, 2004) and inverted-u effects have all been demonstrated (Berlyne, 1974; Nasar, 1994; Saklofske, 1975). This dissertation takes a novel approach where both pleasure and interest will be examined allowing us to compare the effect of environmental complexity on each.

There is also reason to believe that complexity may shape interest more strongly than pleasure; several studies have demonstrated that stimulus complexity predicted interest while failing to predict pleasure (Silvia, 2005; 2008; Day, 1967; Humphrey, 1972). Such an interpretation is reasonable if we assume that interest is an epistemological emotion and the complexity provides information. In addition, a negative effect of complexity on pleasure has been observed, while the much discussed inverted-u relationship has been elusive (Reber et al, 2007; Stamps, 2003). Thus, environmental complexity may differentially affect pleasure and interest; the aim of this research is to demonstrate such differences, and discover which properties of the environment may drive such effects. Specifically, whether complexity results in pleasure or interest may depend on how the complexity is presented and processed by the viewer rather than by the degree of complexity alone.

Thus, the first objective of this dissertation is to consider the variable effect of environmental complexity on emotional response, by arguing that positive responses are composed of many positive emotions, with pleasure and interest serving as two key examples.

1.4. Objective #2: Stimulus Properties and Complexity

As described in Section 1.2 much of the previous research on the effects of environmental complexity failed to quantify complexity objectively. It is crucial to define and describe the degree of complexity an environment possesses for several reasons. First, such objective measures of complexity allow us to compare between environments more easily. Second, they allow us to design experimental conditions and environments whose objective complexity vary in a systematic manner. Third, beyond allowing for the creation of novel, experimental environments, it may be possible to quantify complexity of real environments thus including them within the theoretical fold. Fourth, if research on potential effects of complexity on response towards the environment is to be applied by architects and design professionals, it is necessary to develop actionable findings and insights—this requires us to quantify complexity thus allowing for the generation of specific levels of complexity, resulting in certain experiences. It is worth noting that several experiments—using both synthetic visual stimuli as well as whole environments—have used a variety of methods to quantify complexity; an examination of this literature will highlight several crucial limitations allowing us to generate a more accurate and systematic objective measure of complexity.

1.4.1. Numerosity and visual complexity.

Increasing the number of elements is one of the earliest and most common manipulations used to generate and quantify complexity (Attneave & Arnoult, 1956). For example, the sequence (A,A,A,A,A) is more complex than the set (A,A,A); as the number of individual elements increases so does complexity. This numerical approach was originally used to manipulate complexity of simple polygons, demonstrating that as number of sides or turns in the polygon increased so did complexity (Attneave, 1957; Day, 1967; 1968; Eisenman, 1966; 1967). Modifying the number or brightness of elements within a shape as well as the elements within object arrays also had a significant positive effect on complexity (Hare, 1974b; Humphrey, 1972; Berlyne, 1970).

When it comes to describing complexity of the environment using such numerical approaches, it becomes necessary to define the aspect of the environment that will be enumerated. The numeric complexity of the built environment can be manipulated using either the geometric aspects of the building (such as façade silhouette or façade articulation) or by considering surface and decorative elements (such as ornamentation, colour, or façade detail). Generally, results are consistent with those seen using synthetic visual stimuli: as the number of elements increases, so does perceived complexity. Building shape, number of vertices, turns, degree of articulation and variety of shapes all demonstrated significant effects on complexity (Stamps, 1999a; 1999b; Heath, Smith & Lim, 2000;). Similar results have been shown when considering decorative elements; increasing number of coloured elements, ornamentation, trim, columns or entrances resulted in increased complexity (Herzog & Shier, 2000; Stamps, 1998b; 1999a; 1999b; Imamoglu, 2000).

1.4.2. Diversity and visual complexity.

An alternative to generating complexity through numerosity is to manipulate the diversity of the elements within a set. For example, the set (A,B,C) is more complex than the set (A,A,A) despite possessing the same number of items; thus complexity ranges from total heterogeneity, where all elements are different, to total homogeneity where all elements are the same. In this way, complexity is captured by the probability of an event's occurrence; unexpected or less common events result in increased complexity. This approach aligns complexity closely to information entropy, a measure developed by Shannon (1948) to describe the amount of information within a message. Thus, since entropy describes information content resulting from diversity of elements, it provides us with a tool by which to quantify complexity of the environment. Additionally, such an approach is aligned with the perspective that complexity is useful because it provides an individual with information regarding their environment (Kaplan, 1987; Kaplan, 1977). These diversity-based measures of complexity have been demonstrated as shaping complexity of synthetic shapes and visual patterns (Hare, 1974a; Berlyne 1974a; Vitz & Todd, 1969; Snodgrass, 1971; Normore, 1974) as well as tones and sound sequences (Vitz, 1966; Hare, 1974a; Normore, 1974).

When it comes to diversity based approaches to quantifying environmental complexity, Stamps quantified complexity objectively using entropy to describe the effect of the environment on perceived diversity in a series of experiments (Stamps, 2002; 2003; 2004; 2010). Using synthetic environments, entropy of both geometric environment properties such as articulation, openings and building shape, as well as featural properties, such as colour and ornamentation resulted in perceived diversity (Stamps, 2002; 2003). Using a meta-analytic approach, the relationship between entropy and perceived diversity was shown to be consistent between different types of both real-world as well as synthetic environments including residential blocks, single family dwellings, high-rise buildings and signs-scapes as well as simple visual and auditory patterns (Stamps, 2003; 2004).

1.4.3. The need for objective measures of environmental complexity.

With few exceptions (some mentioned above), much of the research on the effect of environmental complexity on emotional response has failed to quantify complexity objectively. Complexity was often determined by asking participants or expert judges (architects and urban planners) to rate the degree of environmental complexity alongside emotional response ratings (Wohlwill, 1968; 1975; Kaplan, Kaplan & Brown, 1989; Herzog, Kaplan & Kaplan, 1982; Nasar, 1981; 1984; 1989). Such approaches are limited for several important reasons. If we assume that experience of the environment involves both an objective aspect of complexity, present within the environment, and an additional subjective experience of complexity, it is necessary to examine both in order to understand the effect of the environment fully. Additionally, the use of design professionals to judge complexity is concerning given that they perceive and conceptualize environments differently from lay individuals, with expert judges perceiving environments as much less complex (Devlin & Nasar, 1989; Gifford & Brown, 2001). Finally, subjective methods of describing complexity cannot be applied easily to inform design decisions as they do not translate directly to the physical environment. For example, it is not instructive to state that for an environment to be pleasing it must possess "7" complexity; such instructions are non-prescriptive and disconnected from the physical environment. Objective measures of complexity are thus necessary to connect the research to environmental design.

Thus, it is necessary to develop a way to quantify environmental complexity accurately and reliably. The research presented above shows that objective complexity can be generated both by increasing the number or the diversity of elements within a set. These numerosity and diversity approaches can be applied to two distinct physical properties of the environment: the featural and the geometric elements of the environment. Increasing the number or diversity of either of these featural or geometric properties may lead to the generation of complexity. Although previous research has examined some of these approaches individually, across numerous experimental procedures, this dissertation will examine these methods under a unified framework in a systematic manner. This will allow us to examine how effective each of these methods is in quantifying and describing complexity and to test how these individual measures affect emotional response.

Thus, the second objective of this dissertation is to examine the effectiveness of both numeric and diversity based approaches for the generation of complexity through both the geometric and featural elements of the environment.

1.5. Objective #3: The Route from Physical Features of the Environment to Emotional Response

Within the emotion literature, it is assumed that emotions are differentiated through a variety of factors, including physiological response, activation of specific neural systems, motivational factors and cognitive processes (Izard, 1993). Similarly, others have argued that emotions are coded by their affective quality, behavioural response and cognitive components (Frijda, Kuipers & ter Schure, 1989), while Moors (2013) suggested that these components result from cognitive appraisals of stimulus properties. Regardless of the specific manner by which emotions are elicited, the literature is clear that a cognition plays an important role; dynamic cognitive appraisals of stimulus proprieties reliably determine a wide range of emotions including, but not limited to, pleasure, interest, curiosity and disgust (Smith & Ellsworth, 1985;

Silvia, 2009; Frijda, Kuipers & ter Schure, 1989; Moors, Ellsworth, Scherer & Frijda, 2013). In this perspective the subjective experience and appraisal of stimulus properties determine emotional response. Yet despite the strong support for the importance of such cognitive factors, the environment experience literature has failed to consider how cognitive appraisals may mediate the effect of complexity on emotional response.

1.5.1. From arousal to cognition.

When it comes to the effect of environmental complexity on emotional response, typically, an arousal or physiological mechanism is argued. For example, Berlyne (1960; 1974) suggested that dynamic shifts in physiological arousal, resulting from complexity determined emotional response. Kaplan (1970) introduced cognition into experience of the environment by arguing that complexity is experienced positively because it provides an organism with new information, allowing it to update and develop a more complete cognitive map of the environment. Considering both information content and arousal, Mehrabian & Russell (1974a; 1974b) demonstrated that appraised information content of an environment predicted arousal inducing quality of the environment; thus the effect of stimulus complexity is mediated by cognitive appraisal of information content.

Despite strong evidence for a cognitive component from the appraisal theory of emotion (Silvia, 2005; 2008; 2010; Moors, 2013; Smith & Ellsworth, 1985)—other than the brief glimpses suggested by Kaplan (1970) and Mehrabian & Russell (1974a; 1974b)—cognitive mechanisms and mediators of environmental complexity on emotional response have not been examined directly in the environment preference literature. Thus, this dissertation aims to consider cognitive components by assuming a distinction between objective and subjective complexity; that the effect of an environment's objective complexity on emotional response results from and is thus mediated by cognitive appraisals of perceived complexity. Although the subjective nature of environmental experience has been assumed previously, this dissertation marks the first instance where mediation will be tested.

1.5.2. The mediating role of subjective perceived complexity.

Using path analysis, this dissertation will examine if the direct effect of objective complexity on emotions of pleasure and interest is mediated by perceived complexity. Objective complexity will be quantified as described in the previous section, relying on both numeric and diversity based approaches, while appraised or subjective complexity and emotional response will be determined using self-report measures. We would expect that objective measures of complexity would predict cognitive appraisals of perceived complexity. Although objective complexity may predict interest and pleasure directly, we expect that the effect would be, at minimum, partially mediated by appraised complexity (Silvia, 2005; 2006). For interest in particular, the direct effect of objective complexity should be mediated by appraised complexity, as has been shown previously (Silvia, 2005; 2008). Although the effect of objective complexity on pleasure is difficult to predict, we expect any possible effects to be mediated by appraised complexity (Smith & Ellsworth, 1985). Indeed, negative effects of complexity on pleasure have been suggested as resulting from difficulty in understanding and processing complexity (Reber, Schwarz & Winkielman, 2004; Reber, Winkielman & Schwarz, 2004).

Thus the third objective of this dissertation is to examine if the direct effect of objective complexity on pleasure and interest is mediated by cognitive appraisals of perceived complexity.

1.6. Summary and Objectives of the Dissertation

Thus, by considering three vital research questions, which have received inadequate attention in the literature, this dissertation attempts to undertake a more comprehensive examination of how environmental complexity shapes emotional response.

First, by considering that positive emotional responses are described by emotions beyond pleasure, this dissertation will examine the effect of complexity on interest alongside pleasure. This approach presents a more nuanced and accurate examination of environmental complexity on emotional response than has been explored previously.

Second, the manner by which the environment can generate and possess complexity will be explored by testing both numeric and diversity based approaches of complexity generation applied to the geometric and featural aspects of the environment. This systematic examination of complexity provides us with a potentially robust and reliable way to describe complexity within the environment.

Third, this dissertation will test if the effect of objective environmental complexity is mediated by subjective, appraised environmental complexity. Such a consideration of subjective, cognitive components, aligns the environment preference literature with the cognitive appraisal theory of emotions, allowing a more accurate perspective on the manifestation of emotional response.

These objectives were accomplished in five experiments, summarized as follows:

Experiment 1.1: Objective complexity was manipulated through numerosity of geometric environmental elements in the form of doorways, resulting in interest but not pleasure.

Experiment 1.2: Objective complexity was manipulated through numerosity of both geometric and featural elements of the environment, in the form of doorways and decorative panels, respectively. Increasing the number of either resulted in interest while failing to affect pleasure; the direct effect was mediated by perceived complexity.

Experiment 2.1: Objective complexity was manipulated using diversity of decorative panels within the environment, and quantified with information entropy. Entropy had a significant negative effect on pleasure, while failing to affect interest; the direct effect was partially mediated by perceived complexity. Additionally, behavioural analogues of emotional response were examined in the form of navigation and forced choice behaviour, demonstrating a strong association with subjective emotional response in the form of avoidance behaviour.

Experiment 2.2: Objective complexity was once again manipulated using entropy of decorative panels but now global and local properties of the panels were manipulated in an effort to elucidate how factors beyond complexity shape emotional response. Entropy had a negative effect on pleasure, while global and local properties, symmetry and panel design, respectively, mitigated the negative effect of entropy on pleasure. Once again, navigation behaviour, in the form of avoidance, was closely related to subjective emotional response.

Experiment 3.0: In an effort to improve ecological validity, an experiment was conducted in the field used entropy to quantify entropy of real-world environments. Entropy predicted perceived complexity; an exhibited positive effect on pleasure and interest was mediated by perceived complexity.

Chapter 2 - Experiment 1.1: Complexity through Numerosity of Geometric Environmental Elements and Emotional Response

2.1. Introduction

The complexity of simple, synthetic visual stimuli can be manipulated in many different ways. Varying the number of sides in a polygon, number of angles and length of lines (Day, 1967; 1968; Eisenman, 1966; 1967), as well as symmetry, organization and distribution of visual symbols (Berlyne, 1971), have all been used successfully to generate complexity. Environmental complexity has been manipulated either using either façade shape (Stamps, 1998; 1999a; 1999b; Heath, Smith & Lim, 2000) or surface details such as colour, ornamentation, texture or trim (Stamps, 1998b; 1999a; 1999b; 2003; Herzog & Shier, 2000; Akalin, Yildirim, Wilson & Kilicoglu, 2009). For both abstract visual stimuli and environments, increased complexity provides greater information to a viewer, meeting a motivational need for information regarding one's surroundings thus resulting in positive emotions (Kaplan, 1979; Kaplan, 1987; Kaplan & Kaplan, 1989). Thus, an environment that features more elements will be more complex, provide more information and thus be experienced more positively than an environment with fewer elements.

Rather than manipulating façade complexity, this experiment manipulates complexity within interior environments, and explores the ability of doorways to generate visual complexity through their influence on the geometry of the environment. Here, a multifaceted approach to emotional response is taken, where emotions of pleasure and interest were both considered. As discussed in the introduction, although both can be considered positive emotions, their structure, predictors, functions and neurological underpinnings are distinct. Regarding the effect of complexity on emotional response, we would generally expect complexity to influence interest positively (Stamps, 2010; Day, 1967, 1968; Wiener et al., 2007) while its effect on pleasure is difficult to predict due to contradictory findings in the literature (Heath, Smith & Lim, 2000; Stamps, 1999a; Vartanian et al., 2010; Wiener et al., 2007). Unlike previous research, the approach taken in this experiment will attempt to dissociate interest and pleasure, in an effort to present a more nuanced examination of positive emotional response.

2.1.1. Complexity of interior environments.

Environmental preference research has focused primarily on the effect of façade complexity on emotional response. Viewing façades results in an experience where participants look *at* the environment as opposed to being *in* the environment; interior environments, on the other hand, position the participants within the environment. Since visual complexity is not limited to façades, we would expect that façade complexity effects should generalize to other aspects of the built-environment. To the best of the author’s knowledge, the effect of complexity on response to interior environments has not been examined. Considering that the average individual spends 87% of their time in indoor environments (Klepeis et al., 2001), it is vital for us to understand how our emotional responses are shaped by features of the interior environment. By focusing on interior environments, we also examine a qualitatively different experience of the environment than has been examined previously.

Complexity of interior environments can be manipulated similarly to façade complexity; either through the geometry or surface details of the environment. In this experiment, complexity will be generated by manipulating the geometry of the environment; specifically, by varying the number of entrances/exits in the environment. As the number of such doorways increases, the shape of the environment will become progressively more complex, providing a viewer with more information. Importantly, the novelty of this doorway manipulation has the added benefit of introducing functional environmental elements; doorways allow for exploration and movement through the environment. Such functional features are rarely considered within the environmental complexity literature. According to Kaplan (1979) and Kaplan and Kaplan (1989), complexity and information can be presented to an individual at their current location, but complexity might also be increased by the suggestion that further exploration will yield new information. Such a manipulation could potentially result in an enhanced effect of information content and complexity on environmental preference.

In one of the rare instances where complexity of interior environments was considered, Stamps (2010) explored how shape and visual occlusion within interior environments leads to exploration. Environmental shape was manipulated by varying the number of sides in the environment (four versus ten sides) while occlusion was generated by placing walls within the environment. Stamps (2010) demonstrated that shape (rectangular rooms versus ten-sided rooms) led to a slight increase in exploration, while occlusion resulted in much larger increase in exploratory behaviour. The occlusion effect was particularly insightful, considering that occlusion suggests possible areas for exploration in a similar manner to our doorways manipulation. Although findings support the importance of environment shape on experience, they do not directly address how geometric properties of the environment, such as shape, affect emotional response.

To the best of the author's knowledge only a single experiment has previously explored the relationship between doorways, complexity and emotional response directly. Along with a number of other factors, Herzog and Shier (2000) compared responses to environments with or without visible entrances; environments with entrances were perceived as more complex and visually rich. This complexity measure had a strong effect on preference ratings and moderated preference for older buildings over modern buildings. Although their results suggest that there was an effect of entrances on complexity and preference, Herzog and Shier (2000) did not vary the number of entrances—the environment either had a single entrance or none at all. Whether or not increasing the number of entrances leads to an increase in perceived or a change in emotional state is unknown. Although Herzog and Shier (2000) marks one of the rare instances where doorways were examined as driving complexity, there is a rich history using both abstract visual stimuli and building façade complexity from which we may draw.

2.1.2. Geometry of space and complexity.

The inclusion of doorways into the environment exerts a tremendous impact on to the shape of visible space in the environment; consider that the shape of visible space in an environment with only one doorway will be dramatically different than the shape of visible space in an environment with four doorways. This shape of visible space is termed an isovist polygon, representing a two-dimensional shape whose properties have been quantified and analyzed in similar fashion to physical shapes, such that number of vertices, length, and jaggedness (perimeter squared divided by area) have all been examined (Dzebic, Perdue & Ellard, 2013; Davis & Benedikt, 1979; Wiener & Bulthoff, 2007).

Examination of isovist properties provides several important consideration regarding complexity and emotional response. Increasing the number of vertices and jaggedness in the isovist polygon lead to increases in perceived complexity (Dzebic, Perdue & Ellard, 2013; Wiener et al., 2007). On the other hand, the effect of isovist properties on interest and pleasure is inconsistent, showing positive effects on interest along with negative effects on pleasure (Wiener et al., 2007), while a lack of significant effects on both measures has also been noted (Dzebic, Perdue & Ellard, 2013). Such discrepancies may be a result of methodological differences; Wiener et al. (2007) used virtual environments, while real-world environments were used in Dzebic, Perdue and Ellard (2013). Experiments have also demonstrated that the effect of isovist shape complexity has a differential relationship on pleasure and interest, where increases in complexity correlated positively with interest and negatively with pleasure (Wiener et al., 2007).

If we consider that isovists can be described by the same metrics as polygons, such as the number of sides and vertices, it may be useful to discuss the effect of polygon complexity on emotional response. Increasing the number of sides in a polygon or the geometric elements within a façade results in increased perceived complexity (Attneave & Arnoult, 1956; Attneave, 1957; Eisenman, 1966; 1967; Day, 1967; 1968; Berlyne, 1972; Stamps, 1998b; 1999a; 1999b; Heath, Smith & Lim, 2000) as does varying the number of vertices, or the irregularity of the polygon (Berlyne, Ogilvie & Parham, 1968; Berlyne & Crozier, 1971; Berlyne & Peckham, 1966). Typically, manipulations of polygon complexity result in positive linear effects on interest (Eisenman, 1966; 1967; Day, 1968), which have been shown to asymptote (Day, 1967). With respect to pleasure, the effect of complexity seems to be either non-significant (Eisenman, 1966) or significant but non-monotonic, featuring multiple peaks with a general downward slope (Day, 1967; 1968). Unlike the literature on simple shape complexity, the effect of façade shape complexity appears to show a positive linear effect on pleasure (Stamps, 1999a; 1999b; Heath, Smith & Lim, 2000).

2.1.3. Experiment 1.1 objectives.

To summarize, both the shape of interior environments as well as the presence of doorways seem to lead to increases in perceived complexity (Nasar, 1994; 1984; Stamps, 2010; Herzog & Shier, 2000, Wiener eta l., 2007; Dzebic, Perdue & Ellard, 2013. The positive effect of complexity on interest is well supported (Stamps, 2010; Day, 1967; 1968; Wiener et al., 2007) while the effect on pleasure is less consistent. Positive effects on pleasure have been shown (Heath, Smith & Lim, 2000; Stamps, 1999a; 1999b; Vartanian et al., 2010), while negative effects have also been observed (Wiener et al., 2007).

Although the literature highlights some relevant findings regarding the effect of complexity on emotional response, this experiment will address two key limitations in the literature. First, departing from the typical examinations of façade complexity, this experiment will examine complexity of interior environments as resulting from the number of doorways within the environment. We can assume that doorways will affect the geometry of space, which should shape complexity and emotional response as seen in research on polygon complexity. Second, as opposed to relying solely on pleasure responses, this experiment considers a multifaceted approach towards emotional response, where pleasure is considered alongside arousal-activation based emotions such as interest. Based on previous research, we expect complexity resulting from doorways to have a linear effect on interest, while the effect on pleasure is more difficult to predict due to the conflicting findings in the literature.

2.2. Methods

2.2.1. The environment.

Virtual environments measuring 7.5 by 7.5 metres were created featuring 0, 1, 2, 4, 5 or 6 doorways. Three of the walls could have a maximum of two doorways, separated by 1.5 metres of wall and measuring 1.5 metres in width each. Dimensions and door positions are presented in Figure 2.1. Other than when 0 or 6 doorways were present, every doorway number could be generated with a number of different doorway positions. For example, two doorways could be placed so they were both on the left wall, or one could be placed on the left wall and the other on the right wall, or they could both be on the back wall. In order to control for possible doorway position effects all possible doorway positions were generated for each level of number of doorways. This resulted in 6 environments with 1 opening, 15 environments with 2 openings, 15 environments with 3 openings, 15 environment with 4 openings and 6 environments with 5 openings. Because 0 and 6 doorways could only be arranged in one manner (no doorways and doorways in all possible positions), the same environment was generated six times for each. This resulted in 69 environments in total. Environments were created using Google Sketchup, and typical carpeting, wall and ceiling textures were applied. To render each environment, the V-Ray add-on for Sketchup was used. For illumination, a total of six globe lights were placed in two columns of three at ceiling level so as to mimic indoor illumination. The globe lights were adjusted to provide diffuse light throughout the environment. For the rendering of each environment, view height was set at 1.75 meters. Each environment was rendered from a central position so that the viewpoint was perpendicular with the back wall and each of the side walls was equally visible. Refer to Figure 2.2 for a broad range of rendered sample environments.

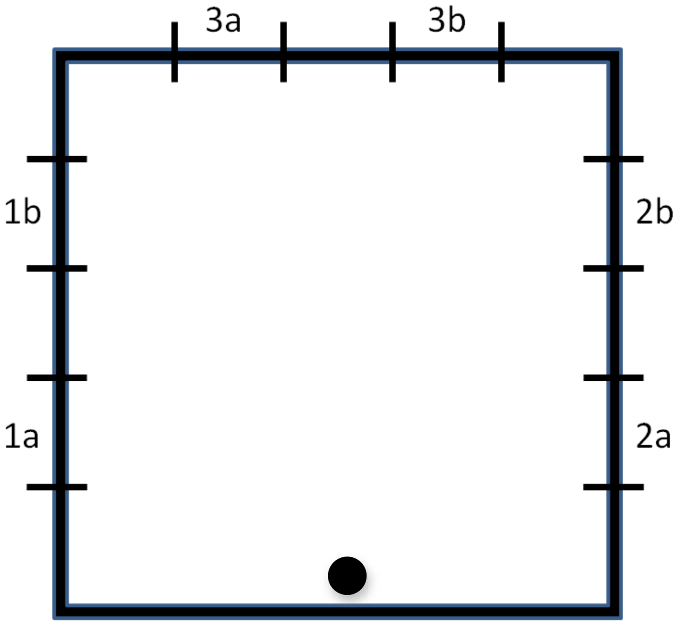
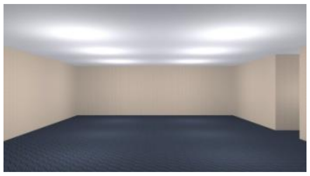
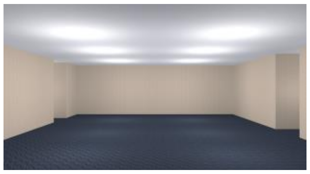
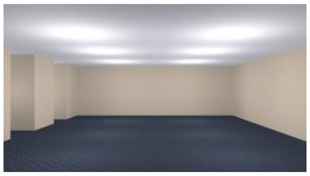
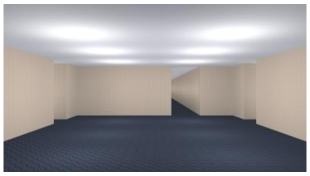
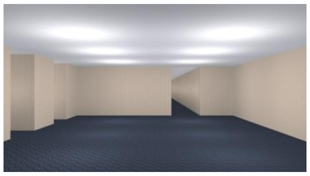
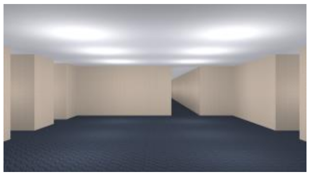
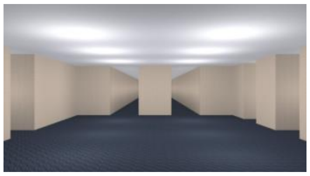


Figure 2.1. Schematic for the environment used in Experiments 1.1 and 1.2. The environment measured 7.5 x 7.5m, and each opening was 1.5m in width and separated by 1.5m. There were a total of six possible doorway positions. The circle represents the position from which the viewpoint into the environment was generated.

0 doorways			
1 doorway			
2 doorways			
3 doorways			
4 doorways			
5 doorways			

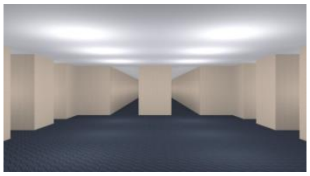
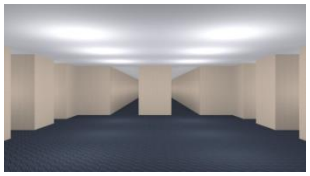
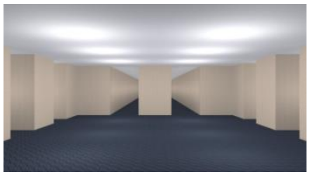
6 doorways			

Figure 2.2. Sample environments from Experiment 1.1.

2.2.2. Emotional response ratings.

In accordance with Russell and Mehrabian (1974a), Silvia (2005) and Berlyne (1971) emotional responses mapping onto pleasure and the arousal/activity dimensions were probed using semantic differential questions regarding pleasure and interest, respectively. Semantic differential responses have been shown to correlate consistently with behavioural measures of emotional response such as exploration, and approach behaviour (Russell & Mehrabian, 1978; Berlyne, 1960). Responses for pleasure and interest were made using a seven-point Likert scale. For pleasure, the question was worded as: "How pleasing is the current environment", the response scale was presented below where 1 was marked as "unpleasant" and 7 was marked as "pleasant". Interest was worded as follows: "How interesting is the current environment", the response scale was presented below, where 1 was marked as "boring" and 7 was marked as "interesting".

2.2.3. Procedure.

Participants were seated at a computer, presented with an informed consent form and instructed to press the spacebar when ready for the instructions. Instructions were presented on the screen following which six example environments were shown (one for each level of number of doorways). Once participants read and understood the instructions, they were free to begin the experiment by pressing the spacebar. Each environment was presented centrally on the screen for a total of 2 seconds, following which a question and Likert scale appeared above the environment. The question would inquire about either interest or pleasure. Responses were made using the 1-to-7 number keys on the keyboard and participants had an unlimited amount of time to make a response. A total of 54 environments were presented twice each; once for interest ratings and once for pleasure ratings, thus completing a total of 108 trials. Order of presentation was pseudo-randomized, so as ensure that same number of doorways was not presented in back-to-back trials. Once the experiment was completed, participants were debriefed, thanked for their participation and were free to leave.

2.2.5. Apparatus.

The experiment was designed in the programming language Python using the Pygame library, allowing for the controlled presentation of stimuli and recording of responses and reaction time. Environments were presented on a 19 inch Samsung monitor using a Dell desktop computer. Each environment measured 1600 pixels in width by 884 pixels in height. Participants were seated in front of the screen at an approximate viewing distance of 80 cm.

2.2.4. Participants.

A total of 26 undergraduate students (16 female) from the University of Waterloo participated for course credit. The experiment was approved by the University of Waterloo Office of Research Ethics and each participant completed an informed consent form prior to beginning the experiment.

2.3. Results

A repeated measures ANOVA was conducted, with number of doorways as a within participants variable. Since each level of number of doorways was experienced multiple times, mean responses per each level per each participant were calculated and used for the repeated measures ANOVA. For pleasure, the main effect of number of doorways was non-significant, $F(5,125) = 0.05$, $p = 0.99$, $\eta_p^2 = 0.002$. For interest, the main effect of number of openings was significant, $F(5,125) = 58.14$, $p < 0.001$, $\eta_p^2 = 0.67$ (Figure 2.3). Pairwise comparisons, applying a Bonferroni correction, demonstrated that all levels of number of doorways were significantly different from one another ($p < 0.05$), except 5 and 6 doorways; 0 doorways ($M = 1.68$, $SD = 0.13$), 1 doorway ($M = 2.45$, $SD = 0.19$), 2 doorways ($M = 2.85$, $SD = 0.16$), 4 doorways ($M = 3.94$, $SD = 0.23$), 5 doorways ($M = 4.62$, $SD = 0.25$) and 6 doorways ($M = 4.83$, $SD = 0.33$). Thus it appears that number of doorways affected interest linearly, while failing to affect pleasure.

As all levels of number of openings, except 0 and 6, featured multiple arrangements of doorway positions, additional repeated measures ANOVAs were conducted at each level to test for any possible doorway position effects. For pleasure, the repeated measures ANOVA was non-significant at each level: 1 opening, $F(5,125) = 0.2$, $p = 0.96$, 2 openings, $F(14, 350) = 0.66$, $p = 0.82$; 4 openings, $F(14,350) = 0.83$, $p = 0.63$; 5 openings, $F(5,125) = 0.59$, $p = 0.7$. For interest, the within doorways repeated measures ANOVAs was significant for 2 openings, $F(14, 350) = 2.55$, $p < 0.01$, with a Bonferroni corrected pairwise comparisons showing that the environment with both openings at the far facing wall ($M=3.77$, $SE = 0.35$, $\eta_p^2 = 0.09$) was more interesting than the environment featuring one doorway on the rear wall and second on the right wall ($M = 2.5$, $SE = 0.22$, $p = 0.15$) and the environment with one doorway on the left wall and second was the right wall (M = 2.35, SE = 0.21, p = 0.07). For all other levels of number of doorways, the effect of doorway arrangement on interest was non-significant: 1 doorway, F(5,125) = 2.28, p = 0.5; 4 doorways, F(14,350) = 1.46, p = 0.13; 5 doorways, F(5,125) = 1.35, p = 0.25.

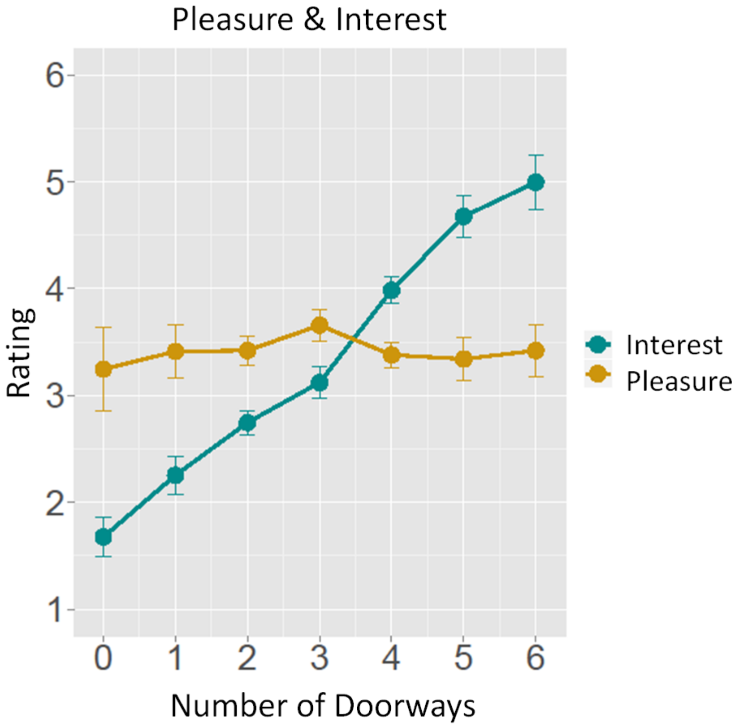


Figure 2.3. Interest and pleasure response as a result of number of doorways. The main effect of doorways was significant for interest and non-significant for pleasure.

Due to the repeated measures nature of this experiment, it was inappropriate to perform bivariate correlation analysis comparing pleasure and interest responses, as it would consider each repeated measure as a unique observation and thus treat the data as a simple sample, discounting the repeated measures nature of the data. An alternative approach that controls for repeated observations was suggested by Bland and Altman (1994; 1995), where partial correlation coefficients were generated by removing variability resulting from within participant multiple observations, allowing us to examine the correlation between repeated measures variables directly. This approach allows us to test the correlation between number of doorways and emotion within each participant. To do this, multiple linear regression was performed, where participants were treated as a categorical variable and entered as random effects, allowing the intercept for each participant to vary, and providing us with a partial correlation coefficient showing the relationship between two variables while controlling for repeated measures. This analysis demonstrated that the partial correlation between interest and pleasure is very weak, $r = 0.08$.

2.4. Discussion

2.4.1. The variable effect of number of features on interest and pleasure.

Increasing the number of doorways affected interest significantly while having no effect on pleasure. This seemingly linear effect on interest coincides with previous research showing that as number of elements increases, so does interest (Nasar, 1994; Eisenman, 1966; 1967; Day, 1968; Wohlwill, 1968; 1975; Stamps, 2010). The lack of difference in interest between 5 and 6 doorways suggests a possible asymptote, as has been shown previously (Day, 1967; Stamps, 2005). The lack of an effect of the number of doorways on pleasure was not unexpected, considering that previous research was inconclusive in this regard (Stamps, 2004; Nasar, 1994).

This experiment marks one of the rare instances where interest and pleasure were considered as independent responses to the environment. Within the environment experience literature, interest and pleasure have often been assumed as equivalent determinants of preference and thus treated as a singular preference measures (Nasar, 1981; 1984; Stamps, 2003;

2004). When both pleasure and interest (or related measure such as excitement) are reported, they often demonstrate congruent relationships, such that both increased positively with complexity (Nasar, 1994; Heath, Smith & Lim, 2000) or, alternatively pleasure shows a quadratic relationship while interest is linear (Wohlwill, 1968; 1975). The findings here highlight a novel relationship between the environment and emotional response; specifically that the environment leads to positive increases in interest and no effect on pleasure. Such a dissociation between interest and pleasure supports the notion that they are distinct emotional responses, differentially affected by environmental complexity.

In addition, doorway position had a significant effect on interest but not on pleasure. Specifically, the arrangement when two doorways were presented on the far wall was perceived as more interesting than several other arrangements where doorways were positioned on the sides. This unexpected result is potentially a consequence of the fact that when the doors are straight ahead of the viewer they are more salient, signifying exploration more directly. In this way the doorways invite exploration and engagement, leading to feelings of interest. Since doorway position affected neither pleasure nor complexity, we can assume that the effect on interest is a result of the fact that positioning doorways on the rear wall activated concepts underlying interest such as engagement and exploration.

Although finding that interest and pleasure were independent is novel for environmental preference research, the dissociation noted here corresponds to research within the emotion literature. Using a variety of visual stimuli including polygons, poems and visual artworks Silvia (2005) and Turner & Silvia (2006) showed that interest can be distinct from pleasure. In Silvia (2008; 2010), interest is a result of two cognitive appraisals, the first consisting of how complex or novel the stimulus is and the second of how well the stimulus is understood. When both complexity and understanding are appraised positively, interest is experienced. It is possible that increasing the number of doorways leads to appraisals of complexity, which in turn result in interest, but not pleasure. Such perspectives depart from Berlyne (1960, 1974) in that, instead of arguing for an arousal mechanism, Silvia (2005a; 2018) champions a cognitive appraisal mechanism underlying the emotional response.

2.4.2. Summary and next steps.

To summarize, Experiment 1.1 showed that doorways have an observable effect on emotional response towards interior environments. Increasing the number of doorways results in differential effects on interest and pleasure; with a positive effect on interest and no effect on pleasure. This finding supports the usefulness of considering positive emotional response as comprising more than pleasure. This also marks the first instance in the environment experience literature that doorway number has been manipulated to affect emotional response.

Although novel, these results leave several unanswered questions and confounds that need to be addressed. Doorways are unique for the fact that they allow for exploration, and thus provide the suggestion that additional information gain may be possible. Thus, doorways provide complexity, not just by their mere presence, but also by allowing for additional engagement with the environment. Indeed, this implied information gain has been suggested as leading to positive emotional response towards environments (Kaplan, 1979; Kaplan & Kaplan, 1989). If this is the case, it is possible that this implied information complexity may lead the environments to be experienced as particularly interesting. Second, we suggest that cognitive appraisals of complexity may mediate the effect of environment on interest but we are unable to test this prediction as appraised or perceived complexity was not measured. Without such a measure of perceived complexity we cannot state that doorways lead to increases in perceived complexity or that our effects are a result of these increases. The following experiment was designed with these questions in mind.

Chapter 3 - Experiment 1.2: Complexity through Numerosity of Geometric and Featural Properties of the Environment and Emotional Response

3.1. Introduction

To more fully understand the effect of doorways on perceived complexity and emotional response, this experiment introduces several novel manipulations. First, this experiment examines if the functional nature of doorways—that they allow exploration resulting in potential information gain—leads them to be experienced as particularly interesting. Second, in order to test if the effect of doorways on interest is mediated by subjective appraisals of complexity, this experiment measured perceived complexity. Third, a presentation duration manipulation was added in an effort to elucidate the time course of emotional response towards the environment.

3.1.1. Perceived complexity.

In the previous experiment, number of doorways was intended to increase the objective complexity of the environment as suggested by previous applications of numerosity as an objective complexity generation method (Attneave, 1957; Day, 1967, 1968; Eisenman, 1966, 1967; Imamoglu, 2000; Stamps 1999a; 1999b). Although it is likely that our manipulation resulted in increased perceived complexity, we cannot be certain, as perceived complexity was not measured. Thus in this experiment complexity responses were measured alongside interest and pleasure.

Measuring perceived complexity allows us to, not only test if doorways served as an effective manipulation of perceived complexity, but also to examine whether the effect of doorways on interest is mediated by perceived complexity. Within the environment preference literature, such cognitive components have been discussed extensively by Stephen and Rachel

Kaplan, where cognition as opposed to arousal, drives the response towards the environment (Kaplan, 1979; Kaplan & Kaplan, 1989). More recently, cognitive appraisals of complexity have been suggested as mediating the relationship between objective complexity and emotional response (Silvia, 2006, 2008). Although perceived complexity has been measured frequently within environmental preference, whether it mediates the effect of environment on emotional response has not been examined. Thus, we can examine directly the path from objective environmental complexity—number of doorways, in this experiment—to emotional response, while also predicting that this direct effect on emotional response is mediated by the cognitive appraisal of perceived complexity.

3.1.2. The "Mysterious" role of doorways as sources of information gain.

In addition to environmental complexity, and the information it provides, available to an individual from their current position in the environment, Kaplan and Kaplan (1989) also suggested a form of inferred or potential complexity available to the individual if they were to explore the environment. This inferred complexity was termed "mystery” and has been shown to result in preference for a wide range of environments (Nasar & Cubukcu, 2011; Herzog & Bryce, 2007; Herzog & Kirk, 2005; Stamps, 2007). In Experiment 1.1, it is likely that doorways suggest possible exploration, perhaps resulting in mystery and increased emotional response. In order to test this hypothesis, an additional environment type was designed, consisting of panels as opposed to doorways. By increasing the number of panels, we increase complexity, but the environment remains enclosed, not allowing for exploration. We would expect that increasing the number of elements, whether they be doorways or panels, would result in increased complexity and that this should shape emotional response, but if the doorways suggest possible information gain through future exploration, we would predict that doorway environments would be experienced as more complex and interesting than panel environments.

3.1.3. Time course of emotional response to environmental complexity.

If we consider that a cognitive component may be responsible for driving the emotional response to environmental complexity, it might be tempting to consider the formation of emotional response as slow and laboured; perhaps requiring prolonged exposure to the environment. However, feelings of pleasure and displeasure arise very quickly, being one of the first judgements we make regarding a stimulus and occurring before conscious awareness (Zajonc, 1980). Such ballistic emotional responses are adaptive, as they allow an organism to react quickly to threats within the environment (Zajonc, 1984). Additionally, environmental preferences are exhibited even after very brief presentation durations, suggesting that perception of the environment and the formation of preference occurs rapidly (Herzog, Kaplan & Kaplan; 1982; Cupchik & Berlyne, 1972). Unfortunately, the time course of interest has not been examined directly, though it appears that complexity can be assessed at very short presentation durations (50 ms) (Cupchik & Berlyne, 1972). Thus by manipulating presentation duration this second experiment will examine the time course of complexity on emotional responses to the environment. This manipulation signals one of the few instances where the time course of emotional response towards the environment was examined directly.

Although emotions are formed quickly, stimuli presented briefly are more difficult to process, resulting in displeasure and other negative emotions (Reber & Schwarz, 2001; Reber & Schwarz, 2001). Indeed this potential decrease in the time available to process information might also negatively influence interest (Silvia, 2005; 2008) and lead to decreased environment preference (Kaplan, 1987). For Silvia (2005b; 2008) and Kaplan (1987), complexity only becomes useful if it can be processed and understood, thus low presentation durations may decrease understanding of the complexity leading to decreased interest and preference.

In order to determine both the time course of emotional response to interior environments as well as the effect of viewing time on interest and pleasure, presentation durations were manipulated. For each level of number of features (doorways or panels), environments were presented for either 50, 500 or 2500 milliseconds (ms). These presentation durations correspond to durations used previously in the literature (Herzog, Kaplan & Kaplan; 1982; Cupchik & Berlyne, 1972).

3.1.4. Experiment 1.2 predictions.

Given the results of Experiment 1.1 and previous findings in the literature, we can make several predictions. First, perceived, subjective complexity should increase linearly with number of features, whether panels or doorways. Second, the effect of number of features on emotional response should be mediated by perceived complexity. Third, because doorways allow for potential exploration and information gain, doorway environments should be experienced as more complex and elicit a stronger emotional response than panel environment. Fourth, perception of complexity should not be affected by presentation duration while emotional response may be (Herzog, Kaplan & Kaplan, 1982; Cupchik & Berlyne, 1972). Because brief presentation durations result in a more difficult and disfluent perceptual processes, we predict that brief presentation durations will decrease pleasure and interest response (Reber & Schwarz, 2001; Reber & Schwarz, 2001; Silvia, 2005; 2008).

3.2. Methods

3.2.1. Experimental design.

A 2 X 4 X 3 repeated measures design was used, with two levels of environment feature type (doorways vs. panels), four levels of number of features (0, 1, 3 or 5; either doorways or panels) and three presentation durations (50, 500 or 2500 ms). Please note that in this experiment, we refer to doorways and panels collectively as features. Since the previous experiment demonstrated that all levels of number of openings differed from one another, except 5 vs. 6 doorways, we limited the number of features to 0, 1, 3 and 5. This range allowed us to examine whether complexity and emotional response increase in a linear fashion with number of features, while keeping the total number of environments manageable. As there was no difference between 5 and 6 doorways in the previous experiment 5 was selected because it could be generated with a number of arrangements, while 6 could only be generated with features in every possible position. Zero features (no doorways or panels) was included as a baseline.

With the additions of the panelled environments, the presentation time manipulation, along with four levels of number of features over 200 trials per question would have been required in order to present all possible combinations. In order to present a wide range of environments while considering time constraints, three arrangements for each number of features were selected pseudo-randomly following two rules. First, due to the symmetrical design of the environments, each arrangement has an alternative version which is symmetrical, for example, position 1a is symmetrical to position 2a (Figure 3.1). As we have no reason to believe that position (left or right side) would affect results, only one of the two options was presented. Second, since features were presented on three walls, it seemed reasonable to select arrangements that distributed the elements somewhat equally across all three walls. By following these two rules, three arrangements for each level of number of features were selected. Please refer to Appendix A for a complete description explaining how the final set of environments was selected. In total, six control environments (no features) plus six environments per number of features—three panels and three doorways—were created based on the description above, resulting in a total of 24 environments as presented in Figure 3.2.

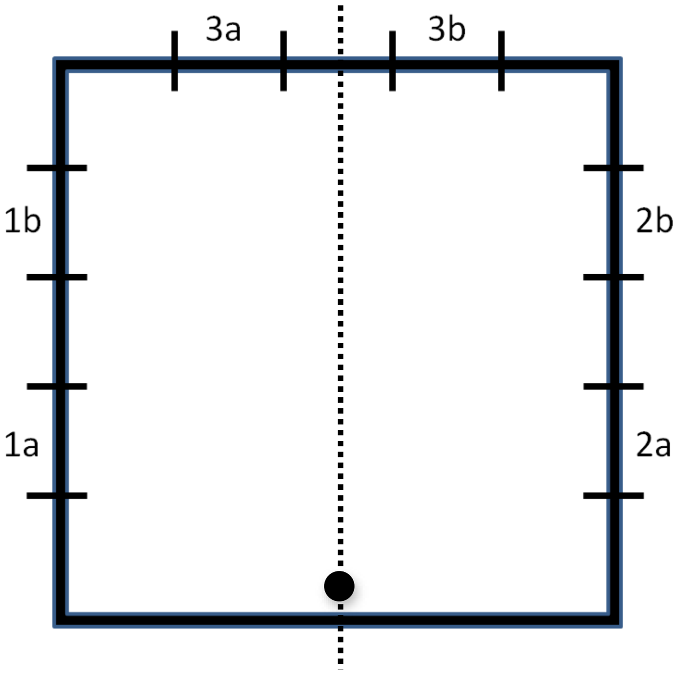
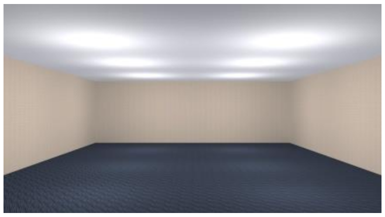
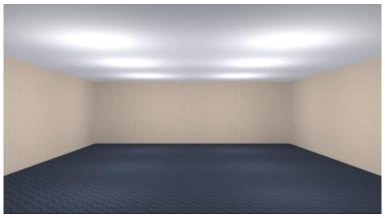
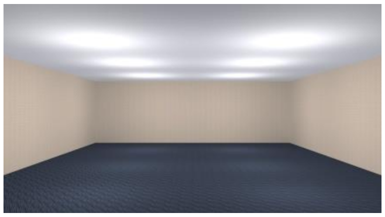
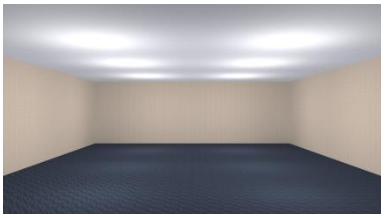
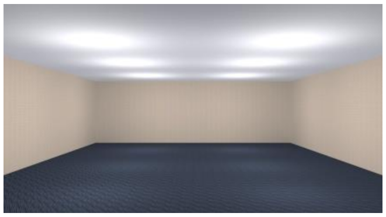
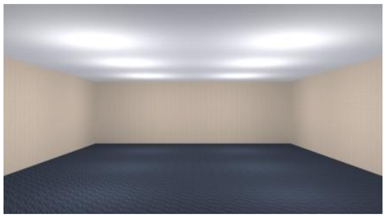
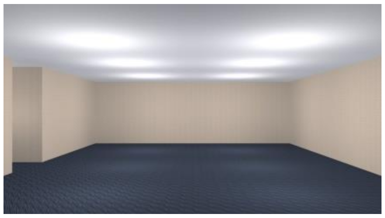
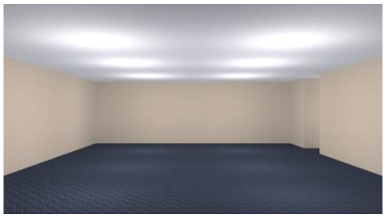


Figure 3.1. Since each image of the environment was taken from the circle, facing 3a and 3b, the environment could be symmetric depending on the feature locations selected as indicated by the dotted line. For example, an environment with a feature presented at 1a would be symmetrical to another environment with a feature presented at 2a.

	Arrangement 1	Arrangement 2	Arrangement 3
0 features	-  	-  	-  
1 feature	1a  	2a  	3b  
3 features	1a, 1b, 2a  	1b, 2b, 3b  	1a, 2a, 3b  

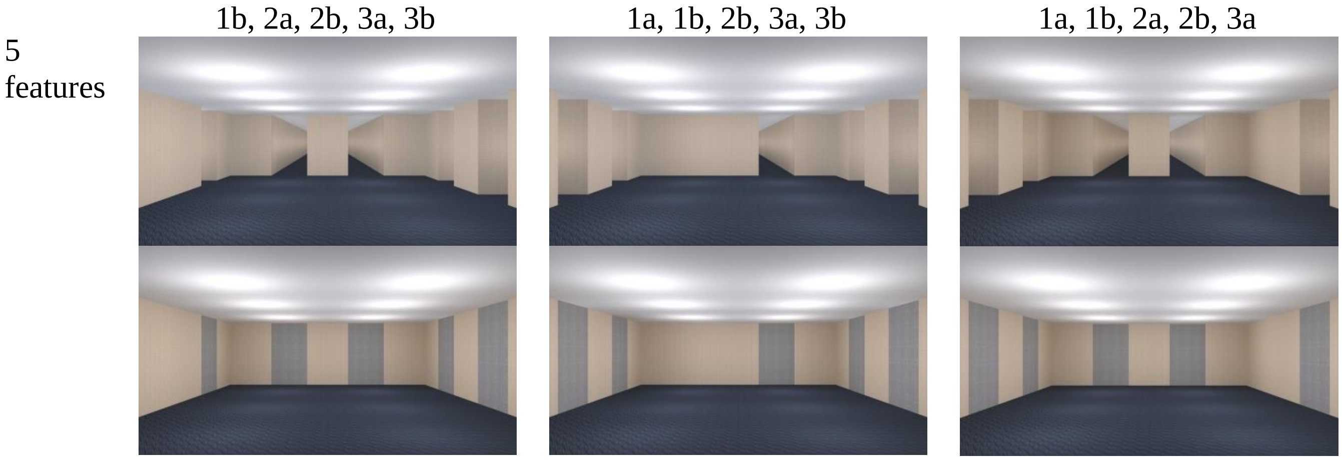


Figure 3.2. The final 24 selected environments. The feature arrangements were selected in order to distribute features across all three walls evenly and to ensure that only one version of a symmetric arrangement was presented. The arrangement of both the doorways and panels was identical.

Even with this reduction of total environments down to 24, if each environment was presented at each of the three presentation durations, there would be a total of 72 presentations per question, resulting in 216 trials per participant. Thus, presentation duration at each level of number of features was counterbalanced using a Latin square approach to ensure all possible environment by presentation durations were presented, resulting in a single presentation duration per environment for each participant (Table 3.1). Such counterbalancing for presentation duration resulted in 24 unique trials where presentation duration was dependent on the set (6 control, 6 doorway, 6 panel environments). Since within each set, the environment by presentation duration was presented three times, once for each emotional response question, there was a total of 72 trials.

Table 3.1.

Experimental design, featuring three distinct sets of presentation duration by environment identity

	Presentation Durations (ms)		
Environment	Set 1	Set 2	Set 3
0a	50	500	2500
0b	500	2500	50
0c	2500	50	500
1a	50	500	2500
1b	500	2500	50
1c	2500	50	500
3a	50	500	2500
3b	500	2500	50
3c	2500	50	500
5a	50	500	2500
5b	500	2500	50
5c	2500	50	500

Note. Each environment corresponds to both a panel and doorway environment

3.2.2. The environment.

The dimensions, overall design (textures and lighting), as well as rendering details, were the same as in Experiment 1.1. This experiment differed in that two types of environments were created; one featuring doorways and the other panels; feature position was selected as described above. Paneled environments were created by closing off the doorways with a textured, grey panel; thus, the positions and dimensions of the panels matched those of the doorways.

3.2.3. Emotional response ratings.

Interest and pleasure were examined using the same semantic differential items used in the previous experiment. Due to the presentation duration manipulation, questions were not presented at the same time as the environment, but instead were presented following the environment; this required a slight change in question wording from the previous experiment. Questions were changed from "How interesting/pleasing IS the environment?" to "How interesting/pleasing WAS the previous environment?" In addition to interest and pleasure, complexity was measured in the form of the question: "How complex was the previous environment?", below which a 7 item Likert scale was presented with 1 marked as "simple" and 7 marked as "complex".

3.2.4. Apparatus.

The experiment was designed in the programming language Python using the Pygame library of functions, allowing for the controlled presentation of stimuli and recording of responses and reaction time. Environments were presented on a 19 inch Samsung monitor using a Dell desktop computer. Each environment measured 1600 pixels in width by 884 pixels in height. Participants were seated in front of the screen at an approximate viewing distance of 80 cm.

3.2.5. Procedure.

Participants were welcomed to the lab and presented with an informed consent form. As presentation duration by feature number was counterbalanced (as described above), there were three distinct experimental sets; participants were randomly assigned to one of the three sets. Once seated at a computer, participants were instructed to press the space bar when ready to begin. At this point, instructions were presented on the computer screen and participants were presented with seven sample environments, one with zero openings and one for each number of features for both doorway and panel environments. Following instructions, participants were presented with six practice trials, where each level of feature number was presented once for both doorway and panel environments. Each of the three presentation times and questions was randomly assigned to two of the environments. The feature arrangements used in the practice trials were not used in the actual experiment. The sequence for each trial consisted of the following: a statement was presented in the centre of the screen that read "Press the space bar when ready for the next trial". Once the spacebar was pressed, a central fixation cross flashed on the screen for 500msec. Following the fixation cross, an environment was presented centrally on the screen, so that the centre of the environment was positioned at the same location on the screen as where the fixation cross was previously. The environment was presented for 50, 500 or 2500 ms. Then one of the semantic differential questions was presented on the screen; the presentation duration and the question were trial dependent. Once a response was made, using the 1-to-7 keys on the keyboard, the next trial would begin with the presentation of the "Press space bar when ready to begin the next trial" instruction screen. Trial presentation within each set was randomized. Following completion of the experiment, participants were provided with a debriefing form, thanked for their participation and were free to go.

3.2.6. Participants.

A total 38 participants (22 female) completed the experiment for course credit. All participants rated interest and pleasure, while due to technical issues, 18 of them also rated complexity. The experiment was approved by the University of Waterloo Office of Research Ethics and each participant completed an informed consent form prior to beginning the experiment.

3.3. Results

3.3.1. Complexity.

For perceived complexity, the interaction between environment type and presentation time was significant, $F(2,36) = 6.89$, $p < 0.01$, $\eta_p^2 = 0.28$. Simple effects analysis suggested a significant difference between 50 ms ($M = 2.25$, $SE = 0.15$) and 500 and 2500 ms ($M = 2.01$, $SE = 0.16$ and $M = 2.00$, $SE = 0.17$) was only present for panel environments. See Figure 3.3 below.

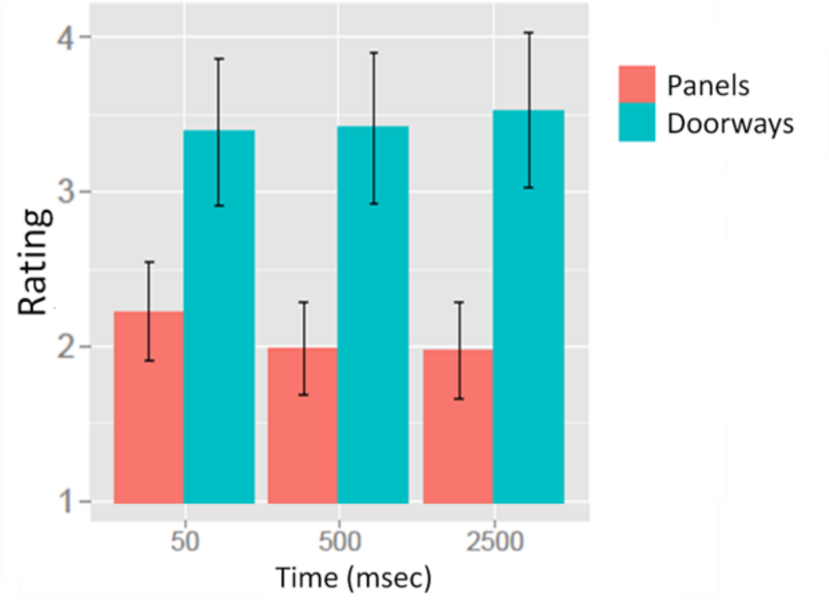


Figure 3.3. The interaction between presentation duration and feature type on complexity ratings. Presentation durations of 50msec were more complex than 500 and 2500msec durations but only for panel environments.

The main effect of feature type on complexity was significant, F(1,18) = 64.46, $p < 0.001$, $\eta_p^2 = 0.79$. Bonferroni corrected pairwise comparisons show that doorway environments (M = 3.49, SE = 0.1) were rated as more complex than the panel environments (M = 2.09, SE = 0.16). There was also a main effect of the number of features on complexity, F(3,54) = 187.96, $p < 0.001$, $\eta_p^2 = 0.913$. Each level of the number of features was significantly different, from the others at an alpha level of at least 0.05, such that increasing the number resulted in increased complexity (0 features: M = 1.04, SE = 0.025; 1 feature: M = 2.03, SE = 0.12; 3 features: M = 3.39, SE = 0.17; 5 features: M = 4.69, SE = 0.19). See Figure 3.4.

The interaction between number of features and environment type was significant, F(2,54) = 53.62, $p < 0.001$, $\eta_p^2 = 0.75$. Simple effects analysis showed that doorway environments were more complex than panel environments at all levels, except at control, where they were equally complex, M = 1.07, SE = 0.04 and M = 1.02, SE = 0.02. It is possible that the interaction is a result of the way in which data was coded in order to run the ANOVA. Since the control condition was an empty room it could not be presented as a doorway or panel environment, thus in order to include it within the ANOVA, three control conditions were randomly coded as doorway environments while the three were coded as panel environments. To test whether the interaction was driven by these control environment, an additional ANOVA was conducted excluding control environments were excluded. Once again, the interaction holds, $F(2,38) = 40.12$, $p < 0.001$, $\eta_p^2 = 0.75$.

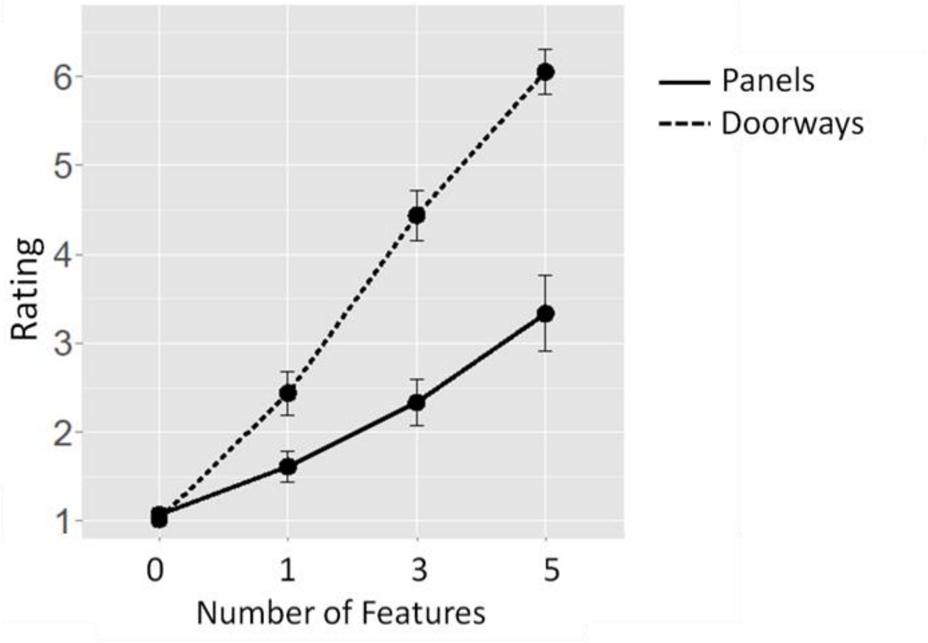


Figure 3.4. The interaction between number of features and feature type as well as the main effect of number of features on complexity ratings.

3.3.2. Pleasure.

For pleasure responses, only the main effect of time was significant, $F(2, 76) = 14.81$, $p < 0.001$, $\eta_p^2 = 0.28$ (Figure 3.5). Bonferroni corrected pairwise comparisons showed that 50 ms ($M = 3.29$, $SE = 0.15$) was less pleasant than both 500 ms and 2500 ms presentation durations ($M = 3.67$, $SE = 0.15$ and $M = 3.85$, $SE = 0.16$).

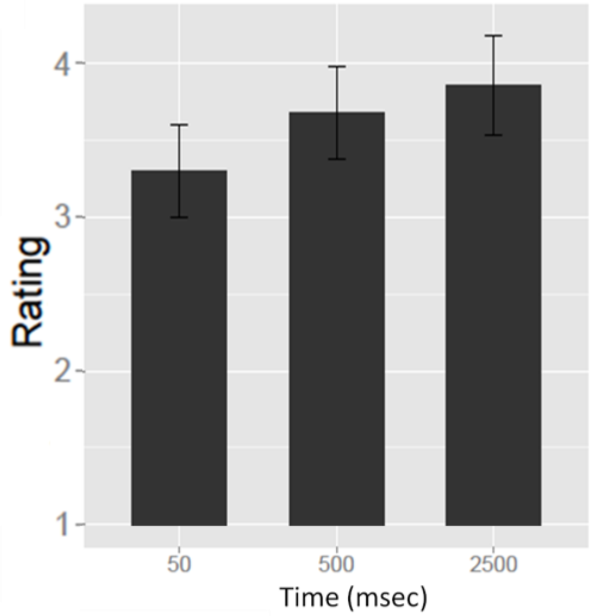


Figure 3.5. The main effect of presentation duration on pleasure ratings.

3.3.3. Interest.

For interest responses, the interaction between feature type and time was significant, $F(2,76) = 3.76$, $p = 0.03$, $\eta_p^2 = 0.09$ (Figure 3.6). Simple effects analysis showed that, for doorway environments, 50 ms was less interesting than 500 and 2500 ms, ($M = 3.54$, $SE = 0.14$; $M = 3.89$, $SE = 0.16$ and $M = 3.96$, $SE = 0.12$), while this effect was absent for panel environments ($M = 2.8$, $SE = 0.16$; $M = 2.76$, $SE = 0.16$ and $M = 2.99$, $SE = 0.17$).

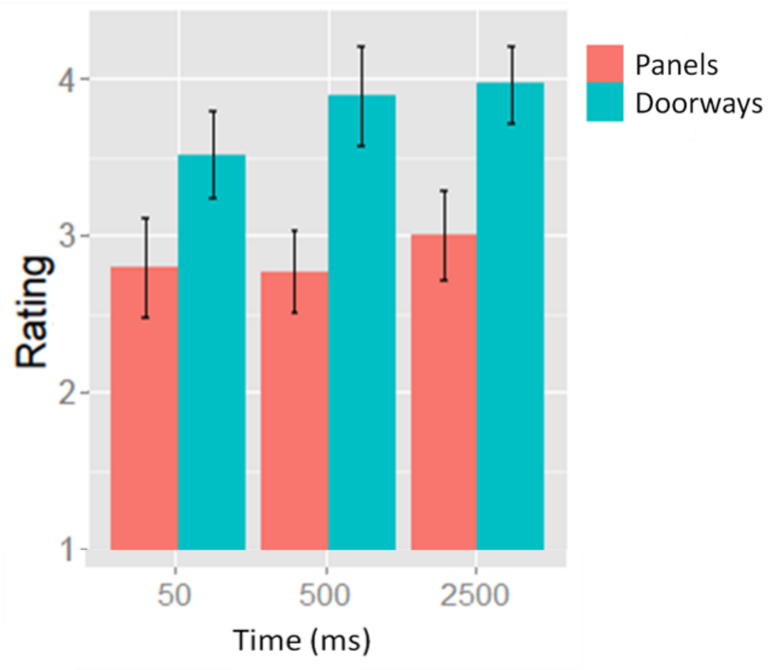


Figure 3.6. The presentation duration by feature type interaction on interest responses was significant so that 50 ms presentation durations were least interesting but only for doorway environments.

Regarding interest responses, several main effects were also significant as displayed in Figure 3.7. The main effect of environment type was significant, $F(1,38) = 33.23$, $p < 0.001$, $\eta_p^2 = 0.47$, where doorway environments ($M = 3.8$, $SE = 0.12$) were more interesting than panel environments ($M = 2.86$, $SE = 0.15$). The main effect of number of features was also significant, $F(1.61, 61.18) = 78.71$, $p<.01$, $\eta_p^2 = 0.67$. Pairwise comparisons using a Bonferroni correction showed that all levels of number of features were significantly different from one another, at an alpha level of 0.05, with interest appearing to increase as number of features increased (0 features: $M = 1.95$, $SE = 0.16$; 1 feature: $M = 2.98$, $SE = 0.13$; 3 features: $M = 3.89$, $SE = 0.14$

and 5 features: M = 4.49, SE = 0.18). Please refer to Figure 3.8 where interest and pleasure are both displayed as a function of feature type and number of features. As was the case for complexity responses, the interaction between number of features and environment type was a result of the way data was coded in order to run the 2X4 repeated measures ANOVA and is thus not a true effect.

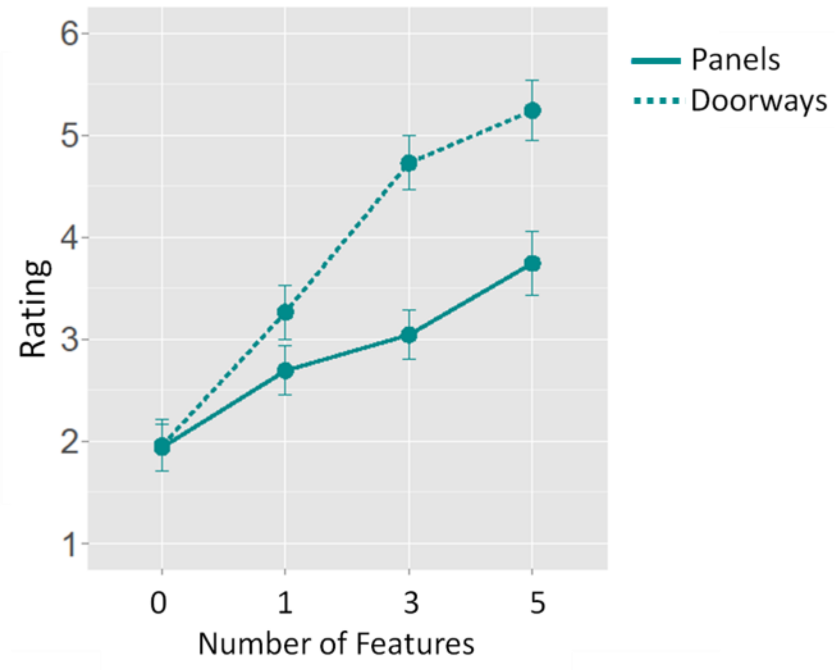


Figure 3.7. The main effects of number of features and environment type on interest ratings.

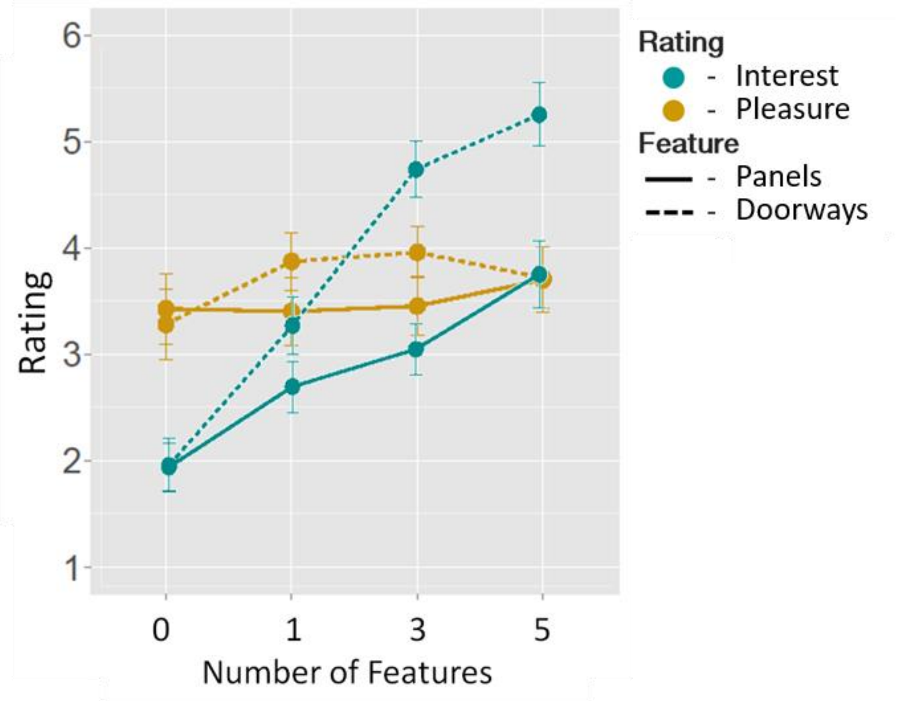


Figure 3.8. The main effects of feature type and number of features were both significant for interest but not for pleasure.

3.3.4. Path analysis.

Path and mediation analysis was conducted as suggested by Preacher and Hayes (2004) and Pedhazur (1997). Emotional responses of interest and pleasure were dependent variables while environment features in the form of environment type, number of features and presentation time were treated as predictors and perceived complexity was considered as a mediator. First, we examined if the physical environment predicted interest and pleasure, following which we examined if these relationships are mediated by perceived complexity. As was the case in the first experiment, and as suggested by Bland and Altman (1994; 1995), within-participant variability was controlled for by considering participants as a categorical variables allowing their intercepts to vary. Thus participants were considered as a random variable while the environmental properties were a fixed effect. Only those effects that were significant at a $p < 0.05$ were included in the final model.

Please refer to Figure 3.9 for the mediation model showing interest as predicted by environmental properties (environment type and number of features) and mediated by perceived complexity. Number of features predicated both interest and complexity positively, while doorway environments were more interesting and complex than panel environments. The direct effect of number of features on interest was partially mediated by complexity scores, Sobel test = 6.42, SE = 0.02; when complexity was included as a mediator the beta coefficient between number of features and interest fell from $\beta = 0.438$ to $\beta = 0.152$ but remained significant, $p < 0.01$. On the other hand, the effect was fully mediated by complexity, Sobel test = 5.44, SE = 0.074, $p < 0.001$, with the beta coefficient between status and interest falling from $\beta = 0.789$ to $\beta = 0.074$, and becoming non-significant, $p = 0.6$. Time predicted neither complexity nor interest. The final model featuring number of features, environment type and complexity as a mediator, predicted 44% of interest responses, $R = 0.66$, $R^2 = 0.44$, $R^2_{(adj)} = 0.41$, $F(21, 434) = 16.31$, $p < 0.001$.

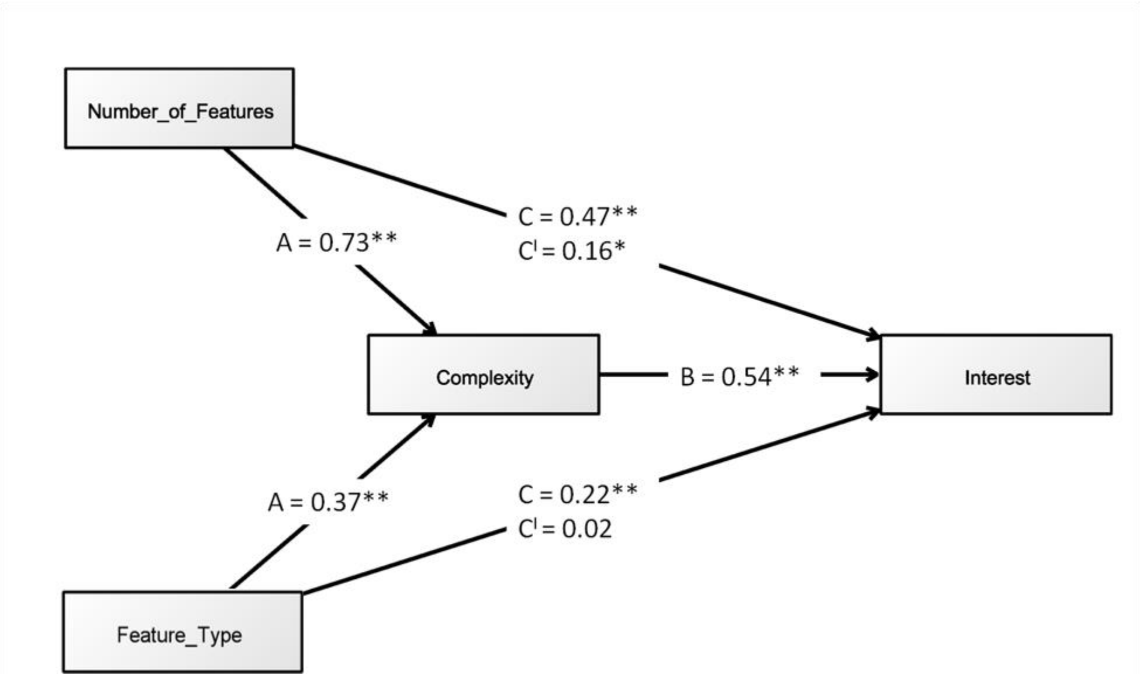


Figure 3.9. Model showing standardized beta coefficients with number of features and environment type as predictors, interest as the outcome variable and perceived complexity as a mediator.

** p < 0.01; ** p < 0.001*

Please refer to Figure 3.10 for model showing pleasure as predicted by time. Pleasure was not significantly predicted by number of openings or environment type but was predicted positively by presentation time. Time did not predict complexity, nor did complexity predict pleasure. A final model featuring time and interest as the only significant predictors of pleasure accounts for 34% of variability in pleasure responses, $R = 0.58$, $R^2 = 0.34$, $R^2_{(adj)} = 0.31$, $F(19, 436) = 20.96$, $p < 0.001$.

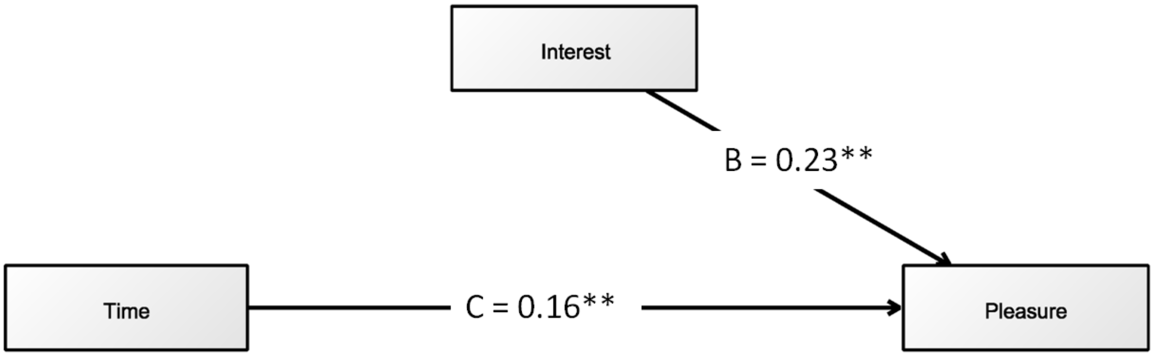


Figure 3.10. Path model showing significant predictors of pleasure. Standardized beta coefficients are displayed.

** $p < 0.001$.

3.4. Discussion

3.4.1. Pleasure and interest.

As was the case in Experiment 1.1, increasing the number of features within an interior environment had a positive effect on interest, while failing to affect pleasure. This positive effect of number of features on interest occurred regardless of feature type; as increasing the number of either doorways or panels led to increased interest. This finding is consistent with other research demonstrating a similar positive relationship between façade complexity and interest response (Stamps, 2010; Wohlwill, 1968; 1975; Heath, Smith & Lim, 2000), but here, for the first time, the effect is demonstrated using interior environments.

Additionally, doorway environments were rated as more interesting than their panel counterparts. This difference could be due to the fact that doorways afford exploration, which may result in additional information gain. This possibility is addressed by Kaplan (1987) where the concept of mystery is defined as environmental preference resulting from the prospect of additional information gained through exploration. Such an effect implicates a cognitive process, where possible future engagement with the environment is factored into the emotional response. Although the interpretation that potential information gain afforded by doorways results in increased interest, a simpler explanation is also viable. Perhaps doorway environments are more interesting for the fact that, from a bottom-up visual perspective, they are more complex; panels are composed of four lines and are two-dimensional, on the other hand, doorways are composed of five lines and appear three dimensional in nature. Indeed, the main effect of status was significant regarding complexity ratings; doorway environments are experienced as more complex. Similarly, recognition and scene categorization occurs preattentively resulting from statistical analysis of the geometry of the space (Oliva & Torralba, 2001). Thus, it is possible that interest was a result of changes to geometry of the space resulting from the introduction of doorways, and thus occurring prior to cognitive appraisals of potential information gain. Although this preattentive perceptual process may explain how changes to the geometry of space are perceived, it does not explain why these changes are experienced as more interesting. It is still possible that, following the preattentive perception of changes to geometry, a cognitive mechanism regarding potential information gain is triggered, resulting in interest. Thus it is still unclear if the positive effect of doorways on interest is a result of the low-level perceptual differences between doorways and panels, or higher level cognitive concepts regarding engagement with the environment and potential information gain.

In the interaction between environment type and time on interest, participants rated 50 ms exposures as less interesting than 500 and 2500 ms exposures, but only for doorway environments. It seems that panel environments are rated as low in interest regardless of presentation time, while interest for doorway environments increased after 50 ms. This suggests that regardless of how long a panel environment is viewed, it will be perceived as equally interesting, whereas doorway environments will be least interesting at brief presentation durations. These effects of presentation duration may be a result of a viewer's ability to make sense of the information present within the environment. Silvia (2005a; 2005b; 2008), for example, demonstrated that interest resulted not simply from complexity, but from complexity that was processed efficiently and that was understandable. Thus, when presented for 50 ms the complexity cannot be interpreted and is experienced as less interesting. If this is the case, how do we explain the lack of effect for panel environments? Although increasing presentation duration may have resulted in improved understanding of panel environments, because they were already low in complexity, interest was not experienced. Thus when an environment is simple, as was the case with the panel environments, improving understandability through increased presentation durations does not affect interest; understanding becomes relevant only when possessing high levels of initial complexity as present in the doorway environments.

Although the physical features of the environment did not affect pleasure, a main effect of presentation time was noted. Our hypothesis was partially supported with a significant effect of presentation time noted on pleasure, but not interest. Brief presentation durations (50 ms) were experienced as least pleasant, while intermediate and longer viewing times were equally pleasant. This finding suggests that pleasure results from processing fluency; at low presentation times it becomes effortful to perceive the environment and thus pleasure decreases (Reber, Schwarz & Winkielman, 2004; Chen, Wu & Wu, 2011). It is tempting to attribute low pleasure at 50 ms as resulting from participants not being able to perceive the environments accurately. This interpretation seems unlikely as there was no interaction between time and number of features regarding complexity ratings, demonstrating that participants were accurately able to perceive and rate complexity even at low presentation durations. Such findings also correspond to research showing that geometry of environments is processed quickly and preattentively (Oliva & Torralba, 2001). Thus, emotional responses are still formed rapidly but brief presentation durations lowered processing fluency thus decreasing pleasure.

As was the case in the previous experiment, a dissociation between interest and pleasure was demonstrated; number of features, feature type, presentation duration and perceived complexity affected pleasure and interest differentially. The pattern of results presented in this first set of experiments demonstrated that when both interest and pleasure were measured the effect of complexity was variable; whereas interest was positively predicted by complexity, pleasure was not. The relationship between interest and complexity is to be expected if we consider interest as epistemological emotion, whose main purpose is information gain (Silvia, 2008). Indeed, principles from a branch of mathematics known as information theory are often used to describe and quantify complexity; the general premise is that complex stimuli carry more information than more visually impoverished stimuli; this information leads to interest (Donderi, 2006a; Gunawardena, Kubota & Fukahori, 2015).

3.4.2. Perceived complexity.

In Experiment 1.1, we made the reasonable assumption that increasing the number of features (doorways) increased the objective complexity of the environment (Berlyne, 1971; 1974), yet were unsure if this would result in increased subjective experience of complexity. Thus, in this experiment we measured subjective complexity, hypothesizing that subjective complexity would increase linearly with increased number of features. This hypothesis was confirmed as increasing number of features resulted in greater perceived complexity with linear regression suggesting that the effect of number of features on complexity was positive and linear. This result is consistent with previous research suggesting that as the number of individual elements increases so does perceived complexity (Berlyne, 1971; Day, 1967; 1968). As described in above in section 3.4.1., the doorways are perceived as more complex than panel environments, either because they allow for additional exploration and information gain or because they contain a greater number of low-level visual elements.

Importantly, an interaction was also noted between feature type and number of doorways, such that doorways were more complex than panels when possessing a greater number of features. Thus, when there are three or five doorways, complexity increases dramatically, as compared to one doorway as well as three or five panels. This suggests an additive effect of doorways and number of features, perhaps resulting from the greater degree of exploratory choices afforded by an environment with many doorways.

Finally, an interaction was noted where brief viewing durations resulted in higher assessments of complexity for panel but not for doorway environments. This interaction could result from the preattentive perceptual process underlying perception of spatial and geometric properties of the environment (Oliva & Torralba, 2006). It is possible that doorway environments tap into this rapid perceptual mechanism, allowing them to be perceived easier at brief presentation durations, thus being experienced as less complex. On the other hand, perception of panel environments cannot tap into this rapid, preattentive perceptual process and are therefore perceived as being more complex at brief presentation durations. Thus, doorways are processed more efficiently than panel environments at brief presentation durations due to a highly specialized mechanism for perception of the holistic, spatial and geometric properties of the environment.

3.4.3. Perceived complexity as a mediator of emotional response.

Moving away from typical bottom-up explanations of complexity on emotional response resulting from arousal, this experiment examined if cognitive appraisals mediate the effect of stimulus properties on emotion (Silvia, 2005a; 2010; Smith & Ellsworth, 1985). In this cognitive appraisal perspective, interest, for example, results from perceived or subjective experience of complexity (Silvia, 2005b; 2008; Turner & Silvia, 2006). Mediation analysis demonstrated that the direct effect of number of features was partially mediated by perceived complexity, while the effect of status was fully mediated by perceived complexity.

The mediating role of complexity has been exhibited using a variety of visual stimuli, but this is the first time it has been demonstrated as underlying emotional response to environments (Silvia, 2005; 2008). Pleasure did not result from perceived complexity, although pleasure may result from other cognitive appraisals, such as goal congruence (Turner & Silvia, 2006). By considering cognitive components underlying emotional response to environmental complexity, this approach positions environmental experience research alongside more nuanced perspectives within the emotion literature, introducing a potentially useful manner by which to conceptualize experience of the environment.

3.4.4. Summary and Conclusions.

In relation to the hypothesized effects, the results of this experiment can be summarized as follows:

Numerosity, both in the form of geometric and featural elements is related to perceived complexity and interest but not pleasure; the effect of number of features on interest was mediated by perceived complexity while doorway environments were experienced as more interesting than panel environments. This may be a result of the fact that doorways suggested additional exploration and information gain, or simply because doorways were more complex perceptually than panel environments. Finally, presentation duration had a negative effect on pleasure while failing to affect interest.

Experiments 1.1 and 1.2 demonstrate, for the first time, that factors which modify geometry of interior environments influence perceived complexity, which has an effect on emotional response. The observed dissociable effect of complexity on interest and pleasure shows the importance of considering more nuanced conceptualizations of emotional response to the environment. A cognitive mechanism was suggested as an alternative to the classic arousal mechanism, demonstrating that interest responses were partially mediated by a cognitive component of perceived complexity.

In Experiments 1.1 and 1.2, increasing the number of features, whether doorways or panels, resulted in complexity, shaping emotional response. This finding holds for both types of features, despite the fact that doorways affect the environment by modifying the geometry of the space, while panels only present information in a two-dimensional fashion. Such numerosity approaches to complexity are common, but others have been suggested, with visual diversity being particularly promising (Donderi, 2006a; Stamps, 2002). For example, if the number of panel features was kept the same, but the identities and properties of the individual panels differed, we might expect a strong effect on complexity. The next two experiments examine such diversity-based manipulations of interior environmental complexity, while still considering a cognitive approach to emotional response where pleasure and interest are both considered.

Chapter 4 - Experiment 2.1: Entropy as a diversity based measure of featural complexity of the environment

4.1. Introduction

Visual complexity can be generated by modifying either the geometry or featural elements of the environment, both of which were employed in the first two experiments; doorways manipulated geometry while panels manipulated featural complexity. Increasing the number of either resulted in increases in perceived complexity and positively influenced emotional response. This positive effect of complexity is argued as resulting from the information contained and communicated by the complexity (Silvia, 2008). Our innate motivation to seek new information is one of our defining characteristics; thus we experience positively those environments which meet this information seeking need (Kaplan, 1985; Biederman & Vessel, 2006). Increasing the number of elements, as we did in the previous experiments, is experienced positively because the increased complexity was informative (Ramanarayan, Bala, Ferwerda & Walter, 2008). Although numerosity is one way by which to generate complexity, another approach is possible. Inspired by information theory, increasing diversity may also affect complexity and thus influence emotional response.

4.1.1. Information theoretic approaches to complexity.

It is possible to increase complexity and thus information content by modifying properties and identities of the individual elements rather than numerosity. Generally, as the overall diversity and heterogeneity of the elements increases so should complexity and information content. For example if we compare a two sets of elements, (A,A,A,A) to (A,B,C,D), we see that the number of elements is the same, but in the first set all elements are the same, while in the second set all different. Intuitively, the second set is more complex and provides us with more information. This suggests that complexity is provided by the probability of an event's occurrence; less likely and less probable events carry more information. This diversity based approach is drawn from information theory (Shannon, 1948; Donderi, 2006a) arguing that information and thus complexity are proportional to the probability of an outcome's occurrence. Consider an intuitive example to demonstrate that less probable events are more informative. You are taking a lunch order for a colleague, and they tell you that they would like sushi. This is the tenth time this month that they have requested sushi; thus, from this expected request, you do not gain any new information regarding their food preferences. Now, consider that instead of asking for sushi, they ask you to get them butter chicken. You gain new information regarding your colleague's food preferences: they like butter chicken! This unexpected butter chicken request is thus more informative than their much more probable and expected request for sushi.

From this simple example, we can see that probability plays an important role in defining information content which can itself be described using information entropy as suggested by Claude Shannon (1948). Originally developed to describe the information content of word and letter strings, entropy relies on probabilities to quantify information content of wide range of stimuli. Shannon's entropy term is calculated as follows:

$$H = -\sum p(x) \log p(x)$$

Similar to other measures of information content, Shannon's entropy uses Boolean values to code an events occurrence but distinguishes itself by placing a strong emphasis on the probabilistic occurrence of the events. By describing all possible events using binary code, we can quantify the amount of information present in a set. Consider event A that occurs with a probability of 0.5, and events B and C that occur with a probability of 0.25. To code the raw information available in these events you would need two bits: (a) could be coded as 00, (b) as 11, and finally (c) as 10. In order to represent the events in terms of such Boolean values, the probabilities are log(2) transformed so that:

p(a) = 2/4

log(2)*2/4 = 1 bit

and

p(b)(c) = 1/4

log(2)*1/4 = 2 bits

Such a general coding scheme considers all possible events without taking into account the probability of occurrences, but instead simply tells you how many bits are required to represent the event. Consider that (a) will occur one out of every two times, thus half of the time, only a single bit will be needed to describe the event (0); two bits will only be needed the other half of the time, when either (b) or (c) occur. Thus, on average, the event will be described by less than two bits. Shannon entropy takes into account such event probabilities and calculates the average amount of information in a set of events, rather than relying on the raw amount of information present in the set. This coding approach is much more efficient than simply coding the raw amount of information present within the events. For the example above, by factoring in the probabilities for each event, and summing them together to represent information carried by all possible events, we get the following:

$$(p_a*\text{bits}_a)+(p_b*\text{bits}_b)+(p_c*\text{bits}_c) = \text{information (bits)}$$

$$(0.5*1)+(0.25*2)+(0.25*2) = 1.5 \text{ bits}$$

This calculation shows us that on average, 1.5 bits are required to present the events (a), (b) and (c); thus this set of events has a total of 1.5 bits of information.

Although Shannon developed a way to quantify information content within a series of events, others have applied similar probabilistic approaches to describe complexity of visual stimuli. By manipulating the probabilistic occurrence of elements within visual arrays, Berlyne (1974b) generated arrays varying in redundancy and uncertainty; uncertain arrays were argued as being more complex and informative. Indeed, as uncertainty increased, participants experienced the arrays as more complex and pleasing. The effect of uncertainty and redundancy on complexity and emotional responses has also been explored using dot and sound sequences (Normore, 1974) as well as area of shapes (Hare, 1974), finding similar effects between complexity and positive experience.

As opposed to the drawing on terms such as uncertainty and redundancy, others have calculated entropy directly for sequences of letters (Vitz & Todd, 1969) and grid type stimuli (Snodgrass, 1971), demonstrating that increased entropy resulted in increased complexity. Within the fields of computer vision and statistical image analysis, entropy has been used as a measure of complexity in numerous experiments, demonstrating consistent effects on perceived complexity (Cavalcante et al., 2014; Perkio & Hyvarinen, 2009; Cardaci, Di Gesu, Petrou & Tabacchi, 2006). Such entropy measures have been shown to affect emotional response as well; positive, linear effects on interest have been noted (Hare, 1974), as well as an inverted-u shaped effect on pleasure (Normore, 1974). In addition to these experiments, relying on impoverished, synthetic visual stimuli, several experiments have examined entropy of complex environments.

4.1.2. Environmental entropy & emotional response.

Diversity of environmental features such as ornamentation and surface details have both been shown to result in complexity and preference (Stamps, 1998b; 1999b). From here, information-theoretic approaches have been applied in an effort to accurately describe the degree of complexity present within the environment. Stamps (2002) manipulated colour, shape and façade articulation, to generate entropy values ranging from 0 to 5.6 bits, demonstrating that increasing entropy through any of these three façade features resulted in increased perceptions of diversity. These increases in entropy resulted in a positive, linear increase in pleasure, while an inverted-u shape relationship was tested but not found. Using a broad range of environment types, ranging from residential blocks, to high-rise buildings, to commercial buildings, Stamps (2004) showed that the relationship between entropy and perceived diversity and complexity was strong and consistent (r = 0.73). Once again the inverted-u relationship between entropy and pleasure was not found, instead appearing to be linear, with both positive and negative relationships exhibited, depending on environment type. Specifically, entropy of older building façades, residential blocks and sign-scapes affected pleasure negatively, while entropy of commercial buildings, high-rise buildings, façade colour, articulation, shape and scale all predicted pleasure positively. Taking a meta-analytic approach, examining simple visual stimuli, whole environments as well as auditory stimuli, Stamps (2003) demonstrated that the relationship between entropy and rated diversity/complexity was consistent and strong (r = 0.87) and that the effect on preference was either linear or asymptotic. In the meta-analysis an inverted-u relationship between entropy and pleasure was found only for auditory stimuli.

Finally, the influence of façade entropy on restorative response has recently been examined (Lindal & Hartig, 2013). Restorative responses occur when environmental features (most often natural elements) lead to a recovery of attentional resources and reduction of stress (Valtchanov, Barton & Ellard, 2010). Façade entropy predicted feelings of being away and fascination, which in turn increased the restorative potential of the environment (Lindal & Hartig, 2013).

The research above suggests that entropy should predict complexity consistently and although its effect on emotional response is less certain, but a positive linear relationship is probable. Crucially, this experiment will test the effect of entropy, not only on pleasure but also on interest, which to this point has not been examined in the environmental experience literature. Prior to testing the effect of entropy on emotional response, we will ensure that entropy serves as a valid manipulation of perceived complexity. Thus, the objective of this experiment is to test the robustness of the complexity effect on interest and pleasure, by employing a novel manipulation of complexity in the form of entropy.

4.1.3. Behaviour and emotional response to the environment.

Most environmental experience research relies on subjective, verbal responses—such as those used in Experiments 1.1 and 1.2—to probe environmental preference and emotional response. Such overreliance on subjective responses may be problematic for several reasons. Although subjective responses using semantic differential approaches have been shown to be both valid and reliable measure of emotions (Kuppens, Tuerlinckx, Russell & Barrett, 2013) the approach requires an individual to disengage from their environment and take an evaluative, introspective stance to judge their current emotional state (Heft & Nasar, 2000). This is different from how we respond to our surroundings and form emotional responses during naturalistic interactions with real environments; we do not necessarily stop, look at our environment and decide how it makes us feel or judge whether we prefer it over another environment. Instead, our experience of the environment is dynamic, occurring in real-time; where our preferences and emotions manifest themselves through our behaviours—we choose to spend time in, and walk through environments that we find pleasing and interesting and avoid those that are unpleasant. Such dynamic behaviour within the environment is a perceptually rich experience; proprioceptive cues, motion parallax, object occlusion/disocclusion and optic flow are all available to an observer actively experiencing and moving through their environment (Gibson, 1976). Indeed such cues, gained from dynamic experiences, result in improved scene perception (Simons & Wang, 1998; Wang & Simons, 1999) and location memory (Christou & Bulthoff, 1999). When it comes to preference and emotional response, Heft and Nasar (2000) demonstrated that static displays lead to higher preference scores as compared to dynamic displays, while responses towards dynamic displays were predicted by a wider range of environmental variables. These findings suggest that subjective verbal responses may differ from behavioural measures of emotional response due to the simple fact that the dynamic nature of moving through an environment results in richer perceptual experience. For these reasons, this experiment will compare subjective ratings of pleasure and interest to behavioural measures of emotional response within large-scale virtual environments.

By comparing behaviour to subjective emotional response, we position emotions as functional; where emotional states determine certain behaviours and coping strategies (Izard, 1992). For example, pleasure results from situations that are conducive to one's current goals and thus lead to behaviours that focus on maintaining current environmental states and situations—if they are goal conducive—or changing the situation towards a more goal conducive state (Frijda, Kuipers & ter Schure, 1989). An individual feeling displeasure in their current situation may engage in behaviours that create a situation that is more conducive to current goals and needs, thus resulting in pleasure. Interest, on the other hand, is related to preparedness for action and acquisition of information (Frijda, Kuipers & ter Schure, 1989; Silvia, 2005, 2008). Thus, feelings of interest result in increased exploratory and information seeking behaviour and prepare an individual to act (Berlyne, 1970; Silvia, 2008). Such functional perspectives have also been expressed by environmental psychology researchers, where positive emotions towards environments are a result of the beneficial interactions with the environment (Kaplan, 1977; 1987). If emotions are closely tied to behaviour, then examining behaviours as opposed to subjective measures may give us a more naturalistic method through which to examine experience of the built environment. Indeed, research using simple visual stimuli demonstrates consistently strong relationships between emotion and behaviour.

Although simple behavioural measures, such as viewing time and viewing selection frequency, have been used as behavioural analogues of emotional response (Wohlwill, 1968; 1975; Berlyne, 1974d, Nasar, date; Silvia, 2005; Stamps, 2003; Bradley, et al., 2011), environments lend themselves to the measurement of a much fuller examination of behaviour—environments, after all, afford exploration and other rich forms of behaviour. Self-reported approach-avoidance ratings have been shown to be dependent on an interaction between pleasure and arousal (Mehrabain & Russell, 1974a), while an examination of environment contour demonstrated that pleasant environments were rated as more approachable (Vartanian, et al., 2013). Although these results show that verbal approach-avoidance responses are aligned with subjective emotional responses, they did not measure behaviour directly. As discussed at the start of this subsection, such subjective responses may not accurately describe emotional response or behavioural intention. By immersing participants in a virtual reality environment, we can measure a wide range of naturalistic behaviours including path selection, time spent in particular areas and movement speed. Virtual reality has been used previously to examine a wide range of phenomena, including navigation behaviour (Barton, Valtchanov & Ellard, 2012; Steck & Mallot, 2000; Ruddle, Pain & Jones, 1997; Newman, Caplan, Kirschen, Korolev, Sekuler & Kahana, 2007), distance estimation (Knapp & Loomis 2003; Messing & Durgin, 2005) and even interpersonal interactions (Llobera, Spanlang, Ruffini & Icrea, 2010). From an environmental experience perspective, VR has been used to explore the restorative effects of nature (Valtchanov, Barton & Ellard, 2010) while others have examined feelings of beauty as resulting from properties of interior environments (Franz, von der Heyde & Bulthoff, 2005).

Perhaps the most relevant research was conducted by Stamps (2010), where entropy was manipulated through varying paintings within virtual environments and interest was probed through exploration time. Results demonstrated that participants spent more time exploring high entropy environments, argued as resulting from increased information content provided by the entropy. Although this finding is informative, it bears mentioning that subjective emotional responses towards the environments were not measured, thus not allowing for a direct comparison between exploration behaviour and subjective emotional response. In addition, the entropy manipulation used by Stamps (2010), was somewhat unusual, accomplished by placing paintings in the environment as opposed to actual features and elements of the environment. In order to address these concerns, this experiment will employ virtual reality to directly examine behavioural analogues of subjective emotional responses of interest and pleasure while manipulating entropy through textured features within the environment. Specifically, a large virtual environment consisting of corridors with forked intersections was created; at each intersection, participants had to select and navigate through one of two possible corridors. The entropy of the two possible corridors differed by manipulating probabilistic occurrence of a series of decorative panels within the corridors. Having such a large, virtual environment allowed us to both immerse participants within the environment and monitor their behaviour while also allowing us to take still images of the corridors and present them to participants to gauge subjective responses of interest and pleasure.

4.1.4. Experiment 2.1 objectives.

To summarize, the objectives of this third experiment are as follows. First, by using entropy of featural elements, we explored an additional method by which to generate complexity, related closely to information content of the environment. Second, this experiment examined the effect of featural complexity as described by entropy on responses of pleasure and interest, and explored whether these effects are mediated by perceived complexity. Once again, this positioned positive emotional response as comprising of both pleasure and interest, independently. These approaches provided us with a powerful comparison to the numerosity based complexity measures used in Experiments 1.1 and 1.2, allowing us to examine the robustness of the complexity effect noted earlier. Third, the experiment compared subjective emotional responses to behavioural measures of emotional response as inferred from exploratory behaviour, thus expanding emotional response beyond simple subjective responses.

4.2. Methods

4.2.1. Generation of entropy.

Entropy can be generated from any set of events or features in the environment with known probabilities of occurrence. Previously, the probability of façade articulation, colour, shape and window trim have been examined (Stamps, 2002, 2003, 2010). Since interior environments, as opposed to façades, were used here, it was necessary to select an environment feature that could vary in a naturalistic manner. In the only other experiment where interior environment entropy was calculated, paintings placed on the walls were used (Stamps, 2010); this approach is potentially problematic as paintings are not part of the built environment, but are instead stimuli placed into the environment. Additionally, the fact that paintings possess meaning and are highly salient, may confound any entropy effects on emotional response. In order to avoid such pitfalls, the environments were created by placing four decorative paint patterns or wallpaper panels in the environment. Please see Figure 4.1 for a visualization of the panels and their position within the environment. By varying identities of the panels—whether they were the same, different or any arrangement in between these two extremes—we generated probabilities per panel identity occurrence and used these to calculate entropy for each environment. Thus when all panels were the same, the environment was least entropic (and least complex), while when all panels were different, the environment was most entropic (and most complex). The probabilities between this total homogeneity and heterogeneity possessed moderate levels of complexity as quantified by their moderate entropy values. Since there are four panel locations within the environment it is necessary to design four distinct panels.

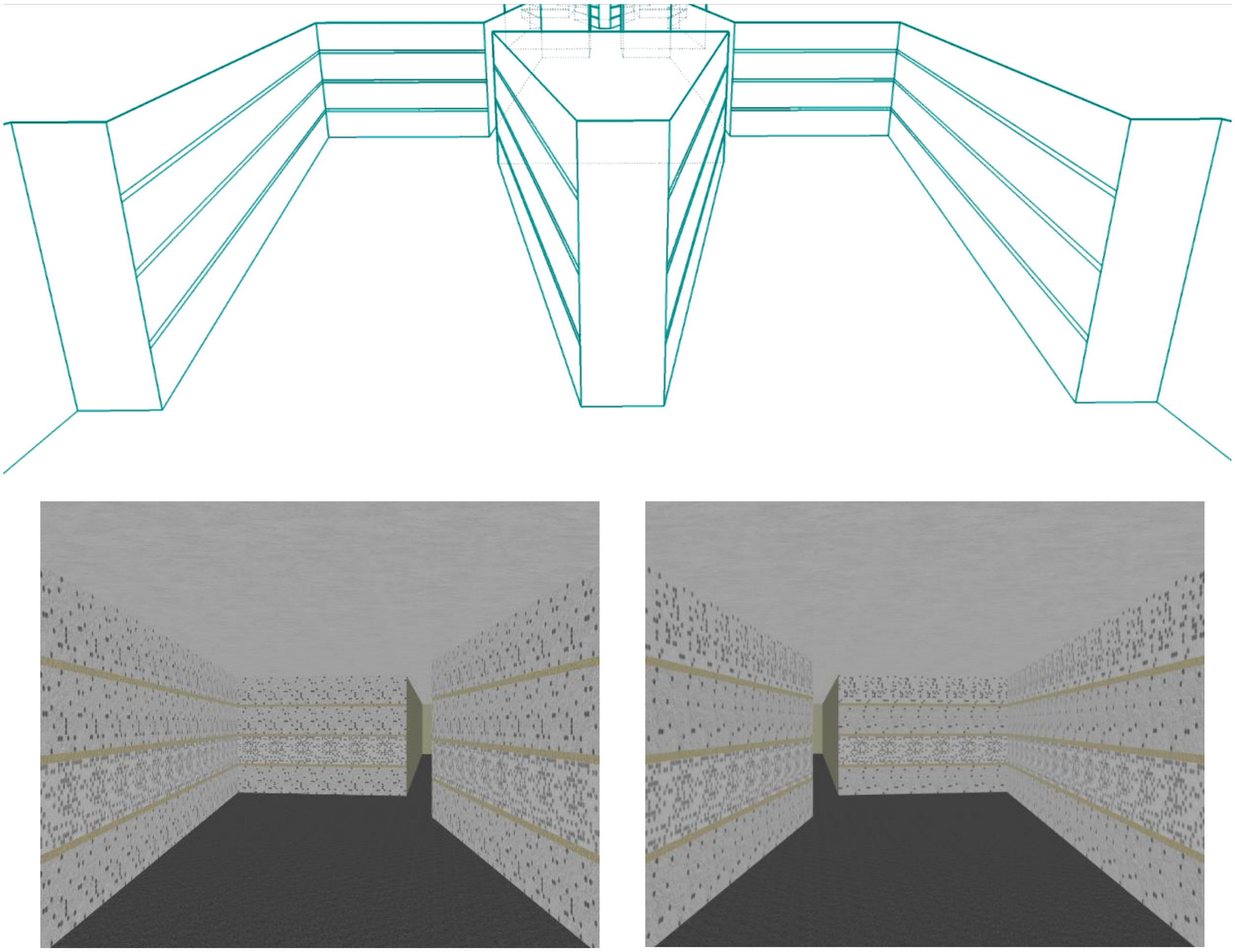


Figure 4.1. Top: Two side-by side corridors with four horizontal panels each. Note that this is a schematic of the environment prior to the application of panel identities (dot densities) and rendering. The identities of these horizontal panels were modified in order to generate probabilities of occurrence from which entropy was calculated. Bottom: Two sample corridor environments with panel identities applied and rendered. A full description of rendering and creation of the panels identities to follow.

Generating panel identities was non-trivial because it is necessary for the panels to be distinguishable from one another yet similar enough so that none of the panel identities was more salient than the others. To create panel identities, dots were randomly placed on each of the four panels; dot density increased exponentially from a minimum of 10 dots/0.5m^2 to a maximum 80 dots/0.5m^2 (Figure 4.2). Thus, panel identities were created by manipulating dot densities on the panels, so as to feature 10, 20, 40 or 80 dots/0.5m^2. Additionally, several other factors were also controlled for including the arrangement and position of each panel, the average environment dot density and the overall frequency of occurrence of each dot panel identity throughout the experiment. For a complete description of how these factors were addressed and entropy was generated, please refer to Appendix C. With a total of four distinct locations where panel identity could vary, a total of five entropy values were generated ranging from 0.00 to 2.00 bits of entropy (Table 4.1).

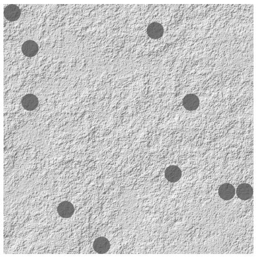
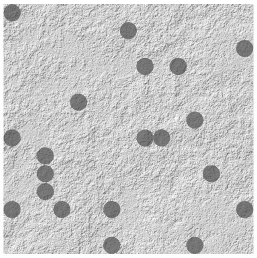
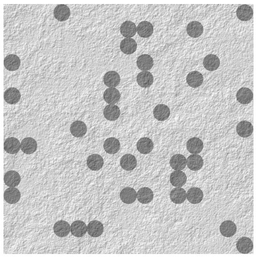
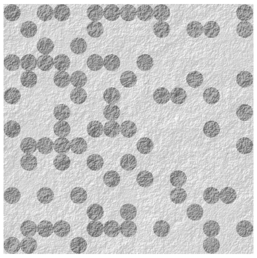
Dot Density (/0.5m^2)	
10	
20	
40	
80	

Figure 4.2. Rendered dot panels, ranging from 10 to 80 dots/0.5m^2

Table 4.1.

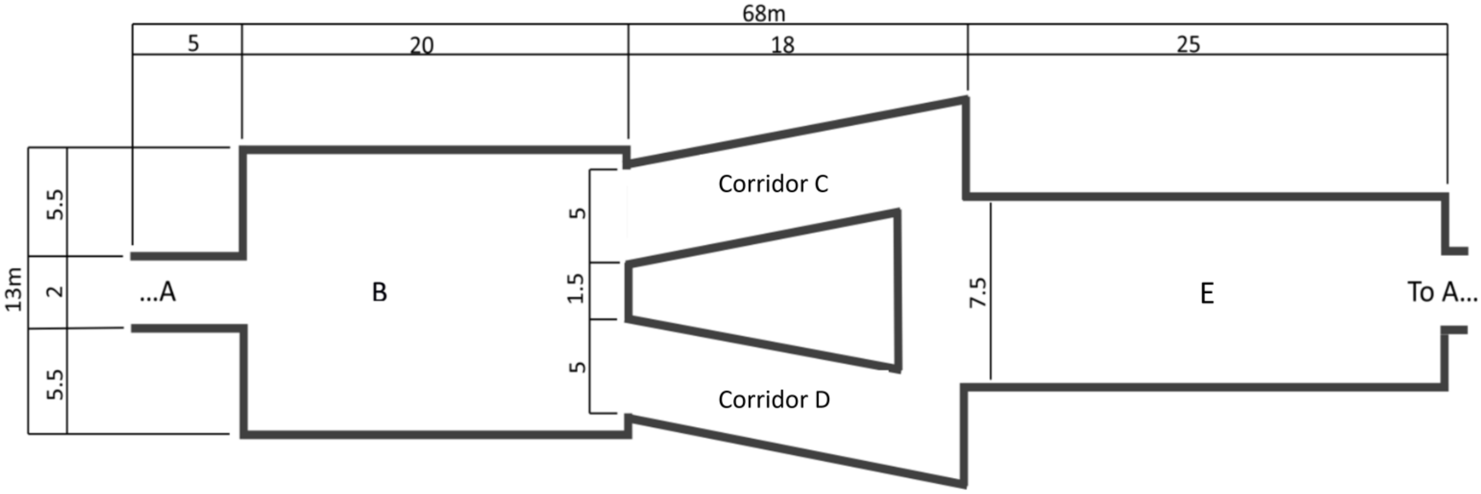
All possible panel probabilities and their corresponding entropy values

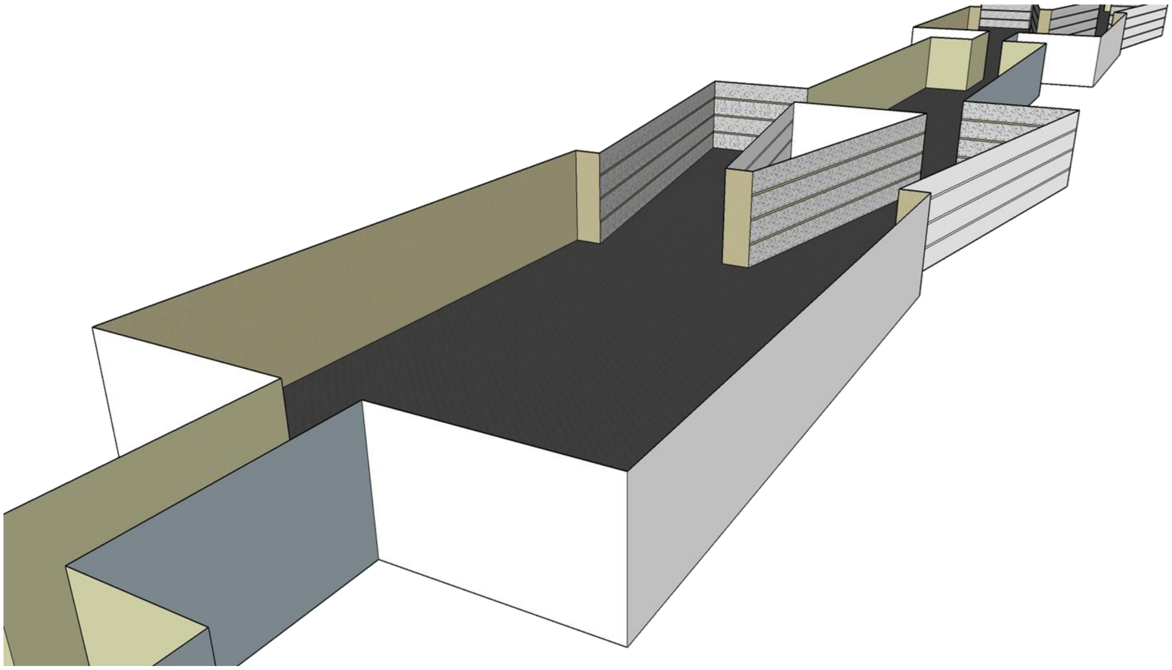
Number of unique panels (associated probabilities)	Entropy (H, in bits)	Notation
1 panel (1 : 4/4)	0	E_0
2 panels (1 : 3/4) (2 : 1/4)	0.81	$E_{0.81}$
2 panels (1 : 2/4) (2 : 2/4)	1	$E_{1.0}$
3 panels (1 : 2/4) (2 : 1/4) (3 : 1/4)	1.5	$E_{1.5}$
4 panels (1 : 1/4) (2 : 1/4) (3 : 1/4) (4 : 1/4)	2	$E_{2.0}$

4.2.2. The virtual reality environment.

In order to examine the third objective of this experiment—to behavioural components of emotion to subjective emotional response measures—a large virtual reality environment was designed allowing us to the effect of entropy on both. Using VR and immersing participants within the environment, we monitored their path selection behaviour as a function of entropy. To examine subjective emotional response, static images of the entropic sections of the VR environment were taken and presented to another set of participants, who were asked to rate complexity, pleasure and interest of these sections. Finally, a third task was devised where yet another set of participants was presented with a static images featuring pairs of entropy environment and required to select the one they preferred. Thus, the creation of the virtual environment allowed us to contrast and compare the effect of entropy on three separate tasks: a virtual reality path selection task, a static image subjective response task, and a static image forced choice task. What follows is a detailed description of this large-scale virtual environment as well as the generation of the static images from this environment. The complete procedure for each task is be presented in Section 4.2.5

The entropy panels described in Section 4.2.1. were applied to individual corridor environments, which themselves were embedded in a larger environment. Individual sections consisted of an intersection, where participants had the option to continue walking down either the left or the right corridor; it was in these corridors where the above mentioned panel entropy arrangements were applied. At the decision point, each of the entropy corridors was visible and participants chose to walk through one of the two corridors. At the end of each corridor was an exit, which would eventually lead to the subsequent section featuring a new intersection decision point and another set of entropy corridors. Thus the environment consisted of a large number of connected sections, each featuring its own decision point where participants had to choose and navigate through one of the two possible corridors varying in entropy. See Figure 4.3 for a schematic of a single section as well as how these sections were joined together to form the environment.


68m
5
20
18
25
13m
5.5
2
5.5
…A
B
5
1.5
5
Corridor C
Corridor D
7.5
E
To A…



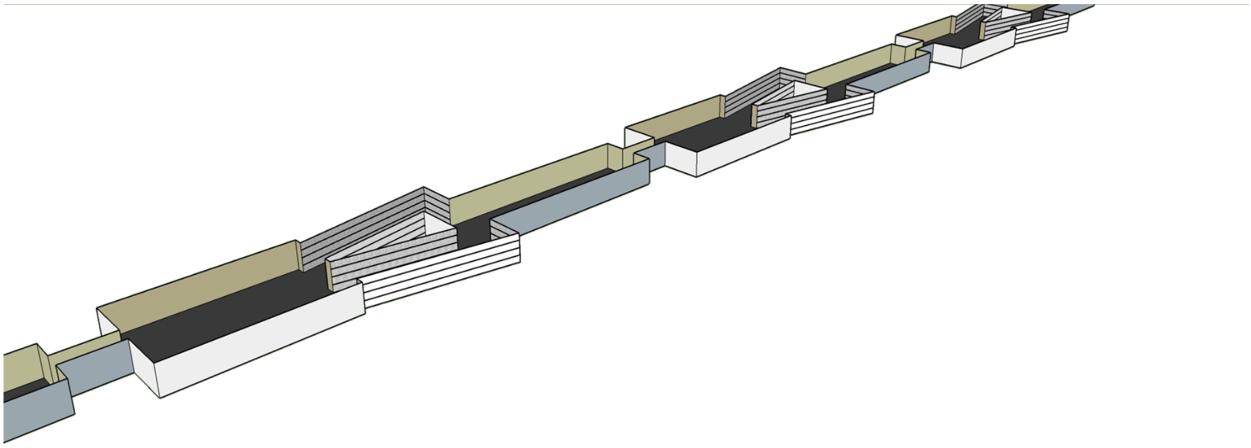


Figure 4.3. Top: Schematic of a single section of the virtual environment. This single section was repeated to form the virtual environment, connected to previous and subsequent sections. Participants would enter each section through the corridor marked "A", at which point they would enter the decision area "B". From here both entropy corridors, "Corridor C" and "Corridor D", were visible, and navigation would continue through one. It is these two corridors that were composed of the four horizontal panels, thus possessing entropy. Once the participant moved through the selected corridor they would enter area "E", which would funnel their movement to a small corridor leading to the next section, marked as "to A...". At this point, they would enter area A for the next section of the environment. Middle: An isometric view of a single section of the environment. Bottom: Isometric viewing showing how individual sections are connected to one another to generate the virtual environment.

The design of the environment required participants to make a choice between two alternatives, either the left or right each possessing differing entropy values. As there were a total of five entropy values, this resulted in ten pairwise comparisons. For each comparison, either of the two entropies was presented in the left or right corridor. In order to control for any possible side of presentation effects, each paired comparison was presented twice, with side of presentation reversed, resulting in a total of 20 pairwise comparisons.

In order to test for a left or right turning bias, control corridors were created, which were composed of walls of a single texture, rather than the panels. As these control corridors did not differ from one another, we could determine turning bias by examining if participants selected either the left or right corridor at a higher frequency. Several pairs of these control corridors were placed at the beginning, middle and the end of the environment.

Due to computational limitations, the environment could not be rendered in real-time, thus a single pseudo-randomized presentation order was created and rendered prior to the experiment. Pseudo-randomization insured that the same entropy was not presented on the same side in back-to-back decision pairs. In addition, in an effort to control for any presentation order differences and considering that each entropy pair was presented twice, presentation order was designed so that the first half and second half of the environment each had one of the two entropy pairs, for example for the $E_{1.0}$ vs. $E_{0.0}$ comparison, in the first half $E_{1.0}$ was presented on the left corridor while in the second half, $E_{1.0}$ was presented on the right. Three control environment pairs were placed both at the beginning of the environment as well as in the middle of the environment. Along with allowing us to test for turning bias, the first set of control environments familiarised participants with the environment while the control environments occurring at the half-way point provided participants with a slight reprieve from the entropy environments. This resulted in a total of 26 trials comprised of two corridor pairs. See Figure 4.4 for presentation order.

Trial	Pair (left - right)
1	Control-Control
2	Control-Control
3	Control-Control
4	1.00-0.00
5	0.81-1.00
6	2.00-0.00
7	1.50-2.00
8	0.00-0.81
9	1.00-1.50
10	1.50-0.81
11	0.00-1.50
12	0.81-2.00
13	2.00-1.00
14	Control-Control
15	Control-Control
16	Control-Control
17	0.81-1.50
18	1.50-0.00
19	0.00-2.00
20	1.00-0.81
21	0.81-0.00
22	1.00-2.00
23	2.00-0.81
24	1.50-1.00
25	2.00-1.50
26	0.00-1.00

Figure 4.4. Paired corridor presentation order in the virtual environment

The environment was designed using Google Sketchup and panels applied as described above. A standard stucco ceiling texture was applied to the ceiling and carpet textures were applied to the floor. The environment was rendered using the virtual reality software Vizard.

4.2.3. Generation of static images.

From the virtual environment described above, static images were rendered in order to test subjective emotional response towards the environments. Static images were captured in Google Sketchup using the V-Ray add-on. Globe lights were placed in each of the corridors, at ceiling level to mimic real-world, interior lighting. Images were taken of each entropy corridor by positioning the camera just inside the corridor (approximately 10m from the back wall) at a height of 1.75m. In addition to images of individual corridors, an additional set of images was generated where the camera was positioned at the intersection thus showing both the left and right corridors.

For the subjective emotional response task, each entropy corridor was presented once with each of the three questions (interest, pleasure and complexity). Presentation order of environments and questions was pseudo-randomized so that the same environment, with a different question did not appear in back-to-back trials. For the static image forced choice task, the same presentation order was used as in the virtual reality navigation task. Complete procedures for each of the experiments follow below.

4.2.4. Apparatus.

The virtual reality environment was presented using an Nvis, nVisor SX60 virtual reality headset. The device features a resolution of 1280X1080 pixels with a diagonal field of view of

60 degrees. The device weighs approximately 1 kg and features two adjustable straps to ensure a tight and comfortable fit.

The static image subjective response and forced choice experiment were designed in the Python programming language using the Pygame library, allowing for the controlled presentation of stimuli and recording of responses and reaction time.

The static image subjective response and static image forced choice tasks were conducted using the iMotions psychological experiment apparatus and toolkit. iMotions allows for controlled presentation of stimuli while recording response and reaction times along with other measures such as facial expression and electrodermal activity, neither of which were significantly affected by our dependent variables. A Shimmer Electrodermal sensor, sampling at 120 Hz, was used in all three tasks. The experiments were presented on a 19 inch Samsung monitor using a Dell desktop computer. Each environment measured 1600 pixels in width by 884 pixels in height. For the static image tasks, participants were seated in front of the screen at an approximate viewing distance of 80 cm.

4.2.5. Procedure.

Participants were randomly assigned to complete either the static image subjective response, the static image forced choice or the virtual reality navigation task.

Static image subjective emotional response ratings

Participants were seated at a desk and iMotions software was started. A Shimmer electrodermal device was attached with a Velcro strap to the forearm of the participant’s non-dominant hand and electrodes were attached to the ring and middle fingers. A statement on the screen informed the participant to press any button when they were ready to begin, at which point instructions were presented. Participants were instructed that they would view a series of environments and rate them on a number of properties including pleasure, interest and complexity. Six example environments were presented; one for each entropy level plus one control environment. Each trial consisted of the following: a random environment was presented centrally on the screen for 2 seconds, followed by one of the three possible questions and a seven point Likert scale, presented above the environment. Participants responded by clicking on any of the numbers on the Likert scale. Once a response was made, participants proceeded to the next trial by clicking on an arrow placed below the environment. The presentation of each environment was preceded by a blank, gray screen, appearing for 0.5 seconds, serving as a mask. The six environments used for the practice trials were designed specifically for the practice session and were not used in the experiment. Once participants rated each environment on all three properties (complexity, pleasure and interest), a message on the screen instructed them that the experiment had concluded and asked them to inform their experimenter. At this point, the experimenters assisted the participants in removing the Shimmer Electrodermal sensor and the participants were free to go.

Static image forced choice task

Participants were seated at a desk and iMotions software was started. A Shimmer electrodermal device was attached with a Velcro strap to the forearm of the participants' non-dominant hand and electrodes were attached to the ring and middle fingers. Instructions on the screen informed the participant to press any key when ready to begin, at which point the procedure was described. Participants were instructed that they would be presented with a series of environments consisting of a left and a right corridor and that they would be required to select one of the two. Following instructions, participants completed six practice trials. The procedure for each trial was as follows. A forced choice environment was presented on the screen for 2.5 seconds, following which a question asking the participant "Which environment do you prefer?" appeared below the environment. Participants used the left and right keyboard keys to make a response, pressing the left keyboard key if they preferred the environment on the left and the right key if they preferred the environment on the right. Once a response was made a gray screen, serving as a mask, appeared on the screen for 0.5 seconds, following which a new pair of corridors was presented. Each paired environment was presented once, and presentation order was matched to the presentation order used in the virtual reality navigation task. Participants were not instructed on how to make their choices; they were free to make their choice by whichever criteria they deemed important. Once all environments were presented, a message on the screen instructed them to locate their experimenter and inform them that the experiment had concluded. At this point, the experimenter assisted the participants in removing the Shimmer electrodermal sensor and the participants were free to go.

Virtual Reality Navigation Task

The experimenter explained the general procedure to each participant and attached the Shimmer electrodermal activity sensor onto the participant's left forearm using a Velcro strap; electrodes were attached to the middle and ring fingers. Next, the virtual reality head-mounted display was placed on the participants and adjusted to ensure a comfortable yet secure fit. Next, the experimenter handed the participants a computer mouse. The participant’s head position controlled heading direction while the mouse controlled movement; pressing the left mouse button resulted in forward movement and the right mouse button in backward movement. Participants were first placed in a large, rectangular practice environment featuring several large obstacles and instructed to navigate through the environment to familiarize themselves with the controls. Once the participants were ready, they were placed in the starting position within the experimental environment and instructed to navigate through the environment. Once each intersection was reached, they were instructed to view both options and continue down whichever of the two corridors they preferred. They were not instructed on how to make this decision. Participants navigated through the environment until they reached the end of the environment, which consisted of a large rectangular room, at which point they were instructed that the experiment had concluded. The experimenter assisted the participants in removing the Shimmer electrodermal device and the VR head-mounted display; the participants were thanked for their participation and were free to go.

4.2.6. Measures.

Static image emotional response ratings and forced choice tasks

A seven-point Likert scale was used to measure interest, pleasure and complexity. Interest was worded as follows: "How interesting is the current environment?”; the response scale was presented below, where 1 was marked as "boring" and 7 was marked as "interesting". For pleasure, the question was: "How pleasing in the current environment?"; the response scale was presented below, where 1 was marked as "unpleasant" and 7 was marked as "pleasant". For complexity, the question was: "How complex is the current environment?"; the response scale was presented below, where 1 was marked as "simple" and 7 was marked as "complex". Response and reaction time were recorded for each response.

For the forced choice task, the selected corridor, whether it was the left or right corridor and reaction time were all recorded.

Virtual reality navigation task

For the virtual reality navigation task a number of behavioural measures were recorded, including the decision made at the intersection, the entropy of the selected corridor, the entropy of the non-selected corridor, and whether the selected corridor was on the left or right-hand side. Time spent at each intersection, while deciding on which corridor to select, was recorded as was the time spent navigating through each of the selected corridors. We also recorded velocity as well as x-y coordinates within the environment for the duration of the experiment.

4.2.7. Participants.

Twenty-five participants (13 female) completed the static image subjective emotional response task, while 25 (18 female) completed the static image forced choice task and 21 (14 female) completed the VR path selection task. The experiment was approved by the University of Waterloo Office of Research Ethics and each participant completed an informed consent form prior to beginning the experiment.

4.3. Results

4.3.1. Static image subjective emotional response ratings.

A repeated measures ANOVA was conducted with entropy as the independent variable, with interest, pleasure and complexity as dependent variables. Since each entropy value was presented multiple times, the ANOVA was conducted using mean responses per level of entropy. All five entropy environments along with the control environment were included in the analysis, allowing us to not only compare differences between entropy values, but also between the control and the entropic environments. All significant effects were significant at a level of at least $p < 0.05$, unless otherwise stated

Complexity

Mauchley's test of sphericity was violated, $x^2(14) = 34.33$, $p < 0.01$, thus degrees of freedom were corrected using Greenhouse-Geisser correction. The main effect of environment entropy on perceived complexity was significant, $F(3.2,76.88) = 69.288$, $p < 0.001$, $\eta^2 = 0.743$ (Figure 4.5). Bonferroni corrected pairwise comparisons demonstrated that all environment entropies were significantly different from one another at an alpha level of 0.05, except $E_{1.5}$ and $E_{2.0}$: Control (M = 1.32, SD = 0.1), E_0 (M = 2.97, SE = 0.22); $E_{0.81}$ (M = 3.67, SD = 0.19); $E_{1.0}$ (M = 4.03, SD = 0.2); $E_{1.5}$ (M = 4.24, SD = 0.15) and $E_{2.0}$ (M = 4.6, SD = 0.24).

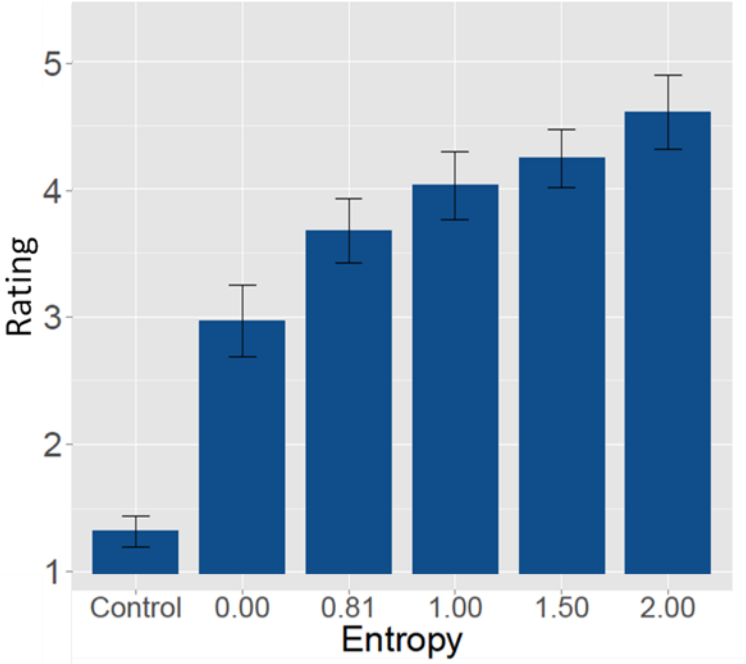


Figure 4.5. The main effect of panel entropy on complexity ratings.

Pleasure

Once again, Mauchley's test of sphericity was violated, $x^2(14) = 75.76$, $p < 0.001$, thus degrees of freedom were corrected using Greenhouse-Geisser correction. The main effect of entropy on pleasure was significant, $F(2.27,54.5) = 6.81$, $p < 0.01$, $\eta^2 = 0.22$ (Figure 4.6). Bonferroni corrected pairwise comparisons demonstrated that $E_{2.0}$ (M = 2.54, SD = 0.18), was significantly less pleasant than all other entropy values, except $E_{1.0}$ (M = 3.14, SD = 0.15, p = 0.54). Due to the conservative nature of the Bonferroni correction, no other comparisons were statistically significant, although $E_{0.0}$ was trending towards being significantly more pleasant than $E_{0.81}$, (M = 3.82, SD = 0.28 and M = 3.14, SD = 0.15, p = 0.11). From a visual inspection of the data it appears that the three moderate entropy environments, $E_{0.81}$, $E_{1.0}$ and $E_{1.5}$, were experienced as equally pleasant, (M = 3.14, SD = 15; M = 3.16, SD = 0.16; M = 3.05, SD = 0.18). $E_{2.0}$ environments were significantly less pleasant than all other environment entropies (M = 2.54, SD = 0.18). Generally, there appeared to be a trend where more entropic environments were perceived as less pleasant.

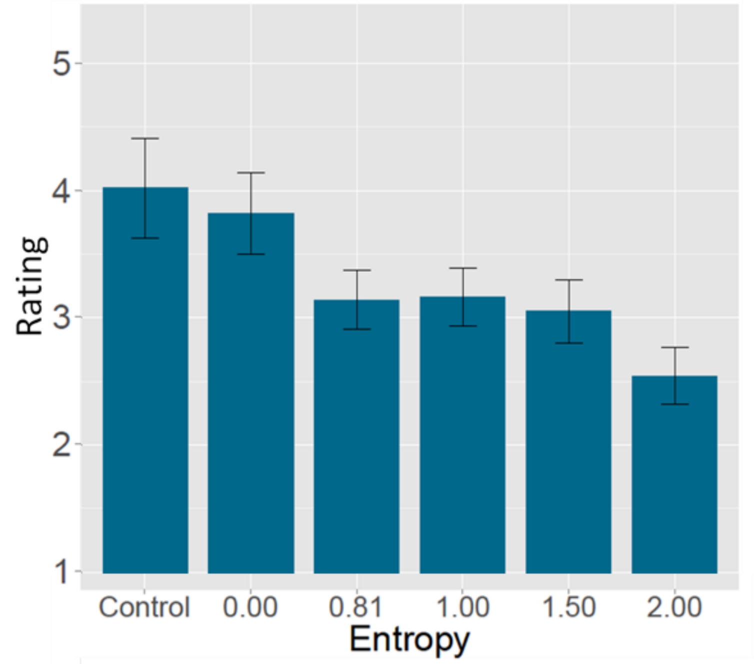


Figure 4.6. The main effect of panel entropy on pleasure ratings.

Interest

A Greenhouse-Geisser correction to degrees of freedom was applied, as Mauchley's test of sphericity was significant, $x^2(14) = 62.25$, $p < 0.01$. The main effect of entropy was significant, $F(2.34,56.51) = 13.813$, $p < 0.001$, $\eta^2 = 0.37$, with effect driven by the control environments (M = 1.9, SD = 0.25) being experienced as less interesting than all the entropic environments. Thus, entropy did not affect interest—all levels of entropy were equally interesting: E_0 (M = 3.64, SD = 0.26); $E_{0.81}$ (M = 3.65, SD = 0.18); $E_{1.0}$ (M = 3.66, SD = 0.2); $E_{1.5}$ (M = 3.77, SD = 0.21) and $E_{2.0}$ (M = 3.82, SD = 0.24).

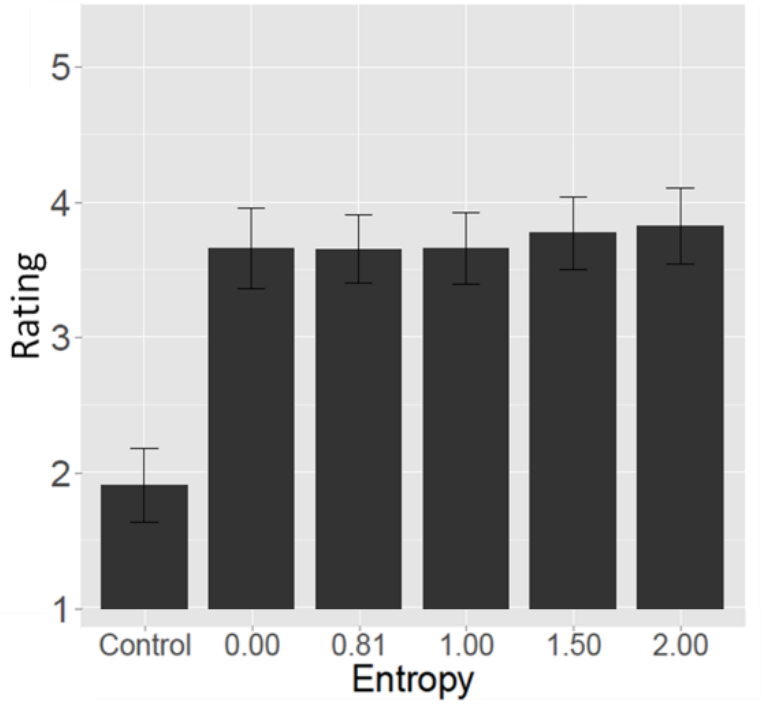


Figure 4.7. The main effect of panel entropy on interest ratings.

Correlations between Interest, Pleasure and Complexity

As was the case in the first two experiments, partial correlation coefficients were calculated while controlling for within participant variability as suggested by Bland and Altman (1994; 1995) (Table 4.1). Entropy had a moderate positive correlation with complexity (r = 0.39) and a moderate negative correlation with pleasure (r = -0.32). Weak correlations were found between complexity and pleasure (r = -0.1) and complexity and interest (r = 0.1). Finally, a weak positive correlation was present between pleasure and interest (r = 0.28).

Table 4.2.

Correlation coefficients for complexity, entropy, pleasure and interest

	Complexity	Pleasure	Interest
Entropy	0.39**	-0.32**	0.09
Complexity		-0.1*	0.11*
Pleasure			0.28*

* $p < 0.05$; ** $p < 0.01$

4.3.2. Static image forced choice task.

Since each entropy environment was presented a total of eight times (paired twice with every other entropy environment), percentage of selection was calculated for each value of entropy. A repeated measures ANOVA was conducted with entropy and side (left vs. right) as independent variables. The main effect of side (left vs. right) was non-significant, F(1,24) = 1.29, p =0.27, $\eta^2 = 0.05$ while the main effect of entropy was significant, F(4,96) = 6.3, p = 0.001, $\eta^2 = 0.21$. With an alpha level of 0.05, E_0 and $E_{1.0}$ were selected at the same percentage and significantly more frequently than all other environments (M = 67.00%, SE = 5.25 and M = 58.00%, SE = 4.67) (Figure 4.8). Environments with 2 bits of entropy (M = 35.5%, SE = 4.66) were selected significantly less often than all other environments except for $E_{1.5}$ (M = 41.00%, SE = 4.12). $E_{1.0}$ was selected more frequently than $E_{1.5}$ while it was selected at the same frequency as $E_{0.81}$, and E0.81 and E1.5 were selected at the same frequency (M = 49.00%, SE = 3.813; M = 58.00%, SE = 4.67 and 41.00%, SE = 4.12). Thus it appears that E_0 environments were most selected, while $E_{2.0}$ environments were least selected. Moderate entropy environments were selected at about the same frequency, except for a slight increase in selection for $E_{1.0}$.

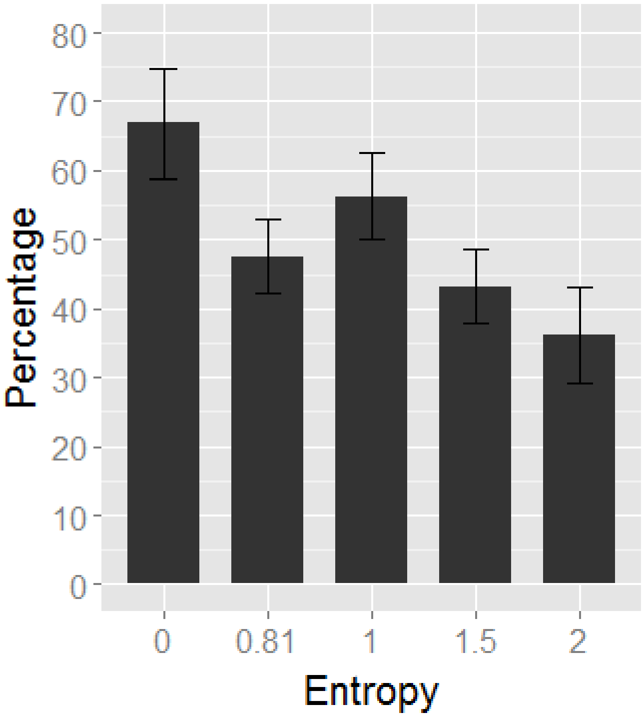


Figure 4.8. The main effect of environment entropy on forced choice selection percentage

4.3.3. Virtual reality path selection task

Frequency of selection was calculated and analyzed in the same manner as for the static image forced choice task described above. The effect of side (left vs. right) was non-significant, F(1,20) = 0.29, p = 0.6, $\eta^2 = 0.01$, while the main effect of entropy was significant, F(4,80) = 4.5, p = 0.01, $\eta^2 = 0.18$. Pairwise comparisons were made using Bonferonni correction, but due to conservative nature of the correction, none of the entropy environments differed significantly from one another. In order to more fully explore and understand the effect and due to the relatively few comparisons made (10), we deemed that the risk of Type I error was slight enough and thus performed pairwise comparisons without correction. In addition, the pattern of results mirror closely the pattern exhibited in the forced choice experiment (Figure 4.9), except that there seems to be more variability in the virtual reality data, leading us to believe that the effect of entropy on selection percentages in VR is real but that we are lacking power. Note that by performing pairwise comparisons without correction, the likelihood of Type I error is increased, and the results should be interpreted with caution. $E_{0.0}$ and $E_{1.0}$ environments were selected with the same frequency, and more often than all other environments (M = 66.67%, SE = 6.42 and M = 54.17%, SE = 3.98) (Figure 4.10). $E_{2.0}$ environments were selected less often (M = 36.91 % SE = 5.28) than all other entropy environments except $E_{0.81}$ environments (M = 45.83%, SE = 3.89). The three moderate entropy environments ($E_{0.81}$, $E_{1.0}$ and $E_{1.5}$) were selected at the same frequency (M = 45.83%, SE = 3.89; M = 54.17%, SE = 3.98; M = 45.83%, SE = 3.38). It seems that participants avoided $E_{2.0}$ environments and preferred E_0 environments while the three moderate entropy environments were neither approached nor avoided.

The effect of entropy on other behavioural measures such as time spent at the decision point, time spent within the selected corridor, velocity and electrodermal activity were non-significant.

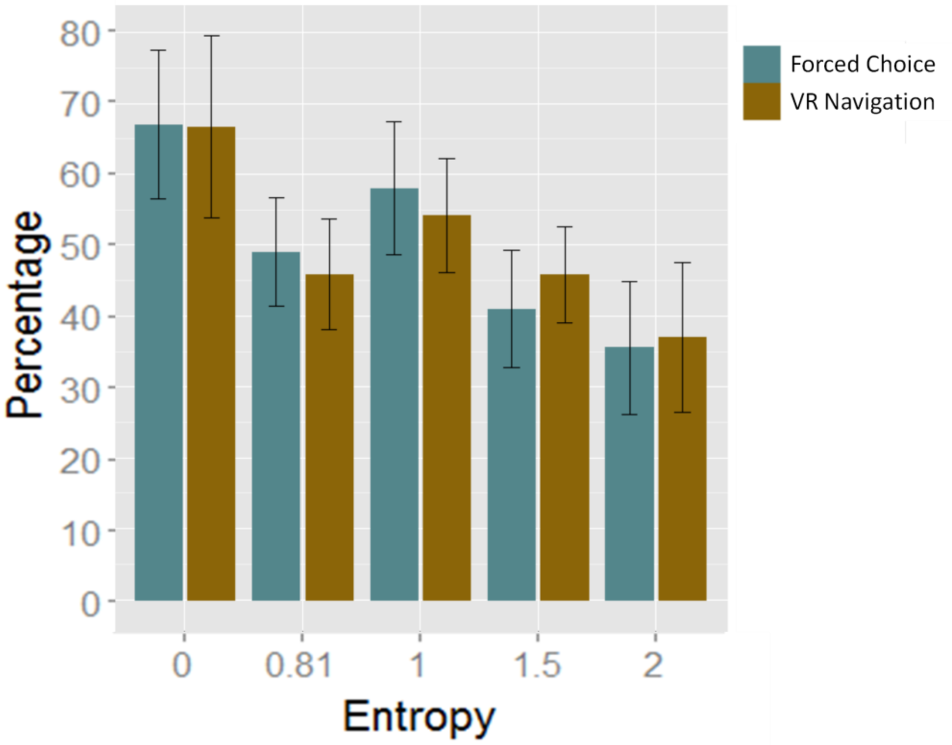


Figure 4.9. The main effect of entropy on both computer forced choice and virtual reality navigation tasks. There appeared to be a strong degree of agreement between the two.

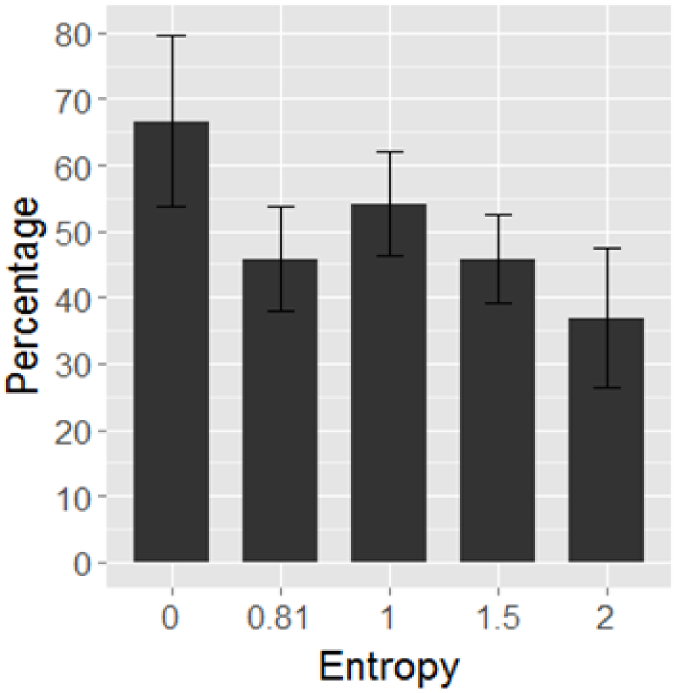


Figure 4.10. The main effect of environment entropy on VR path selection percentage.

4.3.4. Path analysis.

Path analysis was conducted using multiple linear regression while controlling for within participant variability by considering participants as a random effect (Preacher & Hayes, 2003; Bland & Altman, 1994). Emotional responses of interest and pleasure were dependent variables, while entropy was considered as a predictor and complexity as a mediator. First, the direct effect of entropy, as well as complexity on emotional response was tested; if the direct effect was significant, the mediating effect of perceived complexity was examined. Only those effects significant at a $p < 0.05$ level were included in the model.

Please refer to Figure 4.11 for the model showing interest as predicted by entropy and complexity. Standardized beta coefficients are provided. Entropy predicted complexity ratings, β

= 0.38, $p < 0.001$, while complexity predicted interest ratings significantly, $\beta = 0.39$, $p < 0.001$. The main effect of entropy on interest was non-significant, $\beta = 0.38$, $p = 0.23$. Overall, complexity scores explained 31% of the variability in interest responses, ($R = 0.56$, $R^2 = 0.31$, $R^2_{(adj)} = 0.28$, $F(25, 572) = 10.49$, $p < 0.001$).

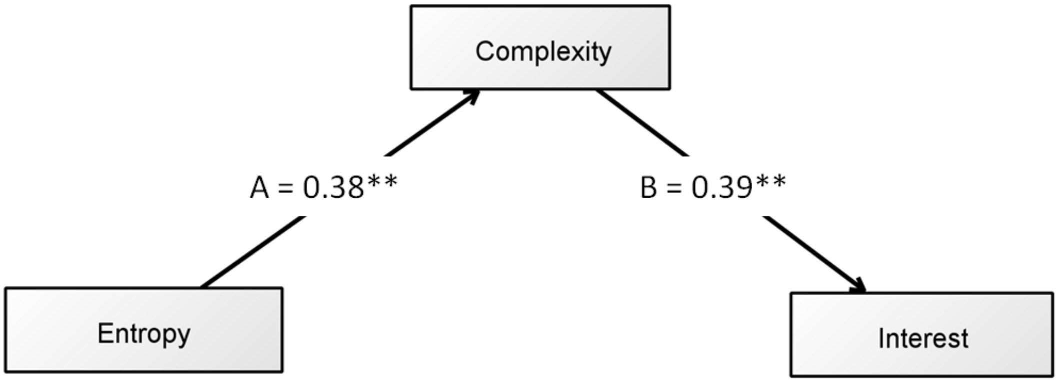


Figure 4.11. The reduced model with interest as the outcome variable.
** *p* < 0.01

Figure 4.12 below shows the final model predicting pleasure responses. The significant, negative effect of entropy on pleasure was not mediated by complexity ratings, Sobel test = -1.4, SE = 0.04, $p = 0.16$. Interest predicted pleasure positively, and partially mediated the effect of complexity on pleasure, Sobel test = 5.88, SE = 0.02, $p < 0.001$. With interest considered as a mediator, the effect of complexity on pleasure increased from $\beta = -0.26$ to $\beta = -0.38$. In the final model, entropy, complexity and interest explained 40% of variance in pleasure responses, ($R = 0.63$, $R^2 = 0.4$, $R^2_{(adj)} = 0.36$, $F(27, 469) = 12.77$, $p < 0.001$).

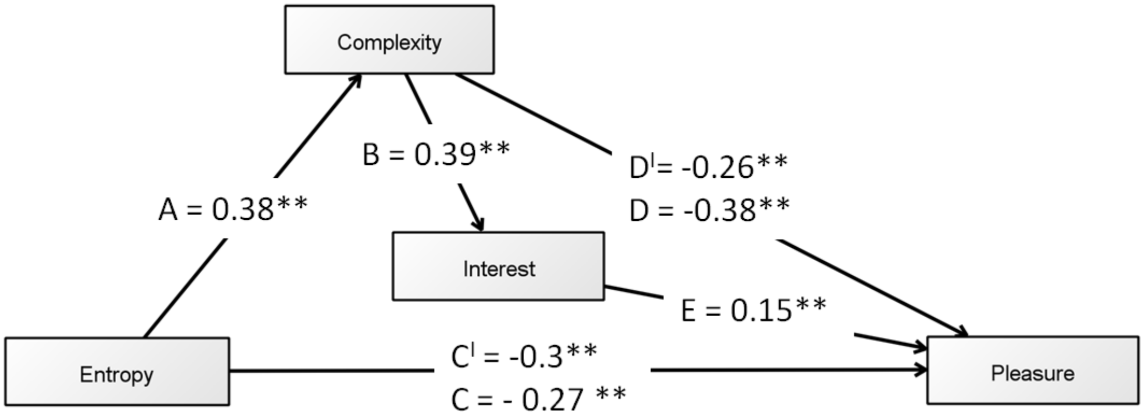


Figure 4.12. The reduced model with pleasure as the outcome variable.
$* p < 0.05$; $** p < 0.01$

4.4. Discussion

4.4.1. Entropy and complexity.

Experiments 1.1 and 1.2 demonstrated that increasing the number of both geometric and featural elements resulted in increases in perceived complexity and affected emotional response. This experiment explored another method of generating complexity by maintaining a constant number features, but varying their individual properties and identities. By using probabilities of an event's occurrence we described the amount of information within the stimulus by calculating entropy (Shannon, 1948), thus allowing us to draw a direct link between information content and perceived complexity. In this experiment, as predicted, entropy of interior environments affected perceived complexity positively—more entropic environments were perceived as more complex.

Although entropy has previously been used to describe complexity of simple visual stimuli (Vitz & Todd, 1969; Snodgrass, 1971; Hare, 1974), as well as façades (Stamps, 2003;

2002), this experiment marks the first time entropy was used to quantify and describe complexity of interior environments. These results provide additional evidence that by quantifying the information content of the environment, entropy serves as a useful tool through which to describe environmental complexity. If environmental preference and emotional response research is to be applied to design more enjoyable built environments, it is necessary to develop a way to quantify complexity; entropy may be a valid and useful tool in this regard.

4.4.2. Entropy and emotional response.

More entropic environments were less pleasant while having no effect on interest. This negative effect of entropy on emotional response is counter to most previous research, where a positive effect on pleasure is typical (Stamps, 1998a; Stamps, 1999b; 2002; 2003; Heath, Smith & Lim, 2000; Devlin & Nasar, 1989). In one rare instance where a negative effect was noted, Stamps (2004) suggested that the direction of the effect was dependent on environment type; complexity in sign-scapes, older buildings and residential blocks resulted in a negative effect on pleasure. The findings here corroborate the possible negative effect of complexity on experience of the environment with an additional environment type. The inverted-u relationship as argued for by Berlyne (1970; 1974) and contemporaries (Hare, 1974a; Normore, 1974; Day, 1967) posits a rise in preference up to an optimal amount of complexity, following which complexity is experienced negatively; a visual inspection of the data presented here fails to support this hypothesis. It is plausible that our environments are so complex that the data are actually exhibiting the negative, right-hand side of the inverted-u curve, but this is unlikely due to the moderate complexity ratings exhibited. This, coupled with the positive effect of complexity in the first experiment, suggests that the effect of complexity on emotional response is linear, but the direction is dependent on environmental features above and beyond complexity. Although, this negative effect of complexity was unexpected, it can be explained in several ways.

Kaplan (1985) suggested that complexity and information content alone are not enough to describe preference; instead the information needed to be understandable. Additionally, by considering the manner in which information is processed researchers have suggested that emotional response is dependent on processing fluency, so that easier to process stimuli are experienced more positively (Reber, Schwarz and Winkielman, 2004; Winkielman, Halberstadt, Fazendeiro & Catty, 2006). From their perspective, complex stimuli are more difficult to process and this disfluent processing is experienced negatively. Due to the synthetic nature of the stimuli used in this experiment, it is conceivable that the negative effect on pleasure could be described by processing fluency as suggested by Reber et al (2004). Due to the unusual design of the dot panels, they may have been difficult to process and this processing disfluency may have resulted in displeasure. As entropy increased, participants were required to perceive and distinguish between a greater number of panels, potentially leading to a more difficult perceptual process and thus resulting in decreased pleasure as entropy increased. This negative effect was not found in Experiments 1.1 and 1.2 because the environments were easily processed. Despite this difference between the present experiment and Experiments 1.1 and 1.2 a crucial dissociation between interest and pleasure was once again noted here.

Complexity had a negative effect on pleasure and a positive effect on interest. This dissociative effect of complexity on emotion is relevant when considering that pleasure and interest are functionally different. As the function of interest is information acquisition (Silvia, 2005, 2008), and interest was low for all environments, we would not expect differences between the environments within an exploratory, information-seeking scenario. Pleasure, on the other hand, functions to create congruency between an individual's current needs and their environment; if an environment does not meet this need, displeasure is experienced and avoidance behaviour may occur. Within this particular experiment, complex environments were avoided, suggesting that displeasure was driving behaviour because interest would predict approach rather than avoidance. These distinctions mean that individuals feeling interest and pleasure may behave differently and that manipulations meant to result in positive emotions may influence certain emotions, such as pleasure, and not others, such as interest. Therefore, probing emotions through pleasure alone is not advisable and may not describe person-environment interaction fully. Although this dissociation is functionally relevant, it is important to note that it differs between the two sets of experiments.

In Experiments 1.1 and 1.2, complexity had a positive effect on interest while failing to affect pleasure. Here, the results are reversed, noting a negative effect on pleasure and no effect on interest. This discrepancy is potentially due to the differences in environment features between the two sets of environments. First, as discussed above, we can assume that the dot panels were difficult to process due to their synthetic, unusual design, potentially accounting for the negative effect of entropy on pleasure. How do we then explain the lack of an effect on interest, as noted in Experiments 1.1 and 1.2? For complexity to have an impact on interest, it is necessary but not sufficient that complexity be present; instead, the complexity also needs to be understandable (Kaplan, 1987; 1988; Silvia, 2005; 2006). This perspective would mean that in Experiments 1.1 and 1.2, complexity had a positive effect on interest because the environment features were understandable and participants could process and cope with the complexity. The particularly unusual quality of the environments in this experiment resulted in complexity, but failed to meet the coping or understandability check necessary for interest. Thus, entropy and number of elements both affect complexity, but emotional response is ultimately a result of the manner in which the complexity is processed.

4.4.3. The path from entropy to emotional response.

Path analysis was conducted in order to explore how both physical features of the environment (as described with entropy) and cognitive concepts (perceived complexity) affect emotional response (interest and pleasure). Although entropy did not affect interest, perceived complexity did, which itself resulted from entropy. As expected, interest remained a result of cognitive conceptualization of environmental complexity (Silvia, 2005) but did not arise directly from objective properties of the environment as described by entropy. Due to the lack of main effect of entropy on interest, entropy is not a reliable way by which to elicit interest directly.

With pleasure as the outcome variable, the relationships between entropy, complexity and response were much more convoluted. The physical features of the environment, as quantified by entropy, and perceived complexity both led to decreased pleasure independent of one another. Thus two distinct effects are noted, one determined by physical features of the environment, the other by cognitive appraisals of perceived complexity. Interest predicted pleasure, which was unexpected, but seems reasonable: we would assume interesting stimuli to be experienced as more pleasant than uninteresting stimuli. This effect of interest partially moderated the negative effect of complexity on pleasure; such that more interesting environments were more pleasing, mitigating the negative effect of complexity on pleasure. This intricate pattern of predictors demonstrates that physical properties of the environment, cognitive components and other emotions all shape pleasure.

4.4.4. Behavioural measures of emotional response.

Under the assumption that emotions are closely tied to patterns of behaviour (Keltner & Gross, 1999; Izard, 1992; Fontaine, Scherer, Roesch & Ellsworth, 2007), it may be possible to infer emotional response through behaviour. For example, interest results in increased exploration (Stamps, 2004; Wohlwill, 1968; 1975; Berlyne, 1974d; Silvia, 2005), while pleasant stimuli are selected more frequently and rank-ordered higher than less pleasant stimuli (Wohlwill, 1975; Heath, Smith & Lim, 2000; Eisenman, 1967). In this experiment, both forced choice results and virtual reality exploration demonstrated that entropy was avoided; more entropic environments were least selected, while less entropic environments were selected more frequently in both tasks. These findings mirror the subjective pleasure ratings, suggesting that emotions as measured with self-report measures are related strongly to behaviour within the environments. Such behavioural outcomes are crucial since they support the notion that environment properties not only shape how individuals feel, but how they behave.

This pattern of results, where high entropy was least preferred and low entropy was most preferred, coincided with subjective pleasure response, with one small difference. There was a slight jump in selection frequency at 1 bit of entropy in both behavioural tasks as compared to pleasure ratings. Although 1 bit of entropy was selected at the same frequency as 0.81 and 1.5 bits, it was also selected at statistically the same frequency as 0 bits of entropy, which was not the case for rated pleasure. This difference could be a result of an interaction between task demands and design of 1 bit of entropy environments. As 1 bit of entropy was generated by presenting two panel identities twice each, certain arrangements were symmetrical while other arrangements were asymmetrical, along the horizontal axis. For example, if one panel identity was placed in the top and bottom positions, while the other was placed in the two middle positions, the environment would be symmetrical. On the other hand, if the panel identities were intermixed, the environment would be asymmetrical. This possible symmetry may have resulted in higher selection frequency for 1 bit of entropy than we would have expected from the rating task due to symmetry leading to more fluent processing (Reber, 2002; Chen, Wu & Wu, 2011). If such ease of processing resulting from symmetry leads to increased selection at 1 bit of entropy, would we not expect to see a similar increase in self-reported pleasure? Why do we only see the positive effect of symmetry during the behavioural tasks? It is possible that the jump is a result of the task specific demands; for the subjective response task, environments were viewed in isolation making it possible to rate environments with different entropy values as equally pleasant. Conversely, for the behavioural tasks, because one environment needs to be selected over another it is not possible to prefer both options equally. Perhaps when required to decide between two environments, the potential symmetry present in 1 bit of entropy becomes the deciding factor driving preference; this problem is not faced during the subjective response task since both can be assigned equal pleasure ratings. In this way, the symmetry effect is slight, functioning as a heuristic by which to make a necessary selection between equally pleasant environments. Although this slight increase in selection is present at 1 bit of entropy, it is important to note that it was not selected more significantly than 0.81 and 1.5 bits of entropy environments.

Although others have compared the self-reported pleasure to simple behavioural measures for visual stimuli (Wohlwill, 1967; 1975; Berlyne, 1971), this marks the first time the relationship was examined using environments and complex navigation behaviour within large-scale, virtual reality environments. Prior to this, behaviour within environments has been inferred through approach-avoidance ratings (Vartanian et al., 2013; Russell & Mehrabian, 1974a;

1974b), or if behaviour in virtual reality was measured, it was not compared to subjective emotional response measures (Stamps, 2010). This direct comparison between subjective emotional response and behaviour helps to demonstrate that the techniques typically used to measure emotional response reliably capture how individuals will behave within the environment. The lack of an entropy effect on other behavioural measures, such as velocity and time spent within corridors, is likely a result of the relatively impoverished design of the environment, which did not allow for much behavioural variability. If measured in a more naturalistic environment these variables may indeed help to describe experience.

4.4.5. Summary and next steps.

Due to the novel nature of the results in this experiment, it is crucial that we attempt to replicate the findings. It seems likely that the effect of complexity is dependent on how information is organized and presented; that the effect of entropy on pleasure may be driven by more than complexity alone. Thus, the next experiment will generate complexity through entropy of panels, considering both local and global properties independent of entropy. Locally, the dot panels in this experiment were highly unusual, and perhaps difficult to process, potentially resulting in the negative effect of entropy on pleasure. In an effort to explore this question, a different set of panels will be used in the following experiment. Globally, it is likely that the organization and arrangement of panels might have influenced emotional response. Indeed, symmetrical stimuli are processed more fluently, resulting in preference and pleasure (Reber, 2002; Chen, Wu & Wu, 2011; Reber, Schwarz & Winkielman, 2004), thus symmetry will be introduced as an additional factor in the following experiment. Both of these local and global considerations stress that complexity alone may not be sufficient to explain experience of the environment.

Chapter 5 - Experiment 2.2: The Effect of Global and Local Environmental Properties on Emotional Response

5.1. Introduction

The previous experiment marked the first instance where entropy was used to manipulate complexity within interior spaces, demonstrating a negative effect on emotional response. Due to the novelty of the findings, it was necessary to attempt to replicate using another set of environments. It is also conceivable that the effects seen in Experiment 2.1 are a result of the quality of the panels along with their arrangements as opposed to entropy itself. In order to test the robustness of the entropy effect, both local and global environment properties were considered in this experiment. Locally, Experiment 2.1 used dot densities to distinguish between the panels, while globally, panel arrangements and the relationship between panels were selected randomly. As opposed to using dot densities to generate panel identities, this experiment identified panels using four-sided polygons presented on each panel. To manipulate global panel arrangement, a total of five vertically positioned panels were used, as opposed to the four horizontal panels used in Experiment 2.1 and symmetry was introduced as an additional global variable. These manipulations allowed us not only to test the robustness of the negative entropy effect exhibited in Experiment 2.1, but to highlight the importance of considering factors beyond entropy.

5.1.1. Local and global environmental properties.

The highly synthetic nature of the dot panels in Experiment 2.1 means that the exhibited effects may have been a result of the dot density manipulation as opposed to entropy itself, or at a minimum, that the dot panels affected complexity independent of entropy. This possibility is concerning because the effect of entropy should occur regardless of the local properties of the individual elements, as entropy only considers the probability of occurrence of the elements and not how the elements are organized or how difficult or easy they are to perceive and process. The experimenter's own observations and participant comments suggested that the dot density panels were highly unusual and potentially disconcerting. Considering that processing difficulty has been argued as leading to negative emotions (Winkielman, Halberstadt, Fazendeiro & Catty, 2006; Reber, Schwarz & Winkielman, 2004), it is possible that the entropy effect was, in fact, a result of local panel properties (the dot densities), which may have been exacerbated by entropy. In order to explore this possibility and test the robustness of the entropy effect, this experiment distinguished panels by four sided polygons placed on panels as opposed to dot densities, allowing for more fluent perception of panel identities. Although, this manipulation considers the local properties of the environment global properties also need to be addressed.

More often than not, entropy is calculated by considering the probabilistic occurrence of a series of events or elements, failing to consider the spatial relationships between the events or elements. Although early work on entropy derived measures of complexity considered the overall arrangements and spatial relationships between elements in the form of grouping and symmetry (Vitz & Todd, 1969; Snodgrass, 1971; Berlyne, 1974d), more recent research connecting entropy and experience of the environment did not address such factors (Stamps, 2002; 2004; Lindal & Hartig, 2013). Experiment 2.1 relied solely on panel probabilities, ignoring spatial arrangement; such a perspective is concerning as it does not accurately reflect how information is perceived and organized by the human visual system. From a gestalt perspective, visual elements are organized and grouped based on a wide variety of global properties, such as proximity, figure-ground contrast, enclosure and symmetry. These heuristics are useful: not only do they allow us to make sense of the visual world, they also lead to more efficient processing of visual information (Berlyne, 1974d; Reber, Schwarz & Winkielman, 2004). Because research suggests that processing fluency affects emotional response positively (Winkielman, Halberstadt, Fazendeiro & Catty, 2006; Reber, Schwarz & Winkielman, 2004) and much of the arguments regarding the effect of complexity on preference revolve around information acquisition (Silvia, 2008; Stamps, 2002; 2004; 2010), it seems likely that global arrangement may shape emotions above and beyond the effect of entropy. To this point, research on environmental entropy has failed to address such possible effects of global properties on emotional response; symmetry was considered in this experiment as manipulation of global arrangement, as it has been previously shown to affect a number of experiences (Chen, Wu & Wu, 2011; Reber, 2002; Vitz & Todd, 1969; Snodgrass, 1971; Berlyne, 1974d; Stamps, 1998a; Mehrabian & Russell, 1974).

The effect of symmetry on both perception of complexity and emotional response has been examined previously. Symmetric visual arrays were perceived as less complex and less arousing (Vitz & Todd, 1969; Berlyne, 1974d) while symmetry resulted in positive hedonic response (Berlyne, 1974d) and both interest and pleasure (Day, 1968). In the rare instances where symmetry was considered in regards to experience of the environment, it decreased environmental complexity (Stamps, 1998a) and arousal response (Mehrabian & Russell, 1974). Under the assumption that entropy shapes environmental experience, because it captures information content, it seems likely that symmetry will have a robust effect on response due to its role in mitigating information complexity (Chan, Wu & Wu, 2011; Mehrabian & Russell, 1974b; Vitz & Todd, 1969). Indeed, symmetry leads to easier assimilation of knowledge (Berlyne, 1974d) and perhaps decreases information processing load, both of which may result in positive effects on emotional response (Reber, 2002; Winkielman, Halberstadt, Fazendeiro & Catty, 2006; Reber, Schwarz &

Winkielman, 2004). Thus, symmetry provides a useful tool by which to manipulate the global arrangement of panels.

It is important to note that, it is possible to consider symmetry within the calculation of entropy. For example, probabilities of whether a stimulus is symmetric, or not, can be generated and thus used to calculate entropy. In order to align our work with previous literature on environmental symmetry, we decided instead to consider symmetry as a factor layered on top of the environmental entropy. This approach has the benefit of allowing us to consider symmetry as independent of entropy. Future research would do well to consider symmetry within the generation of entropy values.

In this experiment, symmetric and asymmetric versions of each level of environmental entropy were generated using environments that allow for mirror symmetry along the vertical plane. Symmetry along the vertical plane was selected, rather than symmetry along the horizontal plane, as vertical symmetry is more easily perceived and processed (Wenderoth, 1994; Corballis & Roldan, 1975). We predict that symmetric environments will be less complex and more pleasant than their asymmetric counterparts, while symmetric environments should be selected more frequently in the VR navigation task. Such effects would argue strongly that experience of the environment consists of not only the amount of information within the environment, but also how the information is processed and assimilated by the individual.

5.1.2. Experiment 2.2 objectives.

In addition to the general objectives of this dissertation, as expressed in the introduction, this experiment had three additional objectives. First, the experiment tested the robustness of the negative entropy effect exhibited in the previous study, by changing both the local and global environment characteristics. Second, by using shapes rather than dots to identify the panels, we tested the effect of local properties on experience of the environment. Third, by manipulating symmetry at each level of entropy, we examined factors that may shape experience, beyond entropy. Specifically, symmetry may allow for more fluent and efficient assimilation of information, potentially demonstrating how arrangement and organization of the panels may shape experience of the environment.

5.2. Methods

5.2.1. Generation of entropy and symmetry.

Panels were identified through four-sided polygons placed on the panels; since each environment was composed of five panels, five distinct polygon panels were needed. The panels were created by manipulating the angles and edge lengths of a square to ensure that overall perimeter and area remained constant, resulting in a square, a horizontal rectangle, a vertical rectangle, and two trapezoids. Each shape was positioned centrally on a $0.5m^2$ square and a textured appearance was created using a randomized filter layer through the Clouds rendering function in the photo editing software GIMP. Panel luminance between panels was controlled using the Matlab program SHINE (Willenbockel, Sadr, Fiset, Horne, Gosselin & Tanaka, 2010). Final panels are visualized in Figure 5.1.

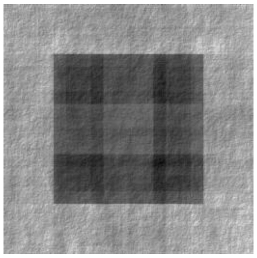
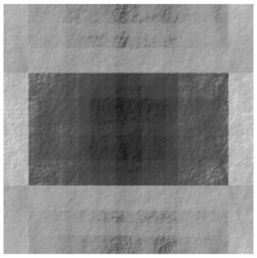
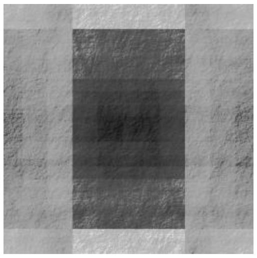
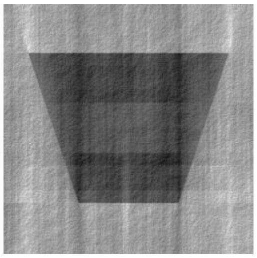
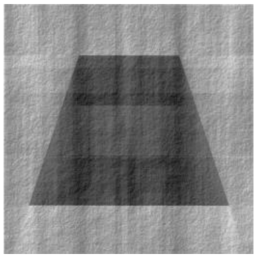
Polygon	
Square	
Horizontal Rectangle	
Vertical Rectangle	
Trapezoid #1	
Trapezoid #2	

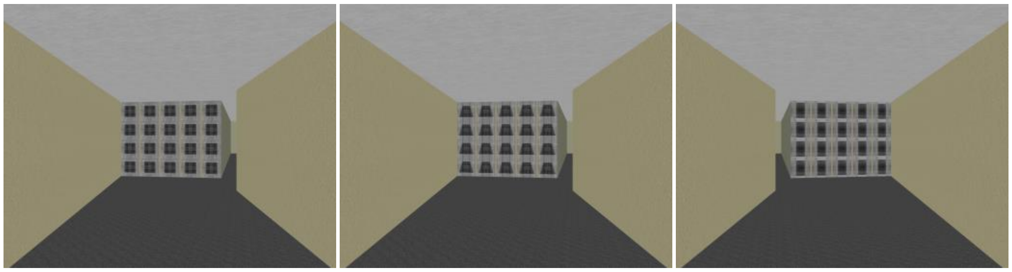
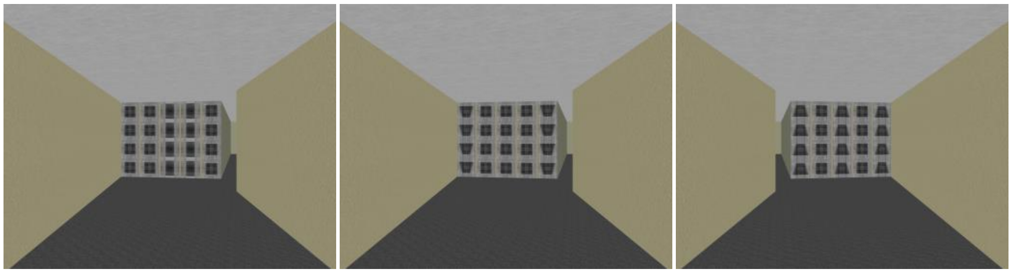
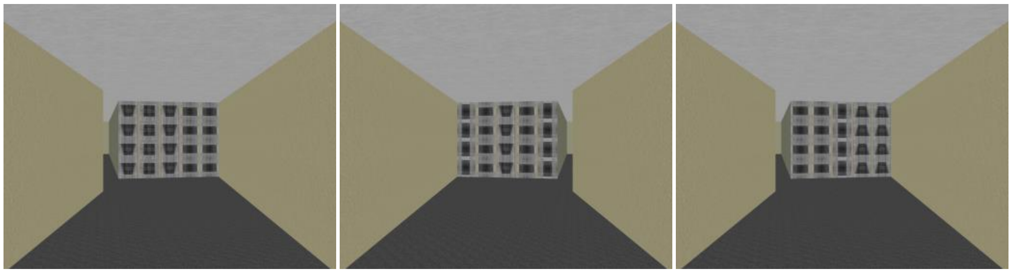
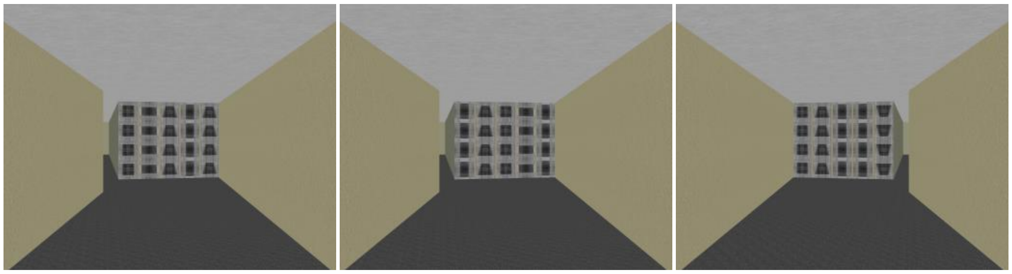
Figure 5.1. The rendered shape panels.

Within each entropy corridor, five columns panels were placed vertically on the back wall, allowing for the generation of seven levels of entropy ranging from 0.00 to 2.32 bits. Refer to Table 5.1 for all possible entropy permutations. To keep the total number of corridor environments manageable, only five entropies, increasing in a linear fashion, were selected: 0.00, 0.97, 1.52, 1.92 and 2.32 bits. Please refer to Figure 5.2 for representative images of the rendered environments. Each of these entropy values could be generated in a number of ways depending on how the panels were arranged and which polygon panels were used. Thus, the panels used to generate each entropy corridor were pseudo-randomly selected to ensure that during the entirety of the experiment, each polygon panel occurred an equal number of times.

Table 5.1.

Polygon panel probabilities and their associated entropy values

Panel Probabilities	Entropy (E)	Notation
1 panel (1 : 5/5)	0.00	$E_{0.00}$
2 panels (1 : 2/5) (2 : 3/5)	0.97	$E_{0.97}$
3 panels (1 : 1/5) (2 : 1/5) (3 : 3/5)	1.52	$E_{1.52}$
4 panels (1: 2/5) (2: 1/5) (3: 1/5) (4: 1/5)	1.92	$E_{1.92}$
5 panels (1 : 1/5) (2 : 1/5) (3 : 1/5) (4 : 1/5) (5 : 1/5)	2.32	$E_{2.32}$

Entropy	
0.00	
0.97	
1.52	
1.92	

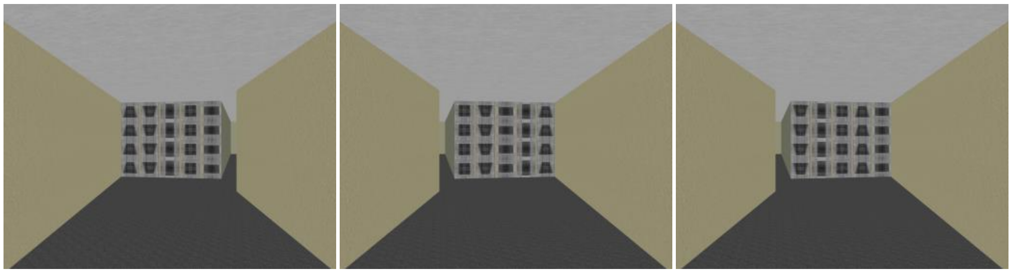
2.32	

Figure 5.2. Three sample environments for each level of entropy.

Regarding symmetry of the environments, asymmetric and symmetric versions of 0.97, 1.52, 1.92 entropy environments were created by manipulating panel arrangement. It was not possible to create symmetric and asymmetric versions of 0.0 and 2.32 entropy environments as for 0.00 all panels are the same, and thus the environment is symmetrical, while for 2.32 all panels are different and thus the environment can only be asymmetric. As visualized in Figure 5.3, the line of symmetry occurred within the middle of the central panel, and the environment was symmetrical if the left and right sides of the environment were mirror images of one another. For each entropy value, whether symmetric or asymmetric, there are numerous arrangements that can be used to generate the necessary panel probabilities (see Appendix C for all possible arrangements). Since each entropy value had to be paired with every other entropy value for both symmetric and asymmetric arrangements, it was not realistic to generate and present all possible arrangements. Instead, two symmetric and two asymmetric arrangements for each level of entropy were randomly selected, resulting in four arrangements per entropy (see Appendix D for selected arrangements). For certain entropy environments, it was not possible to generate truly symmetric arrangements, but instead, pseudo-symmetric arrangements were used. For example, at 1.92 bits of entropy three shape panels were presented once each, it was therefore not possible to distribute these three panels in a manner which would result in symmetry. For example one of the arrangements for 1.92 bits of entropy featured two distinct panels on the far right and the far left positions and a third unique panel in the middle locations, while the panels positioned to the immediate right and left of the middle panel were the same. In this instance, since the interior panels were symmetric and the environment possessed clear organization and structure, the arrangement was coded as symmetric although the environment was only partially symmetrical.

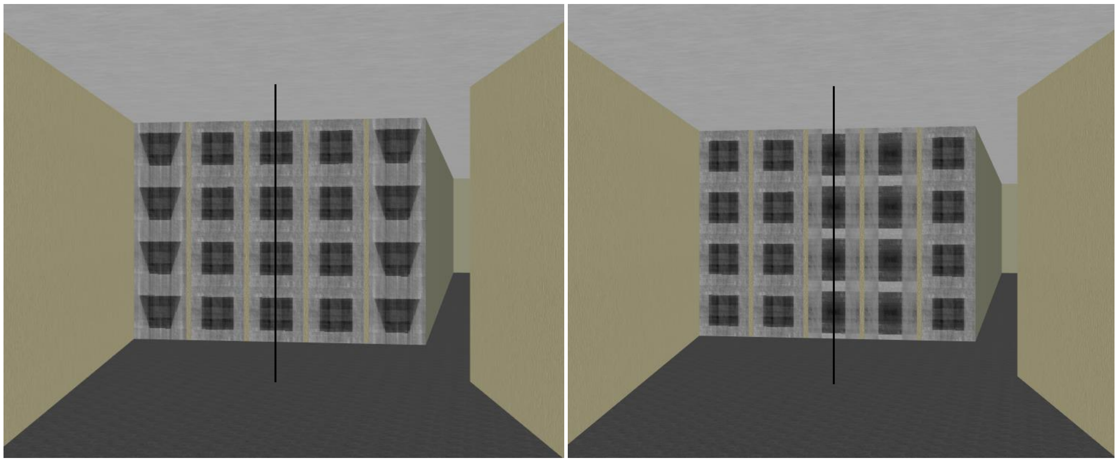


Figure 5.3. Both of the environments contain the same level of entropy (0.97), but the left environment is symmetrical along its vertical axis while the right environment is asymmetrical. The vertical line is presented here to illustrate axis of symmetry and was not present during the experiment.

5.2.2 The environment.

The environments' dimensions and overall structure were the same as in the previous experiment. The primary difference was the positioning of the panels vertically on the far wall within each corridor. Due to the inclusion of the symmetry variable and a fifth entropy value, the overall length of the environment increased in order to accommodate all possible paired comparisons. Each entropy environment pair was presented four times, allowing us to test the effect of entropy, symmetry and presentation side as follows: 1) both symmetric, 2) both asymmetric, 3) left symmetric, right asymmetric and 4) left asymmetric, right symmetric, resulting in a total of 40 trials. Since the virtual environment model needed to be generated and rendered prior to the experiment, it was not possible to randomize presentation order, instead order was pseudo-randomized following several rules to ensure that environment pairs were evenly distributed throughout the environment. First, due to the large number of trials, it was decided to present control environments every five trials so as to give the participant a mental break from viewing shape panels. This resulted in eight control conditions and increased the total number of trials to 48. Second, each entropy environment was presented twice per block, as defined by the five paired environments between control environments. Third, within each block, each entropy environment was presented on alternate sides and paired with a different entropy environment. For example, the first block paired $E_{0.00}$ with $E_{1.52}$ and with $E_{0.97}$; $E_{0.00}$ was positioned on the left side when presented with $E_{1.52}$ and on the left side when presented with $E_{0.97}$. See Appendix D for final environment entropy trial order.

5.2.3. Apparatus, procedure and measures.

Due to the nearly identical results between the forced choice and path selection tasks in the previous experiment, only the path selection task was conducted alongside the subjective emotional response task. Generation of static images, apparatus, recorded measures and overall procedures for the two tasks were the same as in Experiment 2.1.

5.2.4. Participants.

Twenty-six participants (17 female) completed the static image subjective response task, while 36 (18 female) completed the VR path selection task. All participants were University of Waterloo undergraduate students and completed the experiment for course credit. The experiment was approved by the University of Waterloo Office of Research Ethics and each participant completed an informed consent form prior to beginning the experiment.

5.3. Results

5.3.1. Static image subjective emotional response ratings.

As it was not possible to generate both symmetric and asymmetric versions of $E_{0.00}$ and $E_{2.32}$, two repeated measures ANOVAs were conducted. In the first ANOVA we collapsed symmetric and asymmetric environments for $E_{0.92}$, $E_{1.52}$ and $E_{1.97}$ and analyzed them along with the control $E_{0.00}$ and $E_{2.32}$ environments, resulting in a single entropy factor with five levels. In the second ANOVA, we eliminated $E_{0.00}$ and $E_{2.32}$ while including the additional symmetry factor for $E_{0.92}$, $E_{1.52}$ and $E_{1.97}$, resulting in a 2X3 repeated measure ANOVA with symmetry and entropy as within participant variables.

Complexity

As Mauchly's test of sphericity was significant, $x^2(14) = 29.96$, $p < 0.01$, degrees of freedom were corrected using Greenhouse-Geisser correction. Symmetry collapsed across entropy, the main effect of entropy was significant, $F(3.14,78.48) = 140.61$, $p < 0.001$, $\eta^2 = 0.849$ (Figure 5.4). Bonferroni corrected pairwise comparisons demonstrated that each level of entropy was significantly different from one another—the control environment was rated as least complex while $E_{2.32}$ environments were most complex. Complexity appeared to increase linearly from control to $E_{2.32}$: Control (M = 1.29, SD = 0.1), $E_{0.00}$ (M = 1.98, SD = 0.16), $E_{0.97}$ (M = 3.35, SD = 0.16), $E_{1.52}$ (M = 3.96, SD = 0.14), $E_{1.92}$ (M = 4.5, SD = 0.15) and $E_{2.32}$ (M = 5.3, SD = 0.17).

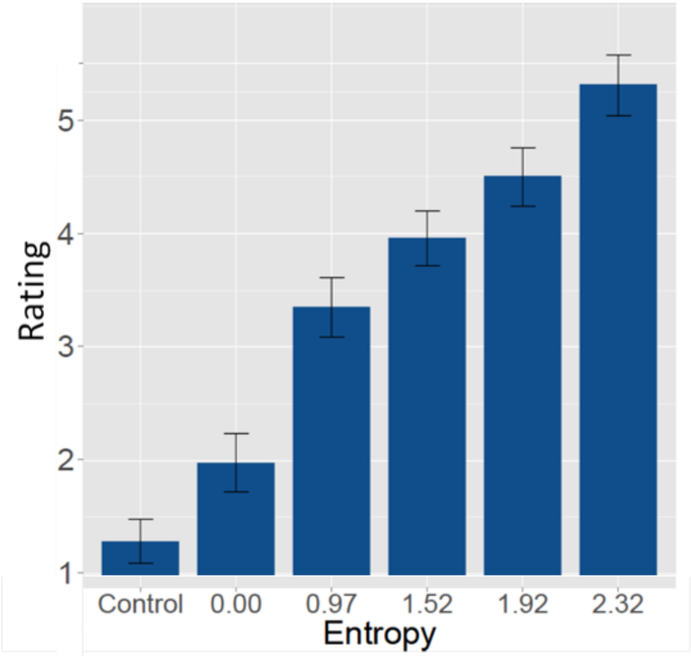


Figure 5.4. The main effect of entropy on complexity ratings

When symmetry was considered along with entropy, the effect of entropy was significant, F(2,50) = 33.88, $p < 0.001$, $\eta^2 = 0.58$, while the effect of symmetry was non-significant, F(1,25) = 0.54, $p < 0.57$, $\eta^2 = 0.02$ (Figure 5.5). Bonferroni corrected pairwise comparisons demonstrated that each entropy value was significantly different from the others, with $E_{1.92}$ most complex, (M = 4.5, SE = 0.15), $E_{0.97}$ least complex, (M = 3.35, SE = 0.16), and $E_{1.52}$ moderately complex, (M

= 3.96, SE = 0.14). The interaction between entropy and symmetry was non-significant, F(2,50) = 1.53, p = 0.31, $\eta^2 = 0.06$.

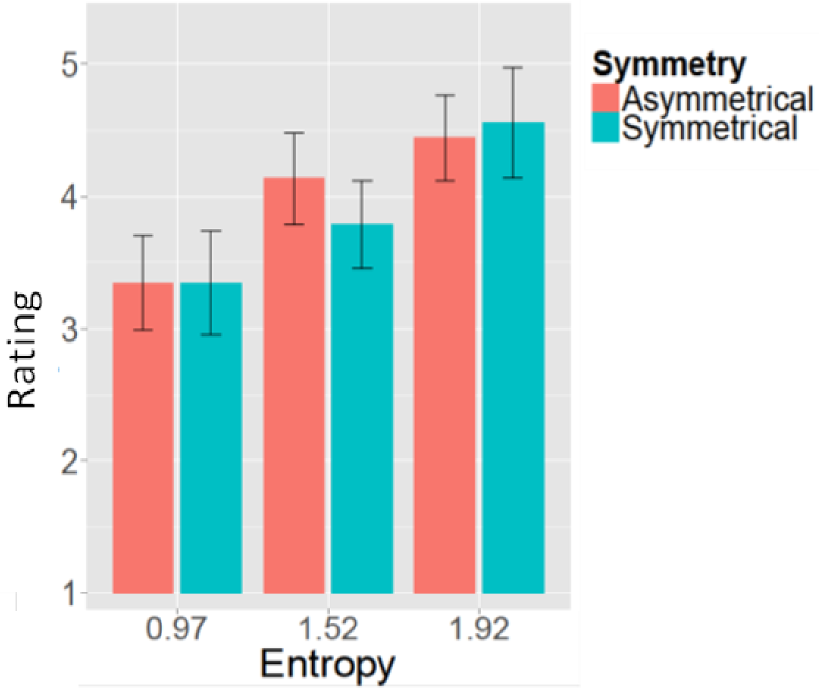


Figure 5.5. The interaction between entropy and symmetry on complexity ratings

Pleasure

A Greenhouse-Geisser correction to degrees of freedom was applied, due to a significant result for Mauchly's test of sphericity, $x^2(14) = 114.42$, $p < 0.001$. With symmetry collapsed across entropy, the main effect of entropy on pleasure was significant, F(5,125) = 12.17, p <0.001, $\eta^2 = 0.38$ (Figure 5.6). Pairwise comparisons demonstrated that $E_{0.00}$, (M = 4.95, SD = 0.24), was more pleasant than all other entropy environments but was equally as pleasant as the control environment, (M = 4.54, SD = 0.37). The control environment was rated equally as pleasant as $E_{0.97}$ and $E_{1.52}$, (M = 4.23, SE = 13 and M = 3.95, SE = 13). $E_{1.92}$ was less pleasant than all other entropies except $E_{2.32}$, (M = 3.32, SE = 0.15 and M = 3.03, SE = 0.22). Thus, there appeared to be a peak at $E_{0.00}$ with a general negative trend as entropy increased.

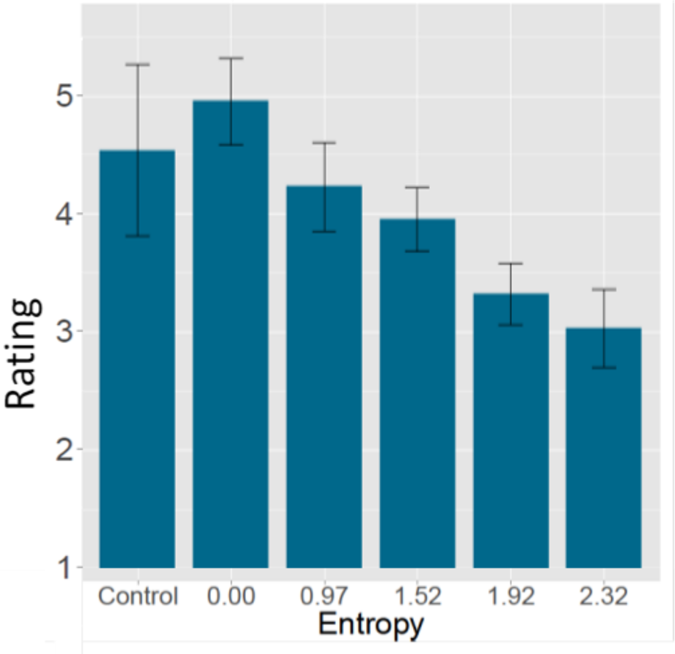


Figure 5.6. The main effect of entropy on pleasure ratings.

Mauchly's test of sphericity for the entropy by symmetry interaction was significant, $x^2(14) = 11.1$, $p < 0.01$, thus a Greenhouse-Geisser correction was applied to degrees of freedom. With symmetry included as an additional within subjects factor, the entropy by symmetry interaction was significant, $F(1.46,36.48) = 17.69$, $p < 0.001$, $\eta^2 = 0.41$ (Figure 5.7). With an alpha level of 0.05, a simple effects analysis showed that symmetric environments were more pleasant only at $E_{0.97}$ and $E_{1.52}$, ($E_{0.97}$: asymmetric, M = 3.31, SD = 0.18 vs. symmetric, M = 5.15, SD = 0.21, $p < 0.001$), ($E_{1.52}$, asymmetric, M = 3.4, SD = 0.15 vs. symmetric, M = 4.5, SD = 0.17, $p < 0.001$) and ($E_{1.92}$, asymmetric M = 3.31, SD = 0.2 vs. symmetric M = 3.33, SD = 0.17, p = 0.95).

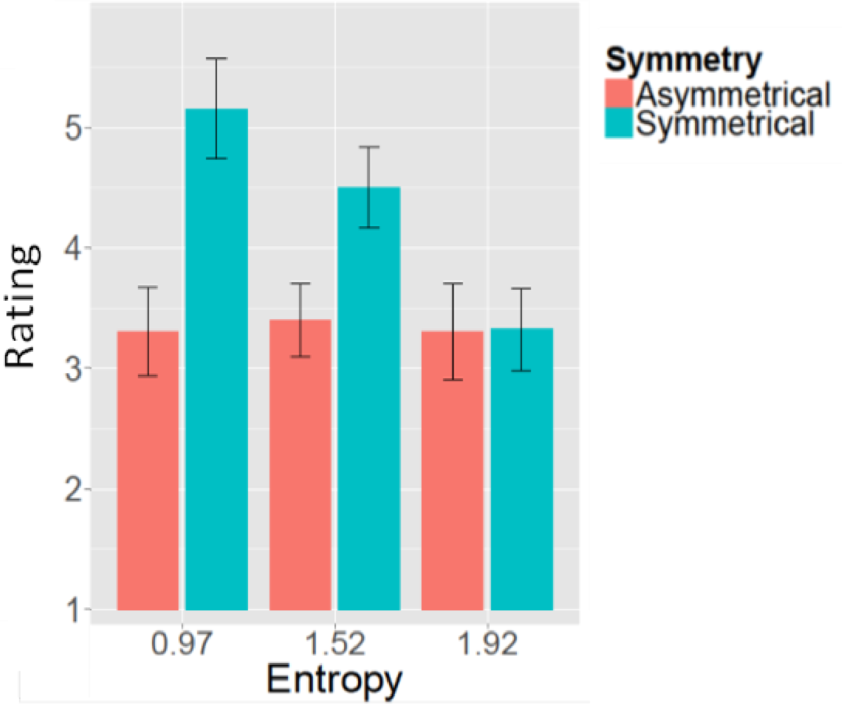


Figure 5.7. Interaction between entropy and symmetry on pleasure ratings

Interest

With symmetry collapsed across entropy, Mauchly's test of sphericity was significant, $x^2(14) = 120.68$, $p < 0.001$; with a corrected degrees of freedom, the main effect of entropy was significant, $F(1.66,41.59) = 13.41$, $P < 0.001$, $\eta^2 = 0.35$ (Figure 5.8). The control environment was least interesting, (M = 2.35, SE = 0.32), while $E_{2.32}$ was most interesting (M = 4.58, SE =

0.24). The three intermediate entropy levels were equally interesting, $E_{0.97}$ (M = 4.06, SE = 0.13), $E_{1.52}$ (M = 4.2, SE = 0.17), $E_{1.92}$ (M = 4.03, SE = 0.2). Entropy of 2.32 was more interesting than all other environments, except $E_{1.52}$, (M = 4.58, SE = 0.24 and M = 4.2, SE = 0.17).

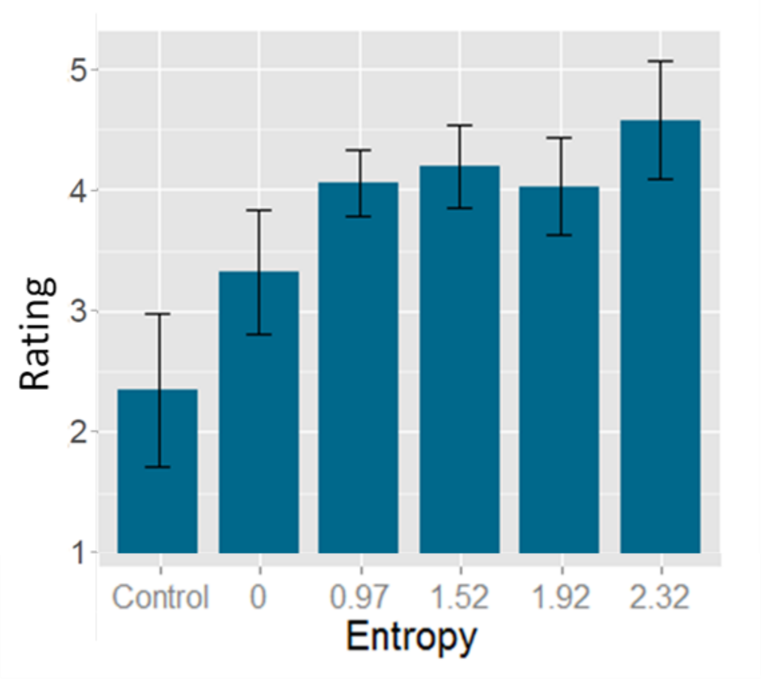


Figure 5.8. The main effect of entropy in interest ratings

With symmetry included as a within subjects factor, the 3X2 repeated measures ANOVA demonstrated a significant main effect of symmetry, F(1,25) = 13.61, $p < 0.01$, $\eta^2 = 0.35$, while the main effect of entropy was non-significant, F(2,50) = 0.51, p = 0.6, $\eta^2 = 0.02$ (Figure 5.9). Symmetric environments were rated as more interesting than asymmetric environments, (M = 4.37, SE = 0.14 and M = 3.83, SE = 0.17). The interaction between entropy and symmetry was non-significant, F(2,50) = 2.45, p = 0.09, $\eta^2 = 0.47$.

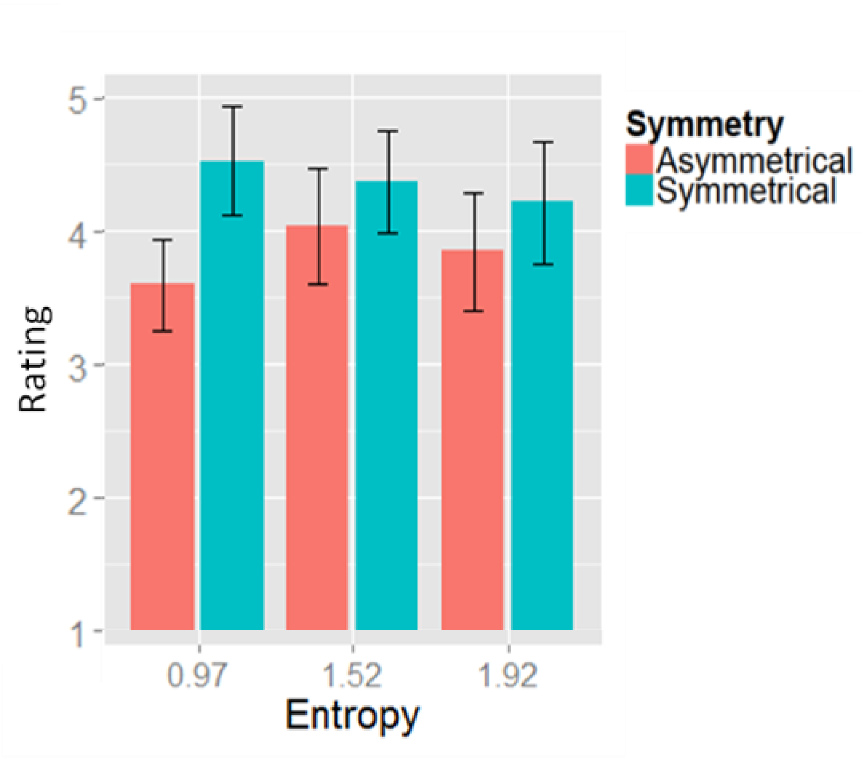


Figure 5.9. Interaction between entropy and symmetry on interest ratings

Correlation Analysis

Partial correlations between physical descriptors of the environment (entropy and symmetry) and the semantic differential responses (complexity, pleasure and interest) were calculated by controlling for within participant variability as recommended by Bland and Altman (1994; 1995). Note that entropy of 0 was considered symmetric while 2.32 was considered asymmetric. Please see Table 5.2 below for correlation coefficients. Of note is that entropy correlated strongly with perceived complexity (r = 0.83) and interest (r = 0.33) and negatively with pleasure (r = -0.55). Symmetry was significantly correlated with pleasure (r = 0.54) and negatively with complexity (r = -0.51). Pleasure and interest appeared to be distinct as they were not correlated (r = -0.001, p = 0.98). The partial correlation considering symmetry alongside entropy with complexity becomes non-significant for symmetry (r = -0.07, p = 0.26) while remaining significant for entropy (r = 0.76, p < 0.01). This suggests that the significant correlation between symmetry and complexity was a result of the fact that 0 entropy environments were code as symmetric and 2.32 entropy environments were coded as asymmetric. Symmetry remained significantly correlated with pleasure and interest even when considering entropy.

Table 5.2.

Correlation coefficients for environmental properties and self-report measures

	Complexity	Pleasure	Interest
Entropy	0.83**	-0.55**	0.33**
Symmetry	-0.51**	0.53**	0.08
Complexity		-0.52**	0.43**
Pleasure			0.001

** p < 0.01

5.3.2. Path analysis.

Path analysis was conducted using multiple linear regression and allowing participant intercepts to vary, thus treating participants as a random effect (Preacher & Hayes, 2004; Bland & Altman, 1995: Pedhazur, 1997). Physical features of the environment in the form of symmetry and entropy were treated as predictors, while emotional responses of interest and pleasure were treated as outcome variables. Perceived complexity was considered as a mediator.

Please refer to Figure 5.10 below for the final model; standardized coefficients are shown. Although entropy predicted both complexity and interest ratings positively, mediation analysis demonstrated that the effect on interest was fully mediated by complexity ratings, Sobel test = 4.68, $p < 0.001$, with the coefficient falling from $\beta = 0.29$ to $\beta = -0.07$ and becoming non-significant, $p = 0.44$. Entropy had a significant, negative effect on pleasure, which was partially mediated by complexity, Sobel test = 2.01, $p < 0.05$. With complexity considered as a mediator, the effect of entropy on pleasure fell from $\beta = -0.5$ to $\beta = -0.36$ but remained significant, $p < 0.05$.

Symmetry predicted both complexity and pleasure while failing to predict interest. Mediation analysis demonstrated that complexity did not significantly mediate the effect of symmetry on pleasure, Sobel test = 0.89, $p = 0.37$.

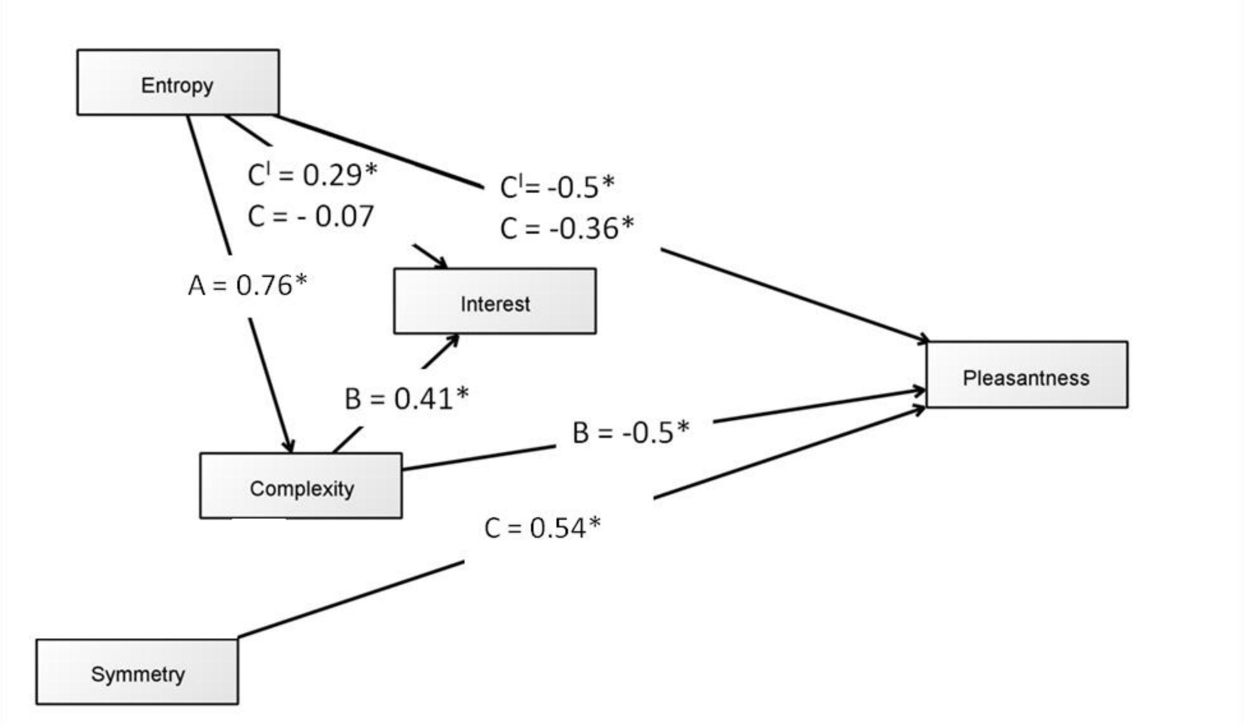


Figure 5.10. The model with emotional response as outcome variables and environment properties (entropy and symmetry) as predictors. Perceived complexity was treated as a mediator. Only coefficients significant at $p < 0.05$ are shown.

5.3.3. Virtual reality path selection.

As was the case with the subjective response data, since entropies of 0.00 and 2.32 could not be presented in both symmetric and asymmetric arrangements, two distinct ANOVAs were conducted. In the first, symmetry was collapsed at each level of entropy allowing us to analyze the effect of entropy using a repeated measures ANOVA. In the second analysis, symmetry was maintained as a within subjects factor along with the three entropies possessing both symmetric and asymmetric arrangements, 0.97, 1.52 and 1.92. This resulted in a 2X3 repeated measures ANOVA and allowed us to examine the effect of symmetry along with entropy.

When symmetry was collapsed across levels of entropy, the main effect of entropy on path selection was marginally significant, $F(4,140) = 2.48$, $p = 0.05$, $\eta^2 = 0.07$ (Figure 5.11) . The effect was driven primarily by the higher percentage of selection for $E_{1.52}$ as compared to $E_{1.92}$ and $E_{2.32}$. Bonferroni corrected pairwise comparisons show that $E_{1.52}$, (M = 54.17, SE = 1.96), was selected more frequently than both $E_{1.92}$ and $E_{2.32}$ (M = 43.92, SE = 2.62 and M = 43.58, SE = 3.36). $E_{1.52}$ was selected as frequently as $E_{0.00}$ and $E_{0.97}$ (M = 53.13, SE = 4.83 and M = 55.21, SE = 2.3). Finally, $E_{0.00}$, $E_{0.97}$, $E_{1.92}$ and $E_{2.32}$ were selected at the same statistical rate.

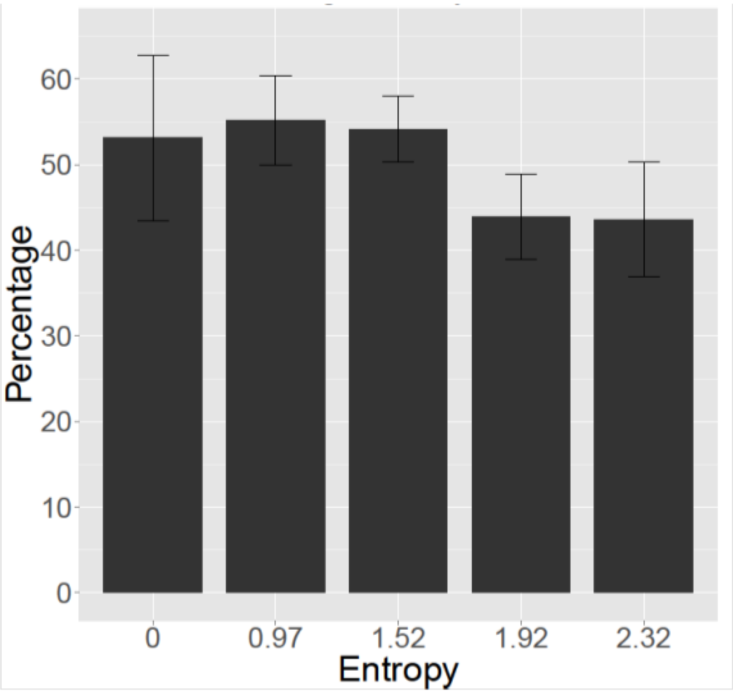


Figure 5.11. Main effect of entropy on virtual reality path selection

When symmetry was considered as an additional within participants variable, the interaction between symmetry and entropy was non-significant, $F(2,70) = 2.89$, $p = 0.06$, $\eta^2 = 0.08$. The main effect of entropy was significant, $F(2,70) = 5.43$, $p < 0.01$, $\eta^2 = 0.13$, while the main effect of symmetry was non-significant, $F(1,35) = 2.06$, $p = 0.16$, $\eta^2 = 0.06$ (Figure 5.12). Simple effects analysis showed that symmetric versions were selected more frequently only at $E_{0.97}$, (symmetric: $M = 60.76$, $SE = 3.86$ vs. asymmetric: $M = 49.65$, $SE = 3.36$, $p < 0.05$). For $E_{1.52}$ and $E_{1.92}$, symmetric and asymmetric arrangements were selected at the same percentage, ($E_{1.52}$ — symmetric: $M = 56.25$, $SE = 2.31$ vs. asymmetric: $M = 52.08$, $SE = 3.09$, $p = 0.28$) and ($E_{1.92}$ — symmetric: $M = 43.06$, $SE = 3.32$ vs. asymmetric: $M = 44.79$, $SE = 3.81$, $p = 0.72$). $E_{0.97}$ ($M = 55.21$, $SE = 2.83$) was selected at a higher percentage than $E_{1.92}$ ($M = 43.92$, $SE = 2.62$, $p = 0.05$), but at the same rate as $E_{1.52}$ ($M = 54.27$, $SE = 1.96$, $p = 1.00$). Finally, $E_{1.52}$ was selected at a higher percentage than $E_{1.92}$. Although the main effect of entropy was significant, it is potentially explained by the trending interaction between symmetry and entropy, specifically at $E_{0.97}$.

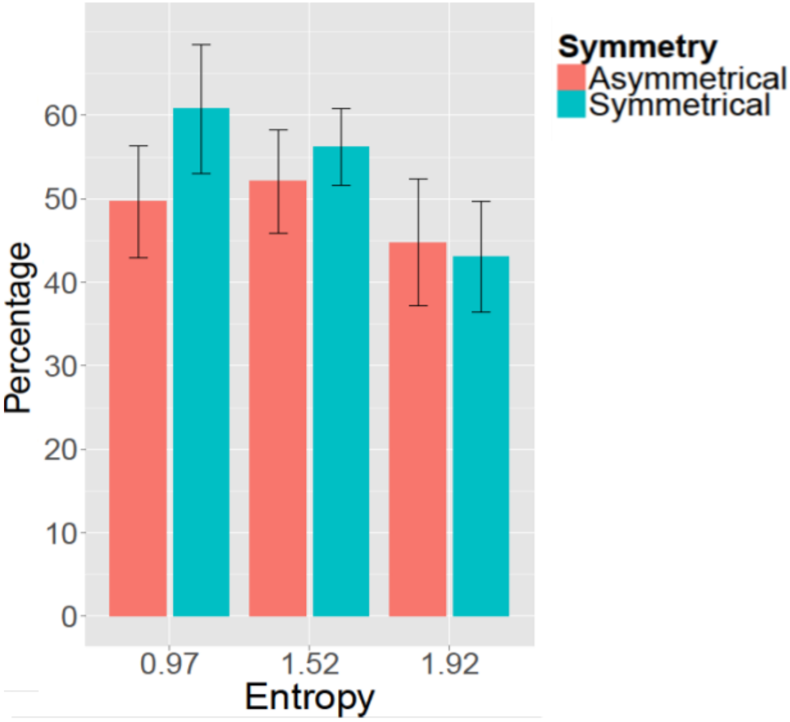


Figure 5.12. The interaction between entropy and symmetry on virtual reality path selection.

5.4. Discussion

The purpose of this experiment was to test the robustness of the negative entropy effect on pleasure seen in Experiment 2.1 and to examine the effect of symmetry on shaping emotional response towards the environment. Once again, entropy predicted complexity reliably while affecting pleasure negatively. In this experiment, entropy also had a significant effect on interest, while interest remained distinct from pleasure. The newly introduced variable of symmetry affected both interest and pleasure. Results between the self-reported ratings were comparable to the virtual reality path selection task. These results suggest some important considerations when examining the effect of entropy on response to the environment.

5.4.1. The effect of entropy and symmetry on perceived complexity.

Although Experiment 2.1 demonstrated that entropy resulted in increases in perceived complexity, it was possible that the effect was a result of the unusual dot density panels used in the experiment. In this experiment, polygons were used to distinguish panels and once again, more entropic environments were perceived as more complex; this coupled with the effect observed in Experiment 2.1 demonstrates that entropy is a reliable and robust way to manipulate complexity. Unexpectedly, symmetric environments were not perceived as less complex; this is unusual as symmetric stimuli are argued as possessing redundant information (Berlyne, 1974d) which in turn resulted in decreased complexity previously (Stamps 1998a; Vitz & Todd, 1969; Chen, Wu & Wu, 2011). The lack of a symmetry effect cannot be explained by participants being unable to perceive the symmetry as there was a significant effect of symmetry on both pleasure and interest.

5.4.2. Effect of entropy and symmetry on emotional response.

In agreement with Experiment 2.1, entropy had a negative effect on pleasure, supporting the notion that complexity may lead to negative emotional response (Reber, Schwarz & Winkielman, 2004). Unlike Experiment 2.1, entropy also had a significant effect on interest—more entropic environments were experienced as more interesting. Although the effect of entropy on interest is rarely examined in the environment experience literature, a positive effect of complexity on interest has been demonstrated previously for a wide range of synthetic stimuli, including dots, visual arrays and even sequences of sounds (Normore, 1974; Day, 1967; Eisenman, 1966; 1967; Berlyne, 1974). These findings support the notion that the effect of entropy on pleasure is consistent across local properties of the events used to calculate entropy, while a novel effect of entropy on interest was also noted.

An interaction between entropy and symmetry on pleasure was observed, where the symmetric environments were more pleasant than the asymmetric environments, but only at entropies of 0.97 and 1.52. The lack of difference in pleasure responses at 1.92 bits of entropy may be because these environments did not possess true mirror symmetry but were instead pseudo-symmetrical insofar that panels were arranged in an ordered fashion. Since symmetry did not reduce complexity, the interaction between symmetry and entropy on reported pleasure cannot be explained by a reduction in complexity. An alternative information processing explanation is tenable; perhaps symmetric environments are not experienced as less complex but they may be processed more efficiently by the visual system thus resulting in the positive effect seen here (Reber, Schwarz & Winkielman, 2004). This explanation is weakened by the fact that it implies that perceived complexity and ease of processing are distinct, yet we would expect the two to be highly related.

Alternatively, it has been suggested that symmetric stimuli are experienced as pleasant because symmetry confers an advantage to an organism from an evolutionary perspective. For example, food sources, prey, predators and other highly salient elements within the natural environment are symmetrical, while less salient environmental factors such as mountains and other geometric features are asymmetrical (Tyler, 1994). It has also been suggested that symmetry reflects overall health and sexual fitness (Møller, 1992; Watson & Thornhill, 1994;

Møller & Thornhill, 1998). Such evolutionary perspectives may explain the interaction exhibited here, but the data do not speak to this argument directly.

There was a main effect of symmetry on reported interest, with symmetric environments being rated as more interesting. This demonstrates that interest is not determined solely by information complexity; the information also needs to be manageable so that the viewer can understand the information presented by the complexity (Silvia, 2005; 2008). Thus, symmetry allows for the information in the environment to be processed more easily, meeting the second requirement for interest to be experienced. Although the effects of both entropy and symmetry on response are insightful, we will next examine whether the effects of the physical features of the environment on emotional response were mediated by perceived complexity.

5.4.3. The path from environment to emotional response.

In this experiment, we predicted that the direct effect of the physical descriptors of the environment, entropy and symmetry, on emotional responses of interest and pleasure would be either partially or fully mediated by perceived complexity. Entropy predicted both interest and pleasure, with the effect on interest fully mediated by complexity, while the effect on pleasure was partially mediated by complexity. Symmetry, on the other hand, predicted pleasure and complexity. Note that the effect of symmetry on complexity is most likely a result of the fact that 0 bit entropy environments were symmetric while 2.32 bit entropy environments were asymmetric; thus symmetry was confounded with entropy. In fact, partial correlations between symmetry and complexity while considering entropy were non-significant; thus the symmetry-pleasure relationship is potentially a result of entropy rather than symmetry per se. With this said, symmetry has been shown to affect pleasure positively in previous research as symmetry creates information redundancy thus allowing for information to be processed more easily (Berlyne, 1974d; Vitz & Todd, 1969). Regardless of this unclear relationship between entropy, symmetry and pleasure, these findings support the argument that emotional responses are at least partially mediated by a cognitive component of perceived complexity.

5.4.4. Dissociation between pleasure and interest and its functional significance.

The pattern of results in both the repeated measures ANOVA and the path analysis strongly suggested that pleasure and interest are distinct. Not only are the two not correlated with one another, but they are differentially affected by entropy, symmetry and perceived complexity, a novel finding in the literature. The effect of entropy and perceived complexity on pleasure was negative; as entropy increased pleasure decreased, while for interest, the effect was positive; as entropy and complexity increased so did interest. Additionally, in the path analysis, symmetry only predicted pleasure while failing to predict interest. These results support a multifaceted approach to positive emotions, where both interest and pleasure are positive, but distinct emotional responses. Here interest is a result of information complexity, as has been suggested previously (Silvia, 2008), while pleasure is, in part, a result of ease of information processing as demonstrated by the negative effect of complexity and the positive effect symmetry on pleasure (Reber, Schwarz & Winkielman, 2004).

The subjective response data showed that entropy simultaneously exerted both a positive and negative effect on emotional response; as entropy resulted in both interest and displeasure. Participants' path selection behaviours demonstrated that individuals were more likely to select low entropy environments. Thus, entropy appeared to lead to avoidance, suggesting that behaviour is driven by the displeasing quality of the environments. Interest is argued as being an epistemological emotion, concerned with exploration and acquisition of information (Silvia, 2005, 2008, 2010), yet in this particular experiment, even though interest may have been experienced, it did not result in exploration of the highly entropic environments. Thus, pleasure was the more salient emotion resulting directly in the avoidance behaviour exhibited in the path selection task. This finding highlights the importance of considering more than one positive emotion when observing environmental response and the value of employing behaviour as a measure of emotional response.

5.4.5. Exploratory comparison between Experiments 2.1 and 2.2.

Complexity

Conceding that comparing across experiments is often problematic, by contrasting the results of Experiments 2.1 and 2.2, we may gain some important insights for future experiments. Typically, entropy is considered a measure of complexity based solely on the probabilistic occurrence of events, remaining agnostic about the specific qualities of the events in question. It seems reasonable to assume that complexity may result from factors beyond entropy, depending on the quality or nature of the events. Indeed certain elements will be more or less complex based on the local visual properties as well as global arrangements of the elements, which in turn will lead to an effect on complexity distinct from entropy. Such considerations might explain the inconsistent effects of entropy on emotional response demonstrated here and elsewhere (Stamps, 2002, 2004). Although entropy affected complexity consistently for both environment types, there appeared to be a general upward shift in complexity scores for the dot environments. When comparing complexity between comparable entropy values, dot environments were experienced as more complex; for example, at 0.00 bits of entropy dot environments were rated as approximately one point more complex (1.98 versus 2.97). Refer to Figure 5.13 where complexity ratings for both Experiment 1.1 and 1.2 are shown on the same axes. At the same time, the control environments, which were the same in both tasks, were rated as equally complex (1.29 versus 1.32). This upward shift in complexity increased gradually with entropy for both environment types, and at around 1.9 bits of entropy dot and polygon environment complexity converged, and were experienced as equally complex. This suggests a potential upper limit to perceptions of complexity resulting from environmental entropy.

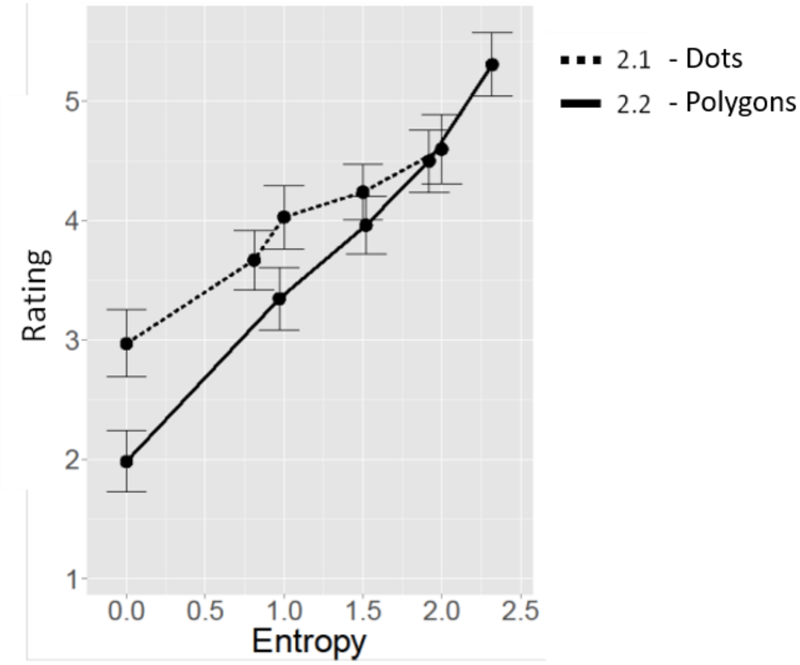


Figure 5.13. Perceived complexity for both Experiment 2.1 and 2.2.

Pleasure and Interest

Entropy had a consistent negative effect on pleasure and the slopes in both of the experiments were similar, but polygon environments were approximately one and a half points more pleasant than dot environments when comparing between similar entropy values. Please see Figure 5.14, where pleasure ratings for both Experiments 2.1 and 2.2 are plotted on the same axes. This pattern of results suggests that shape panels are experienced as more pleasant regardless of entropy values and that this difference may be a result of dot panels being more complex as described above. The question then becomes, why are dot panels more complex? As was suggested earlier, the nature of the dot panels, the fact that they are difficult to distinguish from one another, may explain this jump in complexity resulting in one of two possible relationships between entropy and pleasure. The first alternative is that difficulty in perceiving and processing dot panels independently results in both an increase in complexity and a decrease in pleasure. The second alternative is that difficulty in processing the dot panels results in decreased complexity which in turn affects pleasure negatively. Without conducting an additional experiment to directly compare dot and polygon environment we cannot convincingly argue for either of these two alternatives, but it is worth mentioning that complexity mediated the effect of entropy on pleasure in both sets of experiments, providing indirect support to the second alternative.

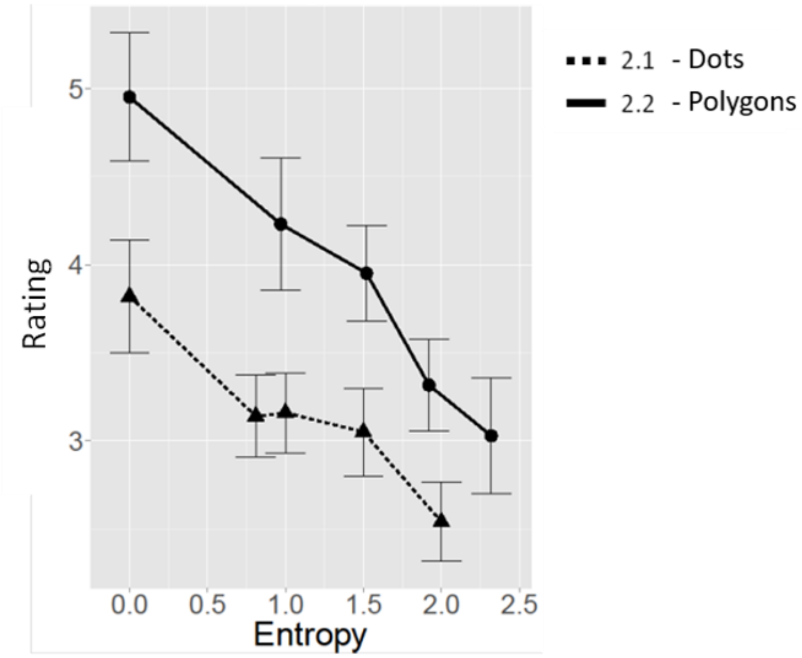


Figure 5.14. Pleasure ratings for both Experiments 2.1 and 2.2

Entropy did not affect interest for the dot environments while it influenced interest positively in the polygon environments. Previous research demonstrates that a stimulus needs to be understandable as well as complex for it to be experienced as interesting (Silvia, 2005, 2008). It is possible that due to the unusual and synthetic quality of the dot panels, participants were unable to make sense of the environments and thus the complexity was not experienced as interesting. On the other hand, the polygon panels were potentially less unusual, allowing participants to more fully understand the complexity, therefore, resulting in a significant effect of entropy on interest. Again, this conclusion is speculative; further research should present both dot and panel environments with the same entropy values, while also recording participants' ability to understand the environment.

Path selection behavior

When looking at the virtual reality path selection data between the two experiments several points should be noted. Refer to Figure 5.15 where path selection for both Experiment 2.1 and 2.2 are plotted on the same axes. Highly entropic environments (above 1.9 bits) were avoided regardless of panel type. For the dot environments, 0.00 bits of entropy was approached, perhaps resulting from the high overall complexity of the environments; perhaps dot environments were so complex, that participants select the simplest of the environments whenever possible (0.00 bits of entropy), thus avoiding the more complex alternatives (any other, higher, entropy value). Polygon environments were generally perceived as much less complex, therefore there was no need to select 0.00 bits of entropy, as most of the alternatives were not overly complex. Instead, behaviour was driven solely by the desire to avoid highly entropic environments (those beyond 1.9 bits), and therefore low and moderate entropy environments were selected at the same frequency. To summarize, in Experiment 2.1 all levels of entropy are equally avoided, except the least entropic option, while in Experiment 2.2, only the two highly entropic environments were avoided, thus moderate and low levels of entropy were equally approached. Regardless of environment type, it appears that the main objective in the path selection task is to avoid highly complex and therefore unpleasant environments, while the specifics of the optimal strategy selected by participants differs slightly between the two experiments.

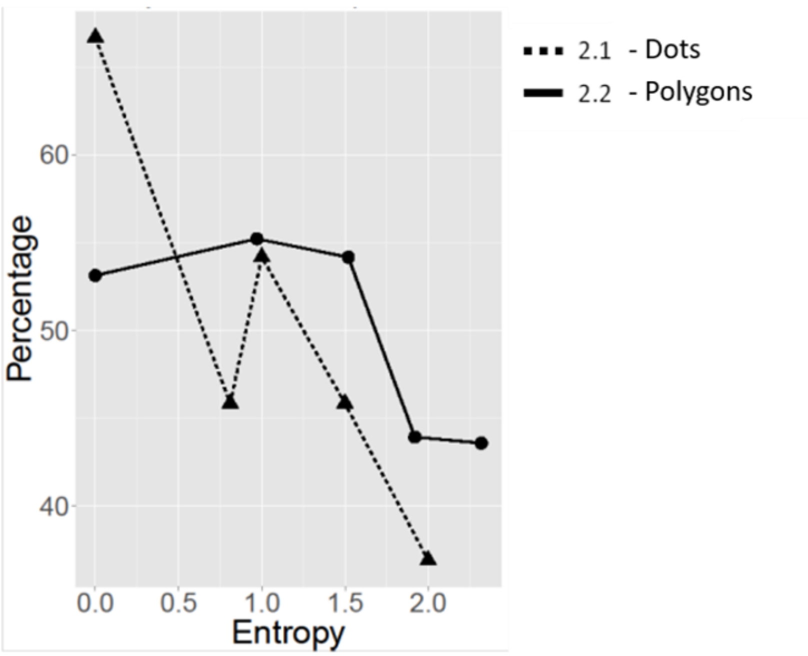


Figure 5.15. Corridor path selection for both Experiments 2.1 and 2.2. Error bars excluded to improve readability.

5.4.6. General conclusions from experiments 2.1 and 2.2.

Despite the apparent differences between Experiments 2.1 and 2.2, a number of conclusions can be made. First, entropy had a reliable effect on perceived complexity. Second, entropy had a consistent and negative effect on pleasure, while its effect on interest was less robust. Third, pleasure and interest remained dissociated, supporting the importance of considering positive emotional response as multifaceted. Fourth, behavioural measures showed that entropy was avoided, and such behaviour may have been a result of displeasure. Fifth, perceived complexity mediated the effect of entropy on emotional response, supporting the notion that cognitive predictors of emotional response need to be considered. Sixth, the effect of local panel properties (dots versus shapes) as well as global properties (symmetry versus asymmetry) demonstrated that entropy alone is not enough to describe the effect of complexity on response; instead, features above and beyond the probabilistic approach of entropy need to be examined.

The four experiments presented to this point relied on synthetic environments, created to test specific hypotheses and providing a high degree of experimental control, but potentially degrading the ecological validity of the findings. The following experiment examined the effect of entropy on emotional response in real-world environments, with the hope of showing that the effect is robust and powerful enough to shape experience within a much less controlled and yet ecologically valid context.

Chapter 6 - Entropy in Real-World Environments

6.1 Introduction

The previous four experiments demonstrated that, although visual complexity shaped experience consistently, it affected interest and pleasure differently. These results were demonstrated using highly unusual synthetic environments, which greatly limited the ecological validity of the findings. Thus, to more closely examine the variable effect of complexity on emotion and to improve ecological validity this experiment aims to examine the effect of entropy using real-world environments.

6.1.1. Response to real-world built environments.

To explore how the physical features of the built environment affect experience, researchers typically take one of two approaches: they either create novel, highly controlled, synthetic environments within known visual characteristics, or they use images of real-world environments and attempt to quantify their naturally occurring visual characteristics. With advances in both graphical software and presentation media, such as virtual reality, it has recently become much more straightforward to create synthetic environments and manipulate specific visual properties in order to test hypotheses. The synthetic environments approach draws from early visual preference research by Berlyne (1970; 1960; 1974c) and contemporaries (Day, 1967; 1968; Normore, 1974); where careful manipulation of visual properties leads to the creation of highly controlled and reliable stimulus sets. Such an approach is favoured by many environmental psychologists, where the physical features of the environment are carefully designed (Stamps, 1998b; 1999b; 2003; 2004; Imamoglu, 2000; Akalin, Yildirim, Wilson &

Kilicoglu, 2009; Heath, Smith & Lim, 2000; Valtchanov, Barton & Ellard, 2010), yet, regardless of the fidelity of these synthetic environments, questions of ecological validity remain.

The alternative, where images of real environments are used, has been employed for both urban (Nasar 1994; 1983; Nasar & Hong, 1999; Herzog & Shier, 2000) and natural environments (Valtchanov & Ellard, 2015; Kaplan, Kaplan & Wendt, 1972; Kaplan, Kaplan & Brown, 1989). This approach faces a different set of issues than the synthetic environment perspective presented above; namely, by using images of real environment it is difficult to quantify the visual properties of the environments in a valid and reliable manner. As opposed to synthetic environments, real environments are messy, and rife with confounds; how to quantify properties such as complexity accurately becomes a non-trivial problem.

Also, regardless of whether synthetic or real environments were used, participants are typically not actually immersed within the environments, instead, static images of the environments are most often used. Such an approach fails to consider the embodied nature of our experiences, where our responses are a result of dynamic interactions between our environment, bodies, behaviour and cognitive processes (Heft & Nasar, 2000; Makeig, Gramann, Jung, Sejnowski & Poizner, H., 2009). We do not simply look into our environment, instead, we are situated within the environment. Experiments 2.1 and 2.2 attempted to draw out this distinction by comparing subjective responses to images with exploration in virtual reality. Thus, this experiment was not only conducted using real environments, but participants were embedded within the actual environment, remedying the two main challenges to ecological validity.

6.1.2. The urban environment.

Using complex, real environments not only allows us to improve ecological validity but also extends the research to consider urban environments. Urban environments are of particular interest because they are often associated with negative outcomes; depression, stress, other mental health issues as well as overall dissatisfaction are common (Hood, 2010; Peen, Schoevers, Beekman & Dekker, 2010; Lederbogen, et al., 2011; Graham, 1993). Yet urban environments do not necessarily have to be experienced negatively; in describing healthy and enjoyable cities, Jacobs (1961) argued for the importance of physical diversity while Appleyard (1981) identified the dulling effect of neighbourhood homogeneity. Such insights have been supported by environmental psychological research, where complexity most often has a positive effect on experience (Heath, Smith & Lim, 2000; Kaplan, Kaplan & Wendt, 1972; Herzog, Kaplan & Kaplan, 1976; Kaplan, 1979; Nasar; 1983). Although Nasar (1994; 1988) makes a strong argument for an inverted u-shaped relationship between complexity of urban environments and preference, the majority of the literature shows a linear effect (Heath, Smith & Lim, 2000; Kaplan, Kaplan & Wendt, 1972; Herzog, Kaplan & Kaplan, 1976; Kaplan, 1979; Stamps, 2002; 2003; Devlin & Nasar, 1989; Herzog & Shier, 2000; Fuller et al., 2007; Lindal & Hartig, 2013). As discussed earlier, many of these experiments on urban complexity failed to objectively quantify complexity, therefore, in this experiment, entropy will once again be used to quantify visual complexity.

6.1.3. Entropy of real-world environments.

When creating synthetic environments possessing specific amounts of complexity, the application of either numerosity or diversity approaches is relatively straightforward, as demonstrated by the previous experiments. The task becomes much more difficult when attempting to quantify complexity through numerosity and diversity of already built environments. Here, entropy may once again serve as an important tool; as long as we can determine how often elements occur within the environment (their probabilities), entropy can be calculated (Stamps, 2002; 2003). In essence, this can be accomplished easily in several steps. First, it is necessary to extract categories describing various classes of features within the environment, such as windows, roof shape, surface material, and doors. These features are then treated as individual sets within the calculation of entropy. Next, it is necessary to determine how many individual occurrences there are in each set. For example, how many times do doorways, or windows occur? Finally, it is necessary to determine how often each type of feature occurs within each set; so within the set of doors, how often is the door red or blue? For example, suppose you identify a total of four doorways in the environment—two are blue, one is green and the last one is brown—thus the set of doors can be described as follows, blue: 2/4, green: 1/4 and brown: 1/4. Such probabilities are then used to generate entropy allowing us to quantify complexity within the urban environment.

6.1.4. The effect of environmental properties on cognition.

To this point, we have made the argument that the physical features of the built environment impact how an individual feels and behaves. From an embodied cognition viewpoint, our environment has a profound impact, not only on our emotions and behaviour but also on our cognition—all are intimately related and shape one another (Makeig, Gramann, Jung, Sejnowski & Poizner, 2009). Yet the effect of environmental properties on cognition has been neglected in the environmental experience literature. Recently, Atchley, Strayer & Atchley (2012) argued that the attention restoring quality of natural environments resulted in increased creativity. Such restorative effects of nature are encapsulated in Attention Restoration Theory

(ART) (Kaplan, 1995; Kaplan & Kaplan, 1989), suggesting that natural environments require less attentional resources compared to urban environments, resulting in restoration of attention resources and driving preference for nature. Although ART is typically concerned with the positive effect of natural environments it may be extended to the experience of urban environments. Since the negative effect of urban environments on executive attention results from the high degree of attention capturing and depleting qualities of elements within urban environments, it is reasonable to assume that more visually complex environments should deplete attention more readily. To test the effect of environment on cognition, we administered a commonly used measure of sustained attention: the sustained attention to response task (SART) (Robertson, Manly, Andrade, Baddeley & Yiend, 1997). The inclusion of this task will allow us to examine how environmental complexity affects cognition; if complexity depletes attention, we would expect performance deficits as a function of environmental complexity.

6.1.5. Experiment 3.0 objectives.

In order to maximize ecological validity, participants were led on a guided walk through an urban centre and asked to rate interest, pleasure and complexity at particular locations whose entropy levels were quantified using entropy. As was the case in the previous experiments, we explored the pattern of relationships between the objective properties of the environment (entropy), cognitive appraisals (complexity) and emotional response (pleasure and interest). In the previous experiments, entropy predicted complexity consistently, while its effect on interest and pleasure was variable; this inconsistency points to the effect of additional factors such as environment context and global arrangement in determining emotional response. Conducting this experiment in real environments allowed us to test whether a rich, urban environment shifts and moderates the effect of complexity on emotional response. Additionally, electrodermal response was measured to test any possible contributions of arousal on emotional response, while a cognitive task in the form of the SART was administered.

6.2. Methods

6.2.1. The environment.

The experiment was conducted in the city of Waterloo, Ontario, Canada within the Uptown Waterloo region, a diverse city centre, featuring over 400 businesses ranging from banks and corporate offices to locally owned bakeries and clothiers. Uptown Waterloo features a large public square at its centre and is bisected by King Street South., which functions as the main transportation artery. A total of seven locations were selected for the experiment, including views featuring a bank, a public square, a cinema, independently owned shops, an office building and an industrial area (Figure 6.1 and 6.2). The locations were selected so as to capture the range of different functions and types of buildings within the area. Geographically, the locations were reasonably close to one another and approximately equidistant, with a total distance of 0.68 km between the locations. To control for location order, participants were assigned to being the experiment either at Location 1 or Location 7.

Location Number	Location Description	Image
1	King St. storefronts #1	

2	Bank	
3	Uptown Square	
4	Office	

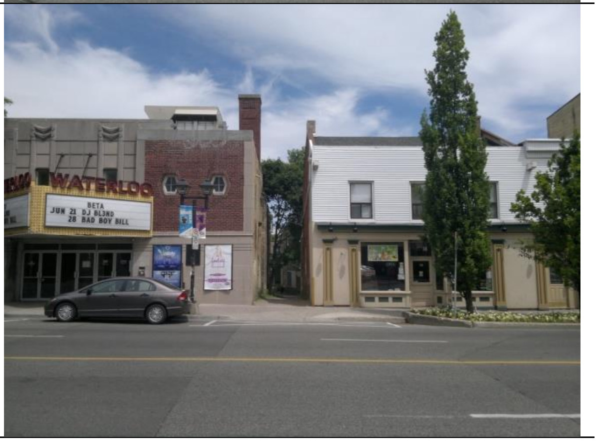
5	Seed Company	
6	King St. storefronts #2	
7	Uptown cinema	

Figure 6.1. Selected locations in Uptown Waterloo, Canada.

Figure 6.2. Uptown Waterloo, Canada with selected locations labeled and route marked

6.2.2. Entropy calculation.

Entropy was calculated as suggested by Stamps (2002), using still photos of each location. Photos were taken at a height of 1.75 m with the camera positioned so as to be parallel with the buildings opposite. Photos were taken using a Nokia N8 HD smartphone digital camera; the 12-megapixel camera features a 28mm wide angle lens, an f/2.8 aperture and a focal length of 5.9mm. The Nokia N8 HD smartphone camera is widely considered best in class (Evans, 2010), allowing us to capture high-resolution images of the environment. A list of feature categories describing the various types of features present within the selected locations was defined. In total, nine different feature categories were generated including roof, door, window, signage, surface material, nature, road, sidewalk and sculptural/massing elements. The total number of distinct occurrences of each feature category was counted. For example, let us say that an image of a location had 6 doorways. Following this determination of overall number, the number of unique occurrences within the set was determined; out of the 6 doorways determined earlier, let us say that out of the 6 total doors, 3 were made from a single piece of glass, 2 were crafted from the same type of wood and a single door was glass but had a distinct push handle running horizontally down its centre. From such occurrence counts we can generate probabilities; in our example: glass door type A: 3/6, wooden door: 2/6, and Glass door type B: 1/6. A trained judge, who was naive to the purpose of the experiment determined the number of occurrences for each image. Entropy was calculated for each feature category using the occurrence probabilities; these category entropy values were summed together to determine environment wide entropy. As shown in Table 6.1, environment entropy ranged from 5.81 to 19.22 bits.

Table 6.1.

Uptown Waterloo Location Entropy Values

Location Number	Location Description	Entropy
1	King St. storefronts #1	10.66
2	Bank	7.09
3	Uptown Waterloo Square	19.22
4	Office building	5.81
5	Seed company	18.4
6	King St. storefronts #2	16.57
7	Uptown Waterloo Cinema	18.87

6.2.3. Measures.

Subjective emotional response ratings

At each location, participants were asked to complete a series of subjective response items, asking them to rate how complex, interesting and pleasant the location was. Questions were answered using a seven-point Likert scale and the same wording as in the previous experiments was used. An additional question regarding how likely participants were to approach or avoid the location was included as an indirect measure of behaviour; asking participants: "How likely are you to avoid or approach the current location?", where 1 represented the low end of the scale and was marked as "avoid" while 7 represented the high end of the scale and was marked as "approach".

Sustained attention to response task

The sustained attention to response task from Robertson, Manly, Andrade, Baddeley and Yiend (1997) was administered to participants through a custom mobile phone application. Participants were presented with 80 consecutive digits, ranging from 0-9 and instructed to press a rectangle on the screen for every digit, except for the digit 3 – when a 3 was present, they were instructed to withhold their response. Each digit was presented for 275 ms and a fixation cross was presented centrally for 825 ms between digits. Presentation of digits was pseudo-randomized so as to ensure that each digit was presented 10 times. Participants were instructed to respond as quickly as possible while maintaining a high degree of accuracy. Due to time constraints and concerns with participant motivation, the SART was administered at every other location.

Electrodermal activity

An Affectiva Q sensor was used to measure electrodermal activity. The sensor records from the ventral surface of the wrist, using two dry electrode sampling at 32 Hz and is attached using Velcro straps. The sensor sampled during the entirety of the experiment, including when walking from location to location, while pressing a button on the sensor inserted a time-stamped marker when each of the locations of interest was reached. Data was stored on the device and uploaded to a personal computer following the experiment using a micro-USB cable. The Affectiva Q sensor has been shown previously to provide reliable and valid measures of electrodermal activity (Sano & Picard, 2011).

6.2.4. Mobile phone application.

A mobile phone application was developed and used to present the subjective response items and the SART. The app was developed using Android Studio for the Android operating system and presented to participants using a Alcatel Pop C1 4015T smartphone. In addition to presenting the subjective response items and the SART, participant location was recorded using the smartphone's GPS capabilities. Once each location was reached, a button on the app would begin the trial, presenting the semantic differential task followed by the SART, if that particular location was one where the SART needed to be administered. Responses for the emotional response questionnaire were made using a drop down menu featuring the digits 1-7, where 1 and 7 were labelled appropriately. Responses for the SART were made by pressing a rectangle presented below the digits. Following the completion of the subjective response and SART at the last location, the mobile app presented participants with a demographics questionnaire, which was answered using a combination of drop down menus and blank response spaces. All information was stored on the smartphone and downloaded to a personal computer by the experimenter for subsequent data analysis.

6.2.5. Procedure.

Depending on location order, participants met the experimenter at a one of two predetermined assigned locations—beginning either at Location 1 or Location 7. Following completion of the informed consent form, participants were instructed on how to use the smartphone app, and completed a practice questionnaire and SART. The Affectiva Q sensor was attached using a Velcro strap to the participant's non-dominant hand after which the experiment began. Participants were led by the experimenter to each location, asked to face a particular direction and instructed to press a button on the smartphone which read "I have reached the next location". Pressing the button began a 60 second observation period, during which the participants were instructed to closely observe the environment in front of them; once the 60 seconds elapsed the phone vibrated, prompting the participants to begin the questionnaire. Upon completion of the questionnaire, participants completed the SART—if that particular location was a SART location. Once completed, the participants were led to the next location where the procedure would begin again with participants being asked to face a particular location and observe the environment for 60 seconds while remaining stationary. As the SART was completed at every other location, participants were randomly assigned so that they completed their first SART either at the first or second location. Once the questionnaire and cognitive task were completed at the final location, participants completed a short demographics questionnaire following which they were free to go.

6.2.6. Participants.

A total of 28 undergraduate students from the University of Waterloo completed the experiment for bonus course credit. Due to technical issues with the mobile application, usable subjective response and SART data was collected from 25 and 23 participants, respectively. Thirteen participants began the experiment at Location 1 and ended at Location 7, while twelve began at Location 7 and ended at Location 1. Seven participants began at location 1 and completed the SART at Locations 1, 3, 5 and 7. Four participants began at Location 1 and completed the SART at Locations 2, 4 and 6. Five participants began at Location 7 and completed the SART at Locations 1, 3, 5 and 7. Finally, seven participants began at Location 1 and completed the SART at Locations 2, 4 and 6. The experiment was approved by the University of Waterloo Office of Research Ethics and each participant completed an informed consent form prior to beginning the experiment.

6.3. Results

6.3.1. Subjective response ratings.

Three repeated measures ANOVAs were conducted with location as the independent variable and each of the four subjective responses as dependent variables (complexity, pleasure, interest and approach-avoidance). Additionally, since two location orders were used, an order effect and a location by order interaction were both tested.

Complexity

The main effect of location was significant for rated complexity, $F(6,138) = 4.73$, $p < 0.001$, $\eta = 0.17$ (Figure 6.3). Multiple pairwise comparisons were conducted using Bonferroni correction demonstrating that Location 1 was less complex than all other locations except Location 4, (M = 1.68, SE = 0.19 and M = 1.84, SE = 0.25, p = 1.00). With the conservative nature of the Bonferroni correction, Location 4 did not differ from any other locations, nor were there any other differences between the locations (Location 2: M = 2.6, SE = 0.25; Location 3: M = 2.72, SE = 0.26; Location 5: M = 2.6, SE = 0.28; Location 6: M = 2.53, SE = 0.25; Location 7: M = 2.76, SE = 0.23).

The interaction between location and order was non-significant, F(6,138) = 1.05, p = 0.4 while the main effect of order was significant, F(23) = 6.03, $p < 0.05$, $\eta = 0.21$. Complexity ratings were higher when participants started at Location 7 and ended at Location 1 as compared to starting at Location 1 and ending at Location 7, (M = 2.71, SE = 0.19 vs. M = 2.05, SE = 0.2).

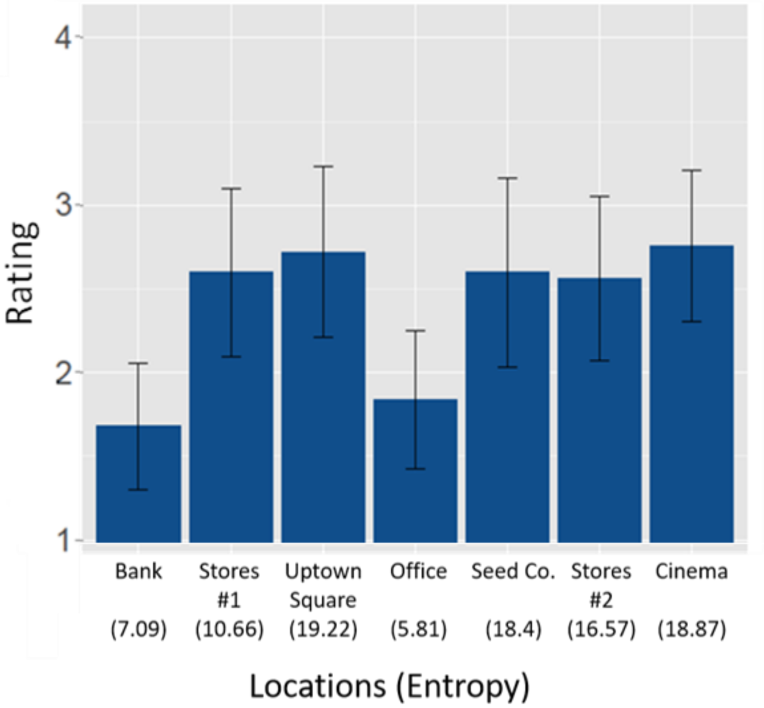


Figure 6.3. The main effect of location on complexity ratings.

Pleasure

The main effect of location on pleasure was significant, F(6,138) = 7.88, $p < 0.001$, η = 0.26 (Figure 6.4). Location 3 was rated more pleasant than all other locations, except Location 2 (M = 4.04, SE = 0.2 and M = 3.4, SE = 0.21, p = 0.49). Location 2 itself was only more pleasant than Location 5, which was the least pleasant location (M = 3.4, SE = 0.21 and M = 2.4, SE = 0.25, $p < 0.05$). All other locations were experienced as equally pleasant (Location 1: M = 3.04, SE = 0.21; Location 4: M =2.48, SE = 0.24; Location 6: M = 3.08, SE = 0.18; Location 7: M = 2.76, SE = 0.2).

The interaction between location and order as well as the main effect of order were both non-significant, F(6,138) = 1.84, p = 0.1 and F(23) = 0.002, p = 0.97.

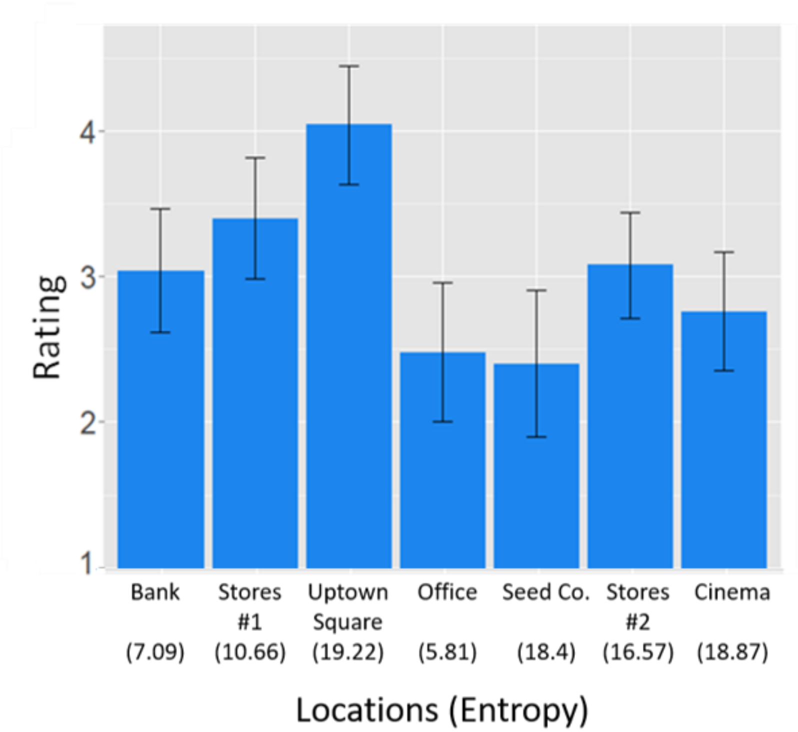


Figure 6.4. The main effect of location on pleasure ratings

Interest

The main effect of location on interest was significant, $F(6,138) = 8.3$, $p < 0.001$, $\eta = 0.27$ (Figure 6.5). Locations 1 and 4 were rated as least interesting ($M = 1.84$, $SE = 0.19$ and $M = 1.68$, $SE = 0.19$), while Location 1 was significantly less interesting than Locations 2 and 3 ($M = 3.04$, $SE = 0.19$ and $M = 3.48$, $SE = 0.24$) and trending towards being significantly less interesting than locations 6 and 7 ($M = 2.76$, $SE = 0.21$, $p =0.06$ and $M = 3.08$, $SE = 0.28$, $p = 0.06$). Location 4 was less interesting than all other locations except Location 1 ($p = 1.00$) and Location 5 ($p = 0.07$). All other locations were rated as equally interesting: (Location 2: $M = 3.04$, $SE = 0.19$; Location 3: $M = 3.48$, $SE = 0.24$; Location 5: $M = 2.64$, $SE = 0.28$; Location 6: $M = 2.76$, $SE = 0.21$; Location 7: $M = 3.08$, $SE = 0.28$).

The interaction between location and order as well as the main effect of order were both non-significant, $F(6,138) = 1.01$, $p = 0.42$ and $F(23) = 2.46$, $p = 0.13$.

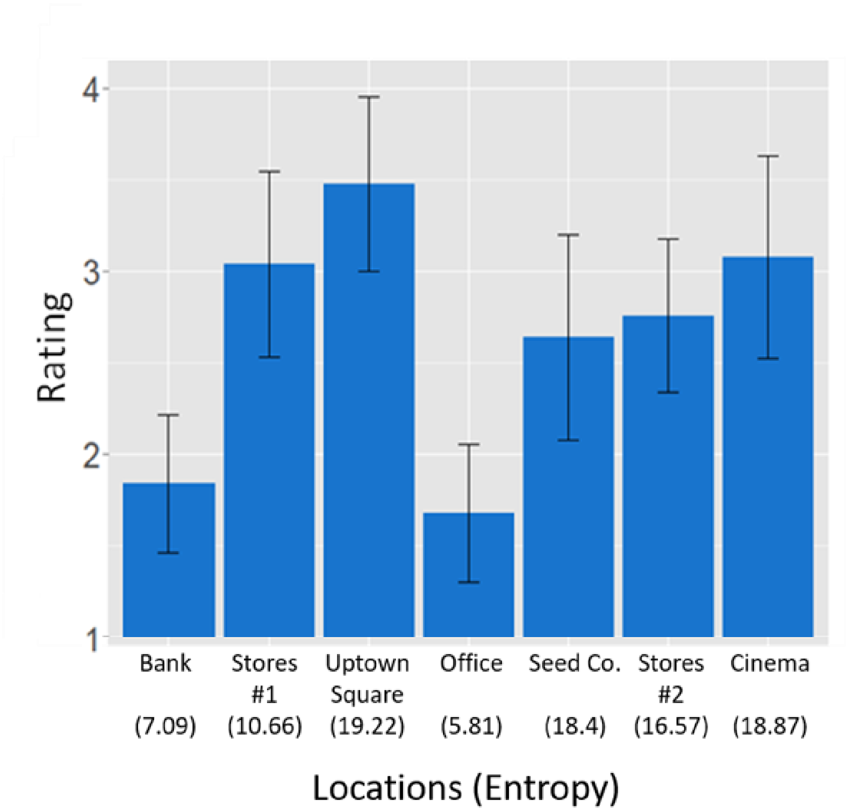


Figure 6.5. The main effect of location on interest ratings

Approach-Avoidance:

The main effect of location on approach-avoidance was significant, F(6,138) = 7.78, p < 0.001, $\eta^2 = 0.25$ (Figure 6.6). The effect was driven by the relatively high approach rating for Location 3, (M = 3.8, SE = 0.23), which was rated significantly more approachable than locations 1, 4 and 5 (M = 2.5, SE = 0.17; M = 2.2, 0.18 and M = 2.6, SE = 0.24). Location 4 (M = 2.2, SE =0.18) possessed the lowest approach-avoidance rating, and was significantly less approachable than all locations except locations 1 and 5, (M = 2.5, SE = 0.17 and M = 2.6, SE = 0.24).

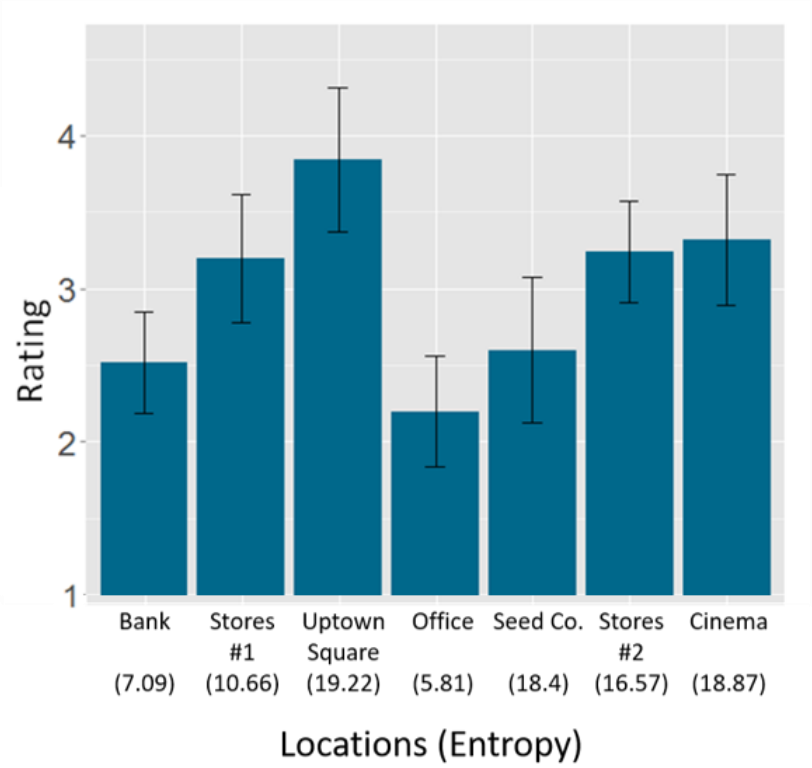


Figure 6.6. The main effect of location on approach-avoidance ratings.

The interaction between location and order was non-significant, F(6,138) = 1.11, p = 0.36 while the main effect of order was significant, F(6,138) = 7.37, $p < 0.05$, $\eta^2 = 0.24$ (Figure 6.7). Approach-avoidance scores were higher if starting at Location 1 and ending at Location 7, as compared starting at Location 7 and ending at Location 1, (M = 3.17, SE = 0.09 and M = 2.8, SE = 0.1). In particular, Locations 2 and 5 were rated much higher when starting at Location 1 as compared to starting at Location 7. (Location 2: Starting at 1: M = 3.54, SE = 0.27 vs. Starting at 7: M = 2.08, SE = 0.36) and (Location 5: Starting at 1: M = 4.31, SE = 0.28 vs. Starting at 7: M = 2.92, SE = 0.23).

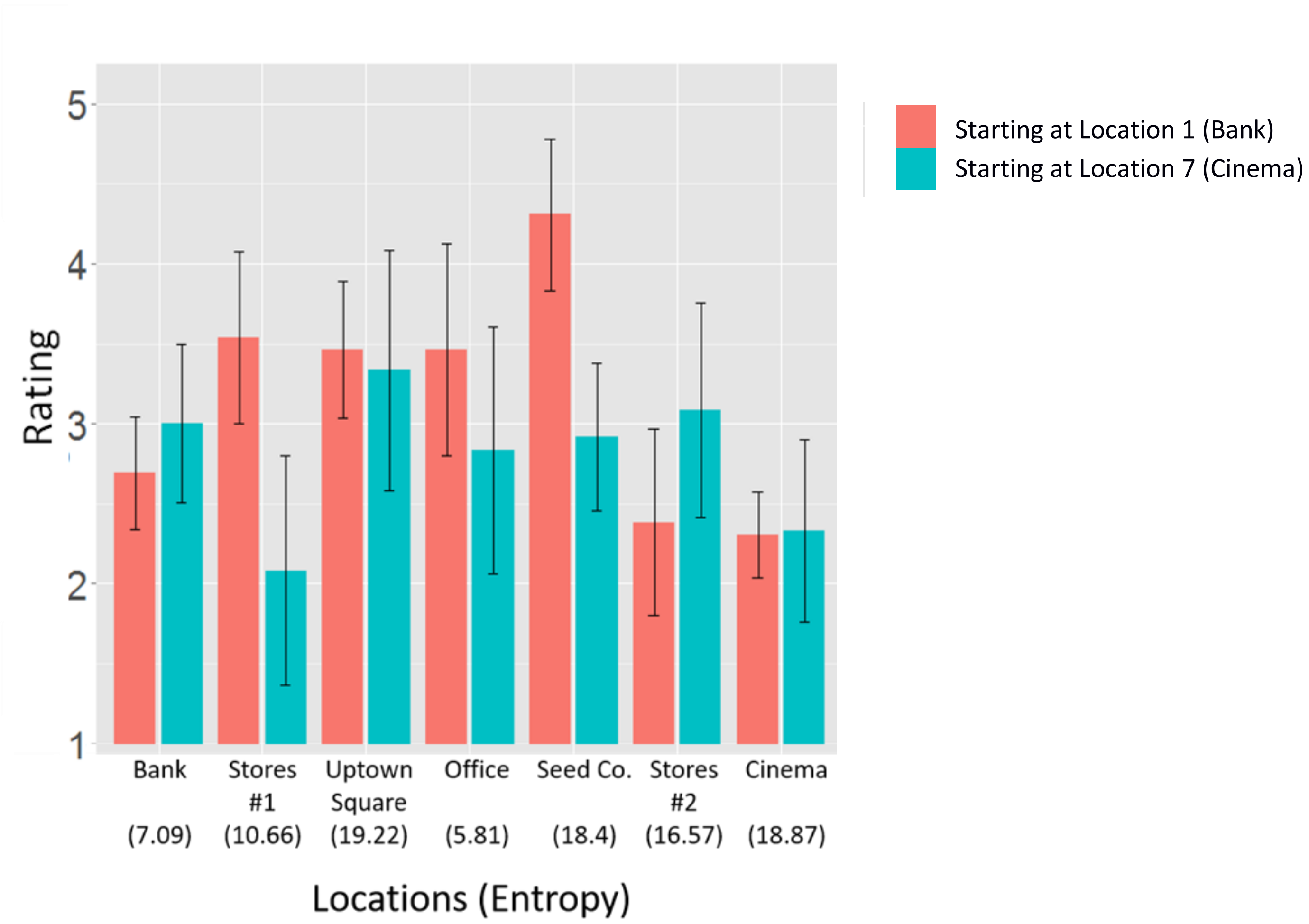


Figure 6.7. Interaction between location and order on approach-avoidance ratings.

6.3.2. Correlation analysis.

Partial correlations were calculated by controlling for within subject repeated observations, as suggested by Bland and Altman (1995). Refer to Table 6.2 for correlation coefficients. Significant correlations were present between entropy and complexity, while interest was correlated with all other variables. Pleasure and interest were both moderately correlated with approach-avoidance.

Table 6.2

Correlations coefficients between entropy and subjective response ratings

	Entropy	Complexity	Pleasure	Interest
Complexity	0.35*			
Pleasure	0.11	0.09		
Interest	0.41*	0.49*	0.46*	
Approach	0.03	-0.06	0.47*	0.54*

* $p < 0.001$

6.3.3. Path analysis.

As in the previous experiments, we examined whether emotions of interest and pleasure were a result of entropy and perceived complexity, using the same statistical approaches. Once again, within participant variability was considered by treating participants as a random effect and thus allowing participant intercepts to vary. Refer to Figure 6.8 for a model showing significant standardized coefficients. Interest was predicted by both entropy and complexity, while entropy also predicted complexity. The direct effect of entropy on interest was partially mediated by complexity, (Sobel test = 3.93, $p < 0.001$). Pleasantness was not predicted by complexity or entropy but was predicted by interest.

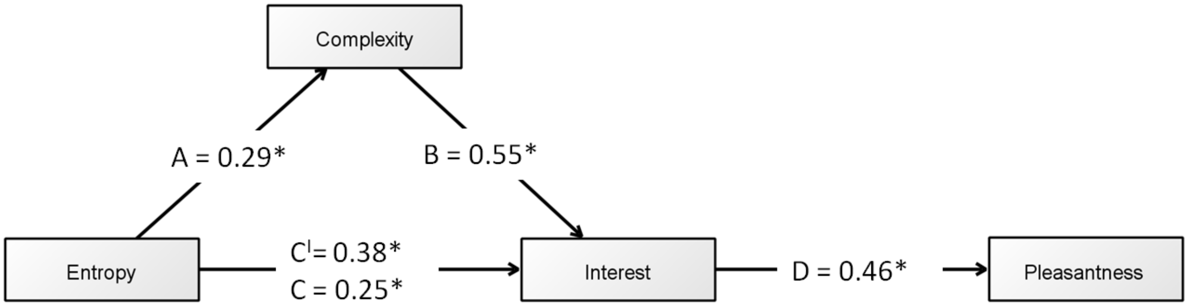


Figure 6.8. Reduced model with interest and pleasure as outcome variables, entropy as a predictor and complexity as a mediator.

* $p < 0.01$; ** $p < 0.001$

Since approach-avoidance scores were also recorded, we tested whether emotional response affected how likely participants were to approach or avoid the environment. Please see Figure 6.9 for the model predicting approach-avoidance ratings, demonstrating that both interest and pleasure significantly predicted approach-avoidance responses. Entropy and complexity did not predict approach-avoidance, thus approach-avoidance was primarily a result of emotional response.

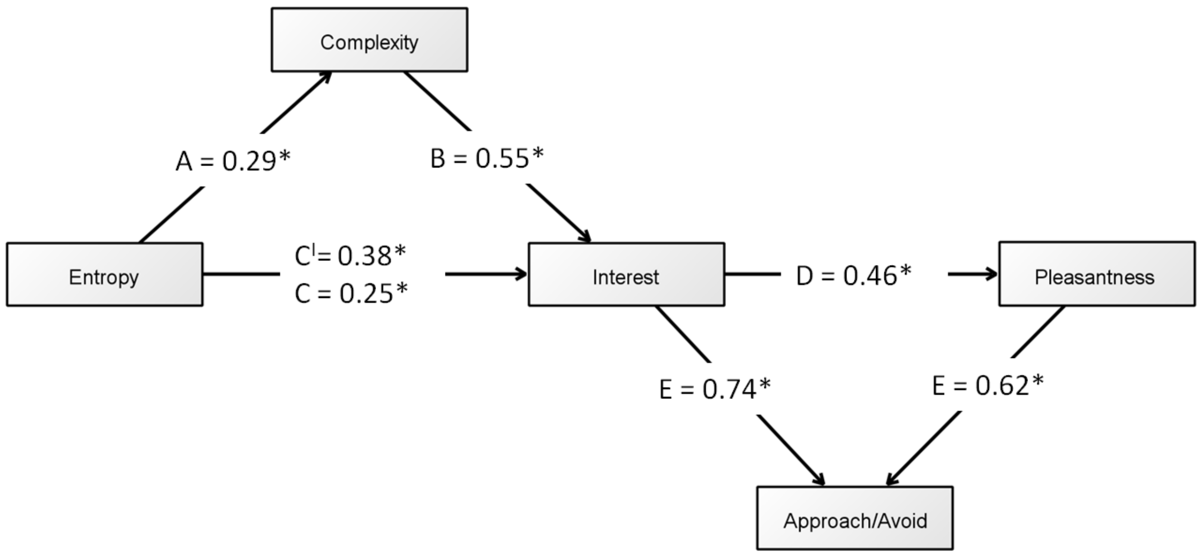


Figure 6.9. The model with approach-avoidance as the outcome variable, predicted by interest and pleasure responses.

** $p < 0.01$; ** $p < 0.001$*

6.3.4. Sustained attention to response task (SART).

Sustained attention to response was analysed by examining both frequency of commission errors—failing to withhold a response following the presentation of a 3—and response time. The main effect of location on both errors and response time was analysed, while location order was included as a between participants variable, and the additional location by order interaction was examined. The main effects of both location and location order on error rate were non-significant, F(6) = 0.45, p = 0.85 and F(1) = 0.01, p = 0.93, as was the location by order interaction, F(6) = 0.25, p = 0.96. Regarding response time, the main effect of location and the location by order interaction were both non-significant, F(6) = 2.06, p = 0.7 and F(6) = 0.05, p= 0.99, while the main effect of order was significant, F(1) = 4.42, p < 0.05 (Figure 6.10).

Response times were quicker when beginning at Location 1 as compared to Location 7, (M = 454.86 ms, SE = 18.9 versus M = 505.288 ms, SE = 14.71).

Regression analysis was also conducted to examine whether entropy predicted SART error rates or response time. Beta coefficients were non-significant for both; β = 0.49, p = 0.1 and β = 0.23 p = 0.82.

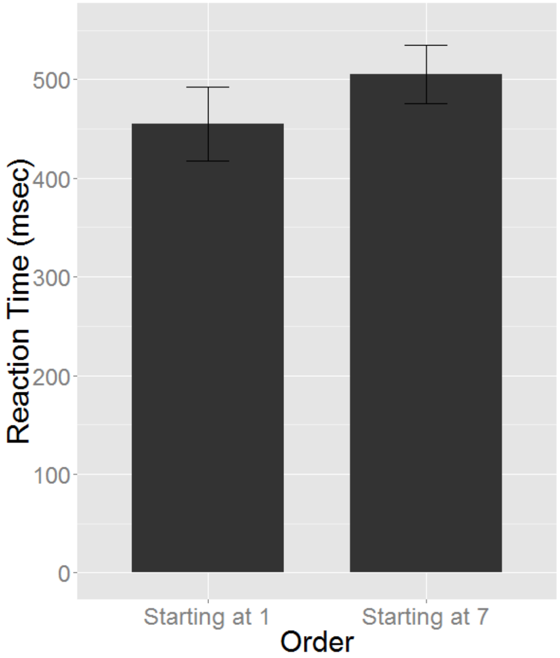


Figure 6.10. Main effect of location order on SART reaction time.

6.3.5. Electrodermal activity.

Typically, EDA is calculated as percentage change from a baseline taken prior to beginning the experiment; we decided against this approach due to the dynamic and active nature of the experiment. It was assumed that EDA would rise drastically while participants walked from location to location, thus any change from a baseline taken prior to beginning the experiment might have been a result of experiment duration and the effect of walking rather than the locations themselves. Thus, EDA was calculated as a percentage signal change from a rolling baseline consisting of a 10-second window just prior to reaching each location. It was hoped that this location specific baseline would allow us to more accurately test the effect of the location on EDA.

Order was included as a between-participants variable and interaction between order and location was tested in addition to the main effect of location. Data points two standard deviations beyond the mean were identified as outliers and excluded from the statistical analysis. The effect of location was significant, $F(6,84) = 5.82$, $p < 0.001$, $\eta^2 = 0.29$ as was the location by order interaction, $F(6,84) = 5.21$, $p < 0.001$, $\eta^2 = 0.27$ (Figure 6.11).The interaction was a result of increased electrodermal response at Location 7 when experienced last as compared to when it was experienced first, (Location 7 when experienced first: $M = 2.37\%$, $SE = 7.19$; Location 7 when experienced last: $M = 31.88\%$, $SE = .34$). As demonstrated by Figure 6.11, EDA was flat across most locations other than the dramatic jump exhibited at Location 7 when experienced last. This suggests that the effect is driven by indeterminate environmental confounds.

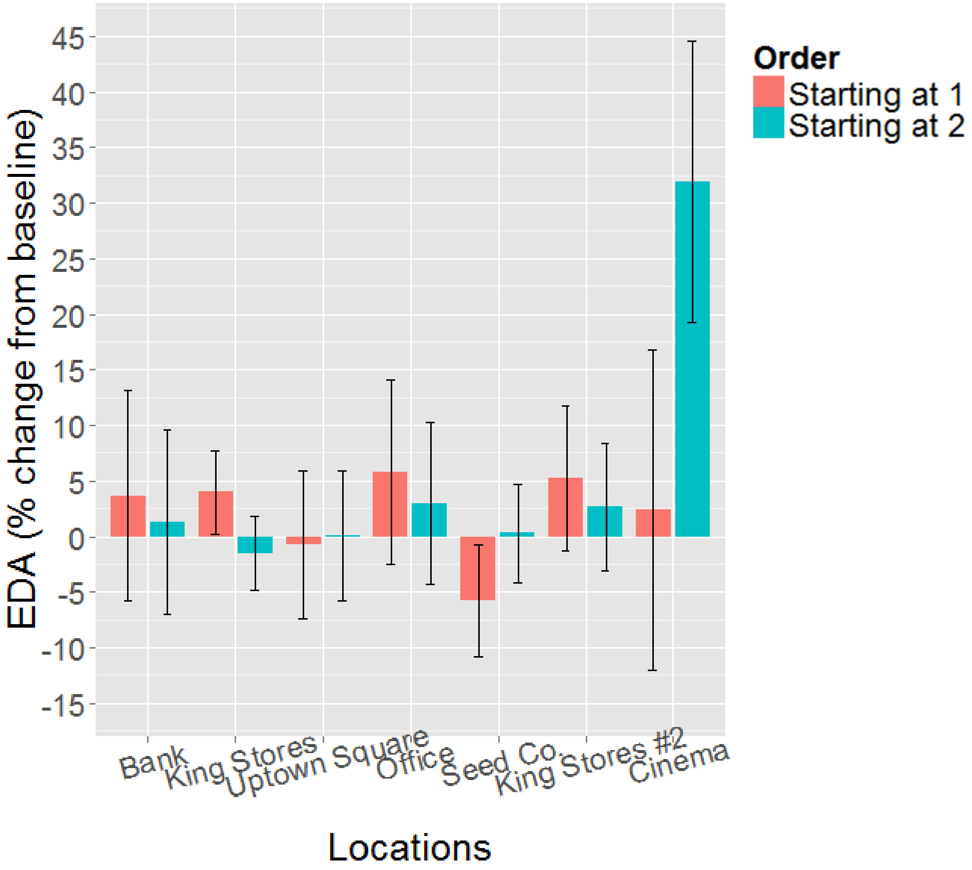


Figure 6.11. The location by order interaction on EDA percentage change from baseline. Interaction was driven by the high response at the cinema when experienced last.

Next, linear regression was conducted to test whether percentage change from baseline predicted emotional responses of pleasure and interest. Much of the classic literature in the field argues for a psychophysiological mechanism, where changes in arousal level lead to positive emotional response (Berlyne, 1970); such an effect was not found here as electrodermal activity failed to predict pleasure or interest, ($R = 0.41$, $R^2 = 0.16$, $R^2_{(adj)} = 0.04$, $F = 1.3$, $p = 0.19$ and $R = 0.37$, $R^2 = 0.14$, $R^2_{(adj)} = 0.01$, $F = 1.07$, $p = 0.4$).

6.4. Discussion

6.4.1. Summary.

As the previous experiments employed highly unusual, synthetic environments, real-world environment were used in this experiment to improve ecological validity. In brief, entropy predicted complexity and interest, while it did not affect pleasure. These results are similar to Experiments 1.1 and 1.2, where complexity shaped interest but not pleasure.

6.4.2. Entropy, complexity and emotional response to real-world environments.

Entropy and perceived complexity differed between the seven locations, with the bank and office locations possessing lowest entropy and experienced as least complex; all other locations possessed similarly high entropy values and complexity ratings. Emotional responses of both interest and pleasure differed significantly between locations; for interest, the effect was similar to that complexity, where the bank and office locations were experienced as least interesting. On the other hand, pleasure did not seem to correspond as closely to complexity ratings, and was driven by the high pleasure ratings for the Uptown Square and low pleasure ratings for the office and Seed company locations. Although these results demonstrate that locations are experienced differently—regarding both cognitive concepts of perceived complexity and emotional responses of interest and pleasure—they do not speak directly to the effect of entropy on complexity or emotional response; correlation and regression analysis are better suited to answer these questions.

Partial correlation analysis demonstrated that entropy and complexity were moderately correlated. This result is especially encouraging because it demonstrates that entropy is an effective way to quantify complexity of real-world environments. When it comes to emotional response, interest was correlated with both complexity and entropy, while pleasure was correlated neither with complexity nor entropy but was correlated with interest. Path analysis confirms that entropy led to interest, and that the effect was partially mediated by perceived complexity; thus interest was a result of both physical properties of the environment in the form of entropy, as well as the cognitive component of perceived complexity.

Conversely, pleasure resulted neither from entropy nor complexity, but it was correlated with interest. Thus only interest was a result of both objective stimulus properties—in the form of entropy—and cognitive components of perceived complexity.

6.4.3. Approach-avoidance as an indirect measure of behaviour.

One of the objectives of this dissertation was to explore the relationship between subjective emotional response and behaviour; because participants were required to remain stationary at each location, it was not possible to develop a reasonable measure of behaviour. Conceding that subjective approach-avoidance scores are not ideal measures of behaviour they do allow us to draw some guarded conclusions regarding behaviour as a function of the emotion inducing quality of the environment. Approach-avoidance scores have been shown previously to predict behaviour (Chen & Bargh, 1999; Russell & Mehrabian, 1978; Hines & Mehrabian, 1979), and a strong, consistent relationship between emotional response and approach-avoidance scores has been demonstrated (Russell & Mehrabian, 1978; Donovan & Rossiter, 1982).

Here, both pleasure and interest predicted approach-avoidance scores positively; participants were more likely to approach interesting and pleasing environments. Since interest is considered an epistemological emotion, underlying exploration behaviour, its effect on approach scores is unsurprising (Silvia, 2008; 2009; 2010). Although pleasure does not have the same exploratory function as interest, it seems reasonable that individuals are more likely to approach pleasant environments. Crucially, approach-avoidance scores were predicted neither by entropy nor complexity, suggesting that approach-avoidance was a result of emotional response rather than the physical properties of the environment directly.

6.4.4. Arousal response to real-world environment entropy.

Research on the effect of complexity on emotional response often argues for an arousal mechanism; that positive response is a result maintaining moderate levels of arousal for both synthetic visual stimuli (Berlyne 1970; 1960) as well as complex environments (Russell & Mehrabian, 1978; Stamps, 2002; 2004). In this experiment, we measured physiological arousal through electrodermal activity, addressing a common failing in most of the literature. Electrodermal response did not differ between locations, but a location by order effect was significant, where the cinema location resulted in greater electrodermal response when it was experienced last as compared to when it was experienced first. Such an interaction is difficult to interpret and may be a result of environmental confounds, with car traffic a likely candidate. When the cinema was experienced last, the location prior was across the street, thus participants were required to use a crosswalk to reach the cinema location; it is possible that crossing the street may have increased arousal response resulting in the high response seen at the cinema location. Although possible, this interpretation would mean that crossing the street at any point during the experiment would result in increased arousal—this was not the case. For example, when they cross this same intersection in the opposite direction an increase in arousal does not occur. Thus, this interaction is most likely a result of unidentified confounds, demonstrating the prevalence of varied confounds when conducting experimentation in the field.

Although the emotion literature demonstrates the important role of psychophysiology in determining emotional response (Bradley & Lang, 2000; Cacioppo, Bernston, Larsen, Poehlmann & Ito, 2000), we were unable to replicate such a result as regression analysis demonstrated that electrodermal activity did not predict interest or pleasure. It is possible that the arousal potential of our environments was not strong enough and/or that our electrodermal activity sensor was not sufficiently sensitive to note any changes in response. Additionally, the lack of an effect may be attributed to difficulties in recording electrodermal activity in the field. Although the device used was designed to mitigate artifacts accrued during movement, as participants were required to walk through a real-environment, introduction of noise into the recording was unavoidable. The development of a meaningful and valid baseline is yet another genuine, non-trivial problem faced when conducting field research. Despite such possible limitations, the results of this experiment suggest that physiological mechanisms may not be the sole nor primary determinants of emotional response to the environment.

6.4.5. Effect of environmental entropy on attention.

In this experiment, participants completed the sustained attention to response task (SART)—a measure of executive attention—at each location; exploring recent research where the environmental properties shaped not only emotions but cognition (Atchley, Strayer & Atchley, 2012). Under the assumption that visual complexity depletes attention, we expected that more complex environments would result in increased error rates and response times in the SART. This prediction was not supported; neither error rates nor response times were affected by environment location, entropy or complexity. The main effect of location order on response time was significant; response times were quicker when starting at King Storefronts #1 as compared to the Uptown Cinema. Similarly to the above effect of traffic on electrodermal response, this order effect may be a result of environmental properties other than visual complexity. Once again, it is possible that crossing the street at the busy street crossing may have had a negative effect on response times at subsequent locations. Future research should attempt to determine if car traffic affects attention negatively, resulting in increased response time.

6.4.6. Comparing entropy, complexity and emotional response between synthetic and real-world environments

Although entropy affected entropy and emotional response as expected, it is worth noting that the values differed greatly from the previous experiments as highlighted in Table 6.3. Due to the greater degree of elements, entropy was significantly higher in this experiment, ranging from 5.81 to 19.22 bits of entropy as compared to Experiments 2.1 and 2.2, where the ranges were 0.00 to 2.00 and 0.00 to 2.32 bits of entropy, respectively. Despite the much higher entropy values, the real-world environment was perceived as much less complex, with a mean complexity of 2.39 as compared to 3.47 and 3.40 in Experiments 2.1 and 2.2. Although the range of entropy values was much greater in Experiment 3.0, the range for complexity ratings was extremely tight (1.08). A similar pattern was present for the emotion ratings, where the real-world environments were less interesting and pleasant, but this time the ranges were somewhat comparable.

Intuitively, we might expect ratings to be made in accordance with a general or global understanding of complexity, pleasure or interest; which should lead the real environments to be rated higher on all three variables. The fact that real environments were instead rated lower, implicates a top-down, comparative processes, limited to the current environment and context (Berlyne, 1971). So ratings in each experiment are made in relation to the mental representations of how complex that class of environment might or conceivably ought to be. Due to the novel, synthetic nature of the environments in Experiments 2.1 and 2.2, ratings were generated through a comparative process relying only on those environments within the experiments. Conversely, in Experiment 3.0, the comparative process was dependent on participants' expectations of how complex and emotion inducing Uptown Waterloo, or other urban centres, might be. Thus, although entropy and emotional response can be reliably manipulated and influenced, the strength of the results may be dependent on top-down factors such as class or type of environment (Stamps, 2004).

Table 6.3.

Descriptive Statistics for Entropy Experiments

	Experiment 2.1				Experiment 2.2				Experiment 3.0			
	Mean	*Min*	*Max*	*Range*	*Mean*	*Min*	*Max*	*Range*	*Mean*	*Min*	*Max*	*Range*
Entropy	0.89	0.00	2.00	2.00	1.21	0.00	2.32	2.32	13.8	5.81	19.22	13.41
Complexity	3.47	1.32	4.24	2.92	3.40	1.29	5.30	4.01	2.39	1.68	2.76	1.08
Pleasure	3.29	2.54	4.03	1.49	4.00	3.03	4.95	1.92	3.03	2.40	4.04	1.64
Interest	3.41	1.9	3.77	1.87	3.76	2.35	4.58	2.23	2.65	1.68	3.48	1.8

6.4.7. Limitations and Future Directions

Along with the several concerns and confounds mentioned already, it is important to acknowledge several limitations in this experiment. Because locations were selected pseudo-randomly with geographic and distance constraints and with an intention to include different types of environments, entropy values did not increase in a linear fashion. Instead, the distribution of entropy values was bimodal, with the bank and office locations possessing relatively low entropy and all other locations grouped together as possessing similarly higher degrees of entropy.

Additionally, it was impossible to dissociate building function from entropy since the two often go hand-in-hand. For example, the office and bank are designed with function primarily in mind and may therefore result in a more straightforward and simple design, resulting in low entropy. Societal expectations of how buildings "should" look also play a role, for example, a bank is designed to look imposing and secure, while office buildings are designed to be simple and wholly functional (Ellard, 2015). Additionally, the average person may associate such buildings with potentially unpleasant actions and purposes such as work and financial matters; thus function, societal expectations and cognitive impressions of the nature of the building is confounded with objective complexity as measured by entropy.

Despite participants being instructed to remain stationary, a certain degree of body and head movement was unavoidable, meaning that what participants perceived was most likely different than the images used to quantify entropy. Moreover, although the camera captured high quality, high resolution images, the field of view was much smaller than the human visual field of view. Since peripheral vision is an important part of human psychological response (Larson & Loschky, 2009; Abahnini, Proteau & Temprado, 1997), it is fair to assume that the images used to calculate entropy failed to accurately consider such factors. With that said, it is important to note that each location was relatively homogenous, so even if we extended the field of view in the images, the general degree of entropy would remain constant between the locations.

Although serving as an initial push towards improved ecological validity, the experimental procedure employed here does not fully capture how individuals experience the urban environment. Participants were asked to remain stationary, observe a particular location and rate the location on a number of variables. This is far from a naturalistic experience; instead pedestrians experience the urban space dynamically and freely as they walk through it rather than stopping at particular locations to observe the environment. Although we tried to capture this moment-to-moment experience using electrodermal response, future research would do well to consider urban experience as dynamic, composed of complex temporal interactions between the individual and a myriad of environmental factors.

This experiment demonstrated the clear difficulties and challenges faced when conducting research in the field. Rather than suggesting that field research should be avoided, this experiment highlights important considerations in conducting such research. Only when such considerations are honestly considered will research be truly meaningful and accurately describe how our experiences of the environment are formed.

Chapter 7 – General Discussion and Conclusions

As more of us choose to live in urban centres, it is vital that we gain a better understanding of how the built environment shapes us. Such knowledge may allow us to design more effective, enjoyable, people-centred environments. The experiments presented here attempt to do just that, by examining the effect of environmental complexity on our experience of the environment. First, where previous research relied predominantly on feelings of pleasure, this dissertation considered positive emotions as composed of many distinct emotions, thus the effect of complexity was considered on interest alongside pleasure. Second, although previous literature has quantified and generated environmental complexity in a number of ways, this dissertation undertook a highly systematic examination of how the environment generates complexity. Specifically, complexity was examined as resulting from either the numerosity or diversity of geometric and featural elements of the environment. Third, we considered if the effect of objective complexity on emotional response was mediated by subjective, perceived complexity, thus introducing a cognitive component into the formation of environmental experience. Fourth, by arguing that emotions are intimately linked with specific behaviours, this dissertation examined the degree of agreement between subjective emotional response and navigation behaviour. These primary research questions aim to deepen our understanding of how environmental complexity affects experience of the built-environment.

7.1. Emotional Response to Environmental Complexity

In all five experiments, complexity had a significant effect on emotional response, but its effect on pleasure and interest was variable, potentially dependent on environmental properties other than complexity. Specifically, the effect of complexity on interest and pleasure was dissociable in the five experiments; affecting one or the other in each experiment. In

Experiments 1.1 and 1.2, complexity had a positive effect on interest, while failing to affect pleasure. A similar effect was observed in Experiment 3.0 using real environments. Contrary to these three experiments, complexity failed to affect interest in Experiments 2.1 and 2.2, while it had a negative effect on pleasure. Thus, it seems that interest and pleasure cannot be predicted reliably by environmental complexity alone.

The variable effects of complexity on emotional response suggest that environmental properties and features other than complexity have an important role in shaping emotional response. Taking an information processing fluency approach, information that is difficult to process may lead to negative experience, while fluency leads to positive experience (Reber, Schwarz & Winkielman, 2004). Thus it is possible that the unusual synthetic nature of the environments Experiments 2.1 and 2.2 resulted in a disfluent perceptual processes leading to displeasure. Indeed, factors improving processing fluency, such as symmetry and more easily distinguishable panels, resulted in increased pleasure response consistent with previous findings (Palmer & Hemenway, 1978; Herrmann, Zidansek, Sprott & Spangenberg, 2012; Makin, Pecchinenda & Bertamini, 2012; Winkielman, Schwarz, Fazendeiro & Reber, 2003). Thus the manner in which complexity is processed—fluently or disfluently—may moderate the effect of environmental complexity on emotional response.

Although processing fluency may explain the negative effect of complexity on pleasure, why did complexity have a positive effect on interest in some experiments and a negative effect on pleasure in others? What determines whether complexity affects pleasure or interest? Again, this pattern of results can be described by factors other than complexity, specifically by arguing for two distinct mechanisms for the perception of environmental complexity. The first mechanism occurs when the environment presents complexity that is understandable and can be incorporated into one’s mental model of the environment; in this instance, complexity has a positive effect on interest, as seen in experiments 1.1, 1.2 and 3.0. This corresponds strongly with recent research showing that interest is composed of two cognitive appraisals, the first being a novelty or complexity check and the second a coping potential check; if both are met, interest is experienced (Silvia, 2005; 2008; Turner & Silva, 2006). Thus, diversity or numerosity determines the first requirement, complexity, while the nature or quality of the visual elements (polygon panels, dot panels, openings, etc.) determines whether the complexity is understandable. On the other hand, when complexity cannot be easily understood and is highly unusual, the second mechanism is triggered where complexity has a negative effect on pleasure. Conceivably, as complexity increases, the information becomes more difficult to process, incrementally decreasing processing fluency and leading to increased displeasure as demonstrated in Experiments 2.1 and 2.2 (Reber, Schwarz & Winkielman, 2004). Thus, the nature of complexity and the manner by which it is presented, whether it is understandable or not, moderates the effect of complexity on emotional response.

Future research should consider the sequence of perceptual processes resulting in this dissociative effect of complexity on pleasure and interest. Perhaps complexity is perceived and if it can be understood and interpreted, interest is experienced while pleasure does not occur. Conversely, it is also possible that complexity is perceived, and if it is processed in a disfluent manner, displeasure is experienced and interest does not occur. Thus the first relationship argues that interest takes precedence and suppresses pleasure response while the second relationship suggests that occurrence of displeasure suppresses interest. Although pleasure is one of the earliest judgments made regarding a stimulus (Zajonc, 1980; 1982), future research should more closely examine these two possible explanations of the sequential nature of pleasure and interest as a response to environmental complexity. Additionally, it is necessary to determine how the understandability as argued by Silvia (2005a, 2008, and 2010) compares to the processing fluency mechanism described by Reber, Schwarz & Winkielman (2004). Although understandability is a cognitive appraisal and processing fluency is perceptual in nature, it is likely that the two are highly related. For example, the possibility should be considered that processing fluency underlies cognitive appraisals of coping potential and understandability. If this is the case, it then seems likely that if processing fluency is low, displeasure occurs, thus suppressing any potential interest response.

Although processing fluency or understandability might moderate the effect of complexity on emotional response, it is unclear when and how exactly it results in pleasure or interest. Additionally, the concepts of understandability, and processing fluency are somewhat vague, difficult to operationalize and lacking in descriptive power. Although we demonstrated that both global and local properties of the environment—panel type and symmetry, respectively—affected pleasure response, processing fluency was not measured directly. Processing fluency can be tested by examining how long it takes to distinguish a test stimulus from a target; environments that are identified more quickly from the target can be argued as being processed more fluently (Palmer & Hemenway, 1978; Reber & Schwarz, 2001). In addition, priming serves as another potential tool, as primed stimuli are processed more fluently and therefore experienced positively (Reber, Winkielman & Schwarz, 1998; Martindale & Moore, 1988). Clearly, the effect of complexity is variable, and examining how complexity is processed may allow us to understand some of this variability.

Although many questions remain regarding the mechanism underlying the effect of complexity on pleasure and interest, this dissertation marks one of the first instances in the literature where both interest and pleasure were examined as distinct emotional responses to environmental complexity. For example, Stamps (2002; 2003) treated interest as synonymous with complexity and not as an emotion alongside pleasure. Additionally, in the rare instances where the effect of environmental complexity on both pleasure and interest was examined, objective measures of complexity were not used (Nasar, 1988, 1994). This dissertation demonstrated that the effect of complexity on emotional response is much more nuanced than previously believed and that, although interest and pleasure are both positive emotions, the effect of complexity on each is dependent on the manner by which complexity interacts with additional factors.

7.2. Objective Measures of Complexity

This dissertation presented a novel, systematic approach to quantifying environmental complexity where geometric and featural elements of the environment exhibited complexity through their numerosity or diversity. To summarize, Experiment 1.1 used geometric properties in the form of doorways and manipulated complexity by increasing the number of doorways. Experiment 1.2 used both geometric and featural properties, doorways and panels, and manipulated complexity by increasing the number of either. Experiments 2.1 and 2.2 used featural properties—two distinct sets of panels—and manipulated complexity using entropy as a measure of diversity. Finally, Experiment 3.0, used featural properties predominantly and generated diversity measures of entropy of real environments. In every experiment, increasing the number or diversity of either environment feature type—featural or geometric—had a significant positive effect on perceived complexity. The first four experiments support the notion that it is possible to create environments possessing specific degrees of complexity while

Experiment 3.0 showed that it was possible to quantify the complexity of existing, real-world environments.

These results are closely aligned with recent research on multidimensional modelling of human perception of complexity (Ramanarayan, Bala, Ferwerda & Walter, 2008; Oliva, Mack, Shrestha & Peeper, 2004; Nadal, Munar, Marty & Cela-Conde, 2010). Using images of various environments, Ramanarayan, Bala, Ferwerda and Walter (2008) suggested a two-dimensional solution for perceived complexity; the first dimension was termed quantity while the second was most accurately described as texture/lighting. Similarly, the solution suggested by Oliva, Mack, Shrestha and Peeper (2004) was comprised of a quantity dimension and a symmetry/organization dimension. Finally, Nadal, Munar, Marty and Cela-Conde (2010), suggest a three factor solution: the first is a numerosity and variety factor, the second, an intelligibility and order factor, and the third a symmetry factor. Although three factors were noted, numerosity played the primary role in shaping complexity. The results of this dissertation coincide with the quantity dimension of complexity. Although diversity was only noted by Nadal, Munar, Marty and Cela-Conde (2010), a close examination of the texture dimension noted by Ramanarayan, Bala, Ferwerda and Walter (2008), demonstrates similarities to our diversity measure. The symmetry/organization dimension identified by Oliva, Mack, Shrestha and Peeper (2004) and Nadal, Munar, Marty and Cela-Conde (2010) is supported by Experiment 2.2, and in previous research where symmetry had a significant effect on experience (Klinger & Salingaros, 2000).

Thus, this dissertation makes the argument that complexity exists both as an objective property of the environment as well as a cognitive concept, experienced subjectively. Although the experience of complexity is subjective, it is necessary to describe complexity objectively for a couple of reasons. First, in order to explore the effect of objective complexity on subjective complexity, it is necessary to develop an objective complexity measure as distinct from subjective, perceived complexity. Second, if such research is to be applied to create more enjoyable and people-centred environments, it is necessary to develop a method by which to operationalize complexity allowing for the design of environments possessing specific, prescribed levels of complexity.

Despite the consistent relationships between objective and perceived complexity, two limitations need to be addressed. Since complexity was not defined for participants and was the only visual property rated, it is possible that complexity ratings varied simply for the fact that something was changing in the environment and not because they perceived the environment as more or less complex. For example, if instead of complexity participants rated "change" or "disorder", the pattern of results might be the same. Although possible, this concern can be addressed in several ways. First, the experience of complexity is in its essence subjective, and thus participants should be allowed to rate complexity by whichever criteria they deem important. Despite this subjective quality, the data demonstrated high agreement between participants as suggested by relatively small standardized error rates. Second, other measures, such as change or disorder, could lead to similar results for the simple fact that these concepts are related, describing that something is changing, different or variable. Indeed, the foundations of complexity research are based on Berlyne's collative properties, which describe a comparative process between stimuli, captured by properties similar to complexity such as novelty, surprise and irregularity; shaping experience through a shared mechanism (Berlyne, 1960, 1971; Stamps, 2002). Thus, researchers have long conceded the relatedness of such terms and concepts, and that they tap into the same cognitive concepts and mechanisms (Berlyne, 1960; 1971; Stamps; 2002).

The approach in this dissertation, where complexity was generated by combining environmental properties with numerosity and diversity resulted in four distinct combinations; numerosity of geometric elements, diversity of geometric elements, numerosity of featural elements and diversity of featural elements. In the experiments presented here, three of the four combinations were examined—all but the diversity of geometric elements. Previous research suggests that increasing diversity of geometric elements should be experienced as more complex (Heath, Smith & Lim, 2000; Stamps, 2002) but future experiments should attempt to replicate these findings with the research methods and approaches used here.

7.3. From Physical Features of the Environment to Emotional Response

In each experiment, objective environmental complexity predicted perceived complexity. As described in the previous section, the direct effect of environmental complexity on emotional response was more variable than expected, either predicting interest positively or predicting pleasure negatively, depending on environment type. Regardless of the nature of the direct effect of complexity—whether positive or negative—it was either fully or partially mediated by perceived complexity in every experiment. These results suggest that, although the effect of environment complexity is variable, it is always mediated by subjective responses of perceived complexity. Thus, emotional response is not only a result of objective complexity present within the environment but also of how an individual perceives and conceptualizes the complexity.

These results are consistent with the appraisal theory of emotion, where emotional response is dependent on the cognitive processes underlying perception of stimulus properties (Smith & Ellsworth, 1985). Thus, emotional response may result not solely from the objective physical complexity within environment, but the manner in which this complexity is perceived and experienced subjectively by an individual. By arguing for the importance of cognitive concepts, such as appraised complexity, this dissertation contrasts with classic arousal based mechanisms (Berlyne, 1971).

The relationship between interest and pleasure was also examined; in all but one experiment, interest and pleasure were correlated. To a certain extent, pleasure results from situations which are congruent with one's current motivations and needs; within the context of these experiments, lacking strong extrinsic goals and internal motivations, we can assume that the basic motivation of information acquisition is strongly activated. Thus, interesting stimuli, which provide understandable information, result in feelings of pleasure. If additional motivations or goals were added, it is possible that the effect of interest on pleasure may dissipate. On the other hand, Silvia (2005a) and Turner & Silvia (2006) demonstrated that interest can result from unpleasant stimuli and that pleasure is not necessary for interest to be experienced.

Our findings are consistent with the information processing model of aesthetic appreciation as argued by Leder and colleagues (Leder, Belke, Oerberst & Augustin, 2004; Leder & Nadal, 2014). Although not dealing with environment per se, the model considers the formation of aesthetic experience, which environments could be seen a subclass of. For Leder, aesthetic response is resultant from a multistage information processing cascade, beginning at low-level perception of stimulus properties and moving to more cognitive processes such as memory integration, classification and mastery (Leder, Belke, Oerberst & Augustin, 2004). The complexity and symmetry measures used here are captured by the perceptual analysis component of the aesthetic appreciation model. This process results in two distinct outputs: aesthetic judgement and aesthetic emotion. Aesthetic judgement takes the form of cognitive appraisals regarding the worth, value and quality of an artwork, resulting from a cognitive mastery stage.

On the other hand, aesthetic emotion is captured by feelings of pleasure or enjoyment occurring from successful information processing. In this way, aesthetic judgement is seen as cognitive and evaluative in nature, while aesthetic emotion is a by-product of information processing. We provide partial support for the notion that aesthetic emotion, in the form of pleasure, is a result of information processing. At first consideration, if we take interest to be cognitive, we might position it as part of the aesthetic judgement response. More recently, Leder and Nadal (2014), suggested that the aesthetic emotion of pleasure is resultant from more complex emotions, derived from cognitive appraisals, such as surprise, awe, and in our case, interest. This second interpretation suggests that pleasure results from interest, and although our data show that interest may lead to pleasure in certain circumstances, the two might be independent of one another (Silvia, 2005a; Turner & Silvia, 2006).

In considering Leder's aesthetic model, it is clear that the experiments presented here only capture the perceptual analysis component of the model. Thus suggesting the need to consider cognitive factors such as environment specific content, expertise, previous experiences and context. It is precisely for these reasons that preferences vary so drastically between architects and lay individuals (Brown & Gifford, 2001). In fact, as a result of their training, education and expertise, even the criteria used by architects to judge the value of the environment is drastically different to that of non-designers (Gifford, Hine, Muller-Clemm, Reynolds & Shaw, 2000). Indeed, in a series of experiments, Silvia demonstrated that cognitive mastery increases ability to makes sense of and understand visual input, thus driving feelings of interest (Silvia, 2005, 2008; Silvia & Turner, 2006). Future research would do well to introduce content, style and expertise into the analysis of emotional response to the environment.

In addition to the role that cognitive factors may play, as described above, our pattern of results suggests that there are two routes through which environmental complexity shapes our responses—a direct route resulting from bottom-up perception of objective stimulus properties of the environment and an indirect route resulting from subjective experience of the environment. Bottom-up perception of environmental geometry and spatial relationships allows for the perception of higher-level concepts regarding the environment, such as environment class or type and underlie the direct effect exhibited here (Oliva & Torralba, 2001, 2006). The indirect effect may, on the other hand, be dependent on various top-down factors such as expertise and prior experience (Leder, Belke, Oerberst & Augustin, 2004; Silvia, 2005a; 2005b). Future research should consider the exact relationship between these two paths; for example, although the direct path feeds-forward to the indirect path, it is also likely that top-down factors may affect direct perception of complexity.

Regardless of the exact relationship of these two potential paths, this dissertation demonstrated that emotional response does not result solely from the stimulus properties, instead emotions result from the manner in which the stimulus properties are understood and conceptualized—that cognitive factors play an important role. Clearly, due to previous research on cognitive underpinnings of emotion, the modest beta coefficients exhibited here, and the unexpected results in experiments 2.1 and 2.2, it would be worthwhile to include additional cognitive components into the model, with understandability a potentially fruitful candidate.

7.4. Behavioural Measures of Emotional Response to Environmental Complexity

In Experiments 2.1 and 2.2, behavioural measures were compared to subjective emotional response; a high level of agreement was demonstrated between the two. Specifically, complex environments were avoided in a virtual reality navigation task, consistent with their low pleasure ratings. In these experiments, behaviour was driven by the aversive, negative nature of the environment while moderately pleasant environments were equally approached. As Experiment 3.0 was conducted in the field, it was not possible to develop a sensible behavioural measure within the constraints of the experiment but approach-avoidance scores were consistent with emotional responses. Crucially, both interest and pleasure predicted approach scores, suggesting that the emotions may shape behaviour.

By using behavioural measures of preference, this dissertation attempted to more accurately reflect how individuals exhibit emotional response towards the environment. Although subjective ratings of emotions may describe what the individual is feeling at the moment, it is an unnatural manner by which to gauge emotions; individuals do not stop in front of the environment and wonder how the environment makes them feel. Instead, emotional response is exhibited through behaviour; individuals will spend more time in enjoyable spaces and explore interesting spaces. By measuring both we demonstrated a strong degree of agreement between subjective responses and behaviour, suggesting the possibility of using behaviour as a direct measure of emotional response. This consideration of behaviour alongside subjective experience positions the environmental experience more closely to the emotion literature where behaviour is considered an important functional component of emotion (Lazarus, 1991; Keltner & Gross, 1999; Frijda, 1994). Thus, the experience of pleasure or interest is marked both by a subjective feeling as well as related patterns of behaviour.

By considering the effect of environmental properties on emotion, it may be possible to design spaces in order to achieve desired behaviours. For example, such findings could be applied to wayfinding systems in large buildings and institutions. By eliciting pleasure (or displeasure), individuals may use (or avoid) certain paths or corridors. By eliciting interest, individuals may be more likely to engage with and explore the environment; thus non-verbal or implicit wayfinding systems may be developed. Emotional response may also shape other forms of behaviour other than wayfinding and navigation choices. For example, if the complexity of a consumer environment is difficult to process or understand, or if the environment is overly simple, consumers may feel displeasure or boredom resulting in avoidance behaviour; a very negative reaction within most real-world contexts. This will mean that individuals may fail to explore a museum, gallery or shopping centre since it will be experienced as uninteresting. On the other hand, if the design of the environment results in pleasure and interest, individuals will spend more time in and engage more fully with the environment. Clearly, environmental complexity can neither describe nor predict behaviour fully, but it provides us with an easily operationalized and workable tool to design environments where specific behaviours are desirable.

7.5. Conclusions

This dissertation makes several important contributions to the literature on the effect of environmental complexity on experience. First, interest was examined alongside pleasure, supporting the notion that emotional response is composed of numerous distinct emotions. Although objective complexity affected emotional response in every experiment, its effect on pleasure and interest was variable, demonstrating that factors other than complexity need to be considered. Second, environmental complexity was quantified through both numerosity and diversity of geometric and featural elements of the built environment successfully predicting perceived complexity. Third, emotional response resulted both from objective complexity as well as the subjective experience of perceived complexity. This consideration of cognitive factors in the form of perceived complexity as mediating the effect of objective environmental complexity on response argued for the importance of moving away from general arousal mechanisms. Fourth, emotional response was treated as being composed of both a subjective emotional state as well as a behavioural component. Exploration behaviour was argued as a way to examine emotional response in a more naturalistic and perhaps ecologically valid manner, with a strong relationship between subjective response and behaviour demonstrated.

Our relationship with the built environment is a complicated one; this dissertation attempts to elucidate several key factors allowing us to develop a better understanding of how the built environment affects us. These research questions have the potential to shape how we design our environments to fit a wide variety of functions. For example, a living room should be pleasing, allowing an individual to relax, while an office should not just be pleasing but engaging and perhaps even interesting. On the other hand, an environment that is very complex, and thus interesting might not be ideal if the function of that environment is to restore and induce relaxation. Thus, it is important to consider the desired function of the environment whether it be to elicit interest, curiosity, collaboration and even excitement, and although many of these experiences are pleasing, they may result from a very specific and distinct set of environment properties. In addition to eliciting desired emotions, environments also need to foster specific behaviours; this dissertation explores exactly this need. Finally, if we are to apply such findings it is necessary to provide architects and design professionals with the tools to design and manipulate visual complexity objectively. This dissertation makes strides in that regard by systemically describing the physical factors underlying environmental complexity. With such tools, it may be possible to design environments that are experienced as engaging and invigorating, where exploration is commonplace: environments which enlighten and uplift rather than bring us down.

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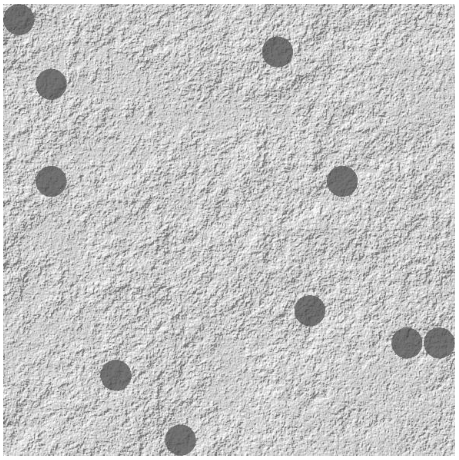
Appendix A

Additional Details Regarding Generation of Environments in Experiment 1.2

For 1 feature, 6 arrangements were possible; considering the symmetry and equal distribution rules the 6 possible arrangements can be reduced down to three arrangements. Random selection of position, following rules, leads to the three following arrangements: positions 1a, 2a and 3b were. For 3 features, selection of three arrangements was more difficult considering that the symmetry and distribution rules do not reduce all possible arrangements down to three arrangements. Generally, by applying the even distribution rule, the following three arrangements were selected. One environment was selected where two panels are presented on one wall, and the third feature is randomly positioned on one of the other walls; this resulted in the arrangement of 1a, 1b and 2a. The second environment was designed so that features are distributed amongst all three walls, and that the features on the right and left walls are exactly opposite one another; this resulted in the arrangement of 1b, 2b and 3b. The third environment was designed so that features were once again disturbed amongst all three walls, but this time the features on the left and right walls were not directly across from one another, but instead positioned diagonally from one another; this resulted in the arrangement of 1a, 2a and 3b. In regards to 5 features, six possible arrangements were possible; considering the symmetry and the distribution rules reduced the six possible arrangements down to three. Random position assignment as constrained by the two rules resulted in the following arrangements: (1b, 2a, 2b, 3a, 3b), (1a, 1b, 2b, 3a, 3b) and (1a, 1b, 2a, 2b, 3a). For 0 openings, one environment was created three separate times.

Dot densities were created using the programming language R, using the graphic visualization library ggplot2, to create a square shape on to which dots were placed using randomized x and y coordinates. The image editing software Gimp was used to generate a textured finish and lighting effects using the clouds and solid noise functions, allowing for the creation of more realistic looking wall panels. Low-level visual properties were matched by applying luminance histogram matching within all panels using the MATLAB add-on, SHINE, which has previously been shown to effectively match low-level visual properties (Willenbockel, Sadr, Fiset, Horne, Gosselin & Tanaka, 2010). Please refer to Figure A1 for final panels.

Dot Density (/0.5m^2)	
10	
20	

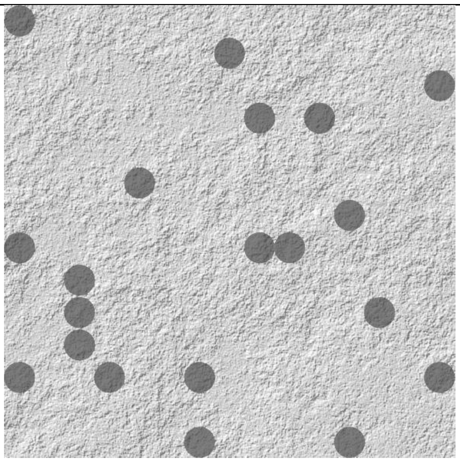
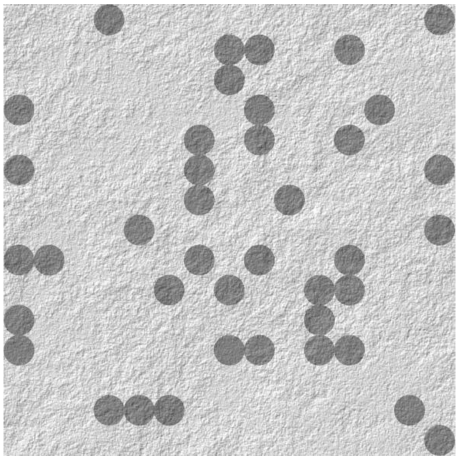
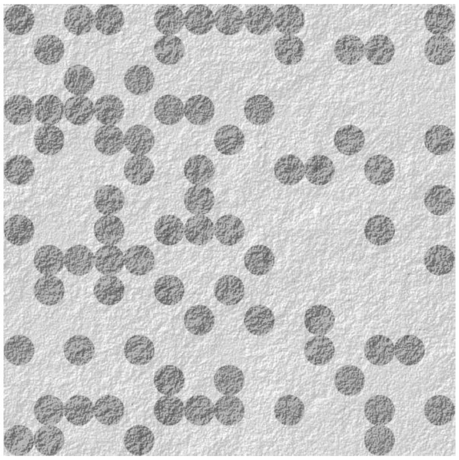
	
40	
80	

Figure A1. Rendered dot panels, ranging from 10 to 80 dots/0.5m^2

Appendix B

Detailed Description of Entropy generation in Experiment 2.1

Since each environment consisted of four panels, complexity was maximized when all of four dot panel identities were presented and thus all the panels were different. On the other hand, complexity was minimized when all panels were the same, thus a single dot panel identity was presented four times. Complexity was generated by varying the panel identity probabilities within each environment, from which we quantified complexity using entropy. For example, when all panels are different, the probability of occurrence for each panel identity is 1/4; when all the panels are the same, the probability of occurrence for panel identity is 4/4. With four areas where panel identity can vary, we had a total of five distinct panel identity arrangements; as each arrangement can be described by the probability of occurrence of any given panel, we can describe the information complexity in each by calculating entropy. In total, five arrangements are possible, generating entropy ranging from 0 to 2 bits. See Table B1 for all possible panel probabilities and their corresponding entropy values.

Table B1.

All possible panel probabilities and their corresponding entropy values

Number of unique panels (associated probabilities)	Entropy (H, in bits)
1 panel (1 : 4/4)	0
2 panels (1 : 3/4) (2 : 1/4)	0.81
2 panels (1 : 2/4) (2 : 2/4)	1
3 panels (1 : 2/4) (2 : 1/4) (3 : 1/4)	1.5
4 panels (1 : 1/4) (2 : 1/4) (3 : 1/4) (4 : 1/4)	2

It is important to mention that most of the above entropy values can be generated in a number of ways, depending on which panel identities are used to generate the probabilities. For example, entropy of 1 bit requires two distinct panels presented two times each; as there are four distinct panel identities, this entropy value can be generated six separate ways depending on which panel identities are selected, as follows:

Combination 1: (dot density = 10/0.5m^2: 2/4) and (dot density = 20/0.5m^2: 2/4)

Combination 2: (dot density = 10/0.5m^2: 2/4) and (dot density = 40/0.5m^2: 2/4)

Combination 3: (dot density = 10/0.5m^2: 2/4) and (dot density = 80/0.5m^2: 2/4)

Combination 4: (dot density = $20/0.5m^2$: 2/4) and (dot density = $40/0.5m^2$: 2/4)

Combination 5: (dot density = $20/0.5m^2$: 2/4) and (dot density = $80/0.5m^2$: 2/4)

Combination 6: (dot density = $40/0.5m^2$: 2/4) and (dot density = $80/0.5m^2$: 2/4)

Thus, all entropy values can be generated numerous ways depending on the panel identities selected. Two bits of entropy is the exception: it can only be generated in one way because all four panels need to be used. Considering the panel identities selected, each entropy level has the following number of possible unique combinations: E_0: four arrangements, $E_{0.81}$: six arrangements, $E_{1.0}$: six arrangements, $E_{1.5}$: eight arrangements and E_2: one arrangement. This factor needed to be considered when deciding the selection of panels for the creation of the experimental environment, so as to ensure that all panel identities were used an equal number of times in the experiment.

It was also necessary to consider overall dot density within each environment. Each panel identity was composed of a specific dot density, but when using four panels to create an environment, the environment as a whole possessed an environment average dot density. Since various combinations of panel identities can be used to generate entropy, using certain panel identities as opposed to others will result in either higher or lower average dot density within the environment which may potentially impact perceived complexity. For example, if we take 1 bit of entropy, and compare combination 1 to combination 6 (as described above), we can see that the average environment dot density for each combination differs greatly—for combination 1, average environment dot density = 30 dots/$0.5m^2$, while for combination 6 average environment dot density = 60 dots/$0.5m^2$. This is problematic because dot densities could be indicative of complexity, leading to potential confounds such that, certain combinations of panel identities might be perceived as more or less complex, despite possessing the same entropy.

Considering both the large number of arrangements for each entropy and the fact that each arrangement features a different environment average dot density, we decided to use only one combination per each level of entropy. This also greatly decreased the overall number of environments, because we did not have to create every single combination per level of entropy. The question then becomes, which combinations should be selected in an effort to control for environment average dot density. Since E_2 only has one combination, requiring each of the four panels to be used, it is reasonable to attempt to match environment average dot densities of all other entropies to the average dot density present in E_2, which is 37.5 dots/0.5m^2. Thus, to control for environment average dot densities, we selected those combinations of panel identifies which most closely matched average dot density present for E_2 (37.5 dots/0.5m2); refer to Table B2 for the final selected environment average dot densities. This selection of panel combinations also ensured that no single panel identity would be overrepresented during the duration of the experiment.

Table B2.

Selected dot panel probabilities and associated environment average dot densities

Entropy	Panel Identity (dots/0.5m^2)	Probability	Environment Average Dot Density (/0.5m^2)
0	37.5	4/4	37
0.81	20	3/4	35
	80	1/4	
1	20	2/4	30
	40	2/4	
1.5	10	2/4	35
	40	1/4	
	80	1/4	
2	10	1/4	37.5
	20	1/4	
	40	1/4	
	80	1/4	

For E_0, since the same panel is presented four times, the closest we could get to the average of 37.5 dots/m^2, was if we used the 40 dots/0.5 m^2 panel four times. The concern with this approach is that it would lead to overrepresentation of the 40 dots/0.5 m^2 in the experiment as it would also have to be used numerous times for other entropy environments as well. In order to avoid this, an additional five panels were created featuring exactly 37 dots/0.5m^2, which were only used to generate E_0 environments.

Even with these panel probabilities and panel identities, each of the entropy combinations can be generated a number of ways, depending on the actual positions of the selected panels within the corridor. This means that many distinct corridor environments, possessing the same entropy, can be created by manipulating the position or arrangement of the appropriate panel identities. For example, if we look at $E_{1.00}$, one potential environment arrangement would consist of the top and bottom panels being 20 dots/0.5m^2 panels, while the middle two panels consisted of 40 dots/0.5m^2 panels. An alternative arrangement could feature 20 dot/0.5m^2 panel in the top position as well as second from the bottom position while featuring 40 dots/0.5m^2 panels in the bottom position and in the second from the top position. Although these two environments will possess the same degree of entropy, they will look different due to the position of the panels. See Table B3 for all possible panel positions per level of entropy. In order to compare all possible entropy pairs, each entropy value needed to be presented eight times. Since $E_{0.81}$ has only four possible arrangements, each one was used twice, while $E_{1.00}$ had six possible arrangements, two were randomly selected to be used twice. Since both 1.5 and 2 bits of entropy there had more than the eight required arrangements, certain arrangements had to be excluded. Considering that certain arrangements were symmetrical versions of one another, we decided to include only one of the two versions. Final arrangements, considering panel combinations, environment wide dot densities and panel arrangements are presented in Table B4.

Table B3.

All possible panel arrangements per level of entropy.

Entropy	Position	Dot Panel Identities											
0.81	Top	20	80	20	20								
	Mid$_{\text{(Top)}}$	20	20	20	80								
	Mid$_{\text{(Bottom)}}$	20	20	80	20								
	Bottom	80	20	20	20								
1.00	Top	20	40	40	20	40	20						
	Mid$_{\text{(Top)}}$	40	20	20	40	40	20						
	Mid$_{\text{(Bottom)}}$	40	20	40	20	20	40						
	Bottom	20	40	20	40	20	40						
1.5	Top	10	10	10	40	80	10	40	80	80	40	10	10
	Mid$_{\text{(Top)}}$	80	10	10	80	40	40	10	10	10	10	40	80
	Mid$_{\text{(Bottom)}}$	40	80	40	10	10	80	10	10	40	80	10	10
	Bottom	10	40	80	10	10	10	80	40	10	10	80	40
2	Top	10	10	10	10	10	10	20	20	40	80	40	80
	Mid$_{\text{(Top)}}$	20	20	40	80	40	80	10	10	10	10	10	10
	Mid$_{\text{(Bottom)}}$	40	80	20	20	80	40	40	80	20	20	80	40
	Bottom	80	40	80	40	20	20	80	40	80	40	20	20
	Top	20	20	40	80	40	80	20	20	40	80	40	80
	Mid$_{\text{(Top)}}$	40	80	20	20	80	40	40	80	20	20	80	40
	Mid$_{\text{(Bottom)}}$	10	10	10	10	10	10	80	40	80	40	20	20
	Bottom	80	40	80	40	20	20	10	10	10	10	10	10

Note. Top, mid($_{\text{top}}$), mid($_{\text{bottom}}$) and bottom represent the position of the panel within the environment. The numeric values represent the associated dot panel identities as described earlier. Thus, $E_{0.81}$ can be generated through four distinct panel positions. For example in the first arrangement, the top, and the two middle panels are 20dots/0.5m^2 panels while the bottom panel is a 80dots/0.5m^2 panel.

Table B4.

Final selected panel identities and arrangements

Entropy	Position	1	2	3	4	5	6	7	8
0.81	Top	20	80	20	20	20	80	20	20
	Mid$_{\text{(Top)}}$	20	20	20	80	20	20	20	80
	Mid$_{\text{(Bottom)}}$	20	20	80	20	20	20	80	20
	Bottom	80	20	20	20	80	20	20	20
1.00	Top	20	40	40	40	40	40	20	20
	Mid$_{\text{(Top)}}$	40	20	20	20	40	20	20	40
	Mid$_{\text{(Bottom)}}$	20	40	20	20	20	20	40	20
	Bottom	40	20	40	40	20	40	40	40
1.50	Top	10	10	80	80	80	40	10	10
	Mid$_{\text{(Top)}}$	80	10	40	10	10	10	40	10
	Mid$_{\text{(Bottom)}}$	40	80	10	10	40	80	10	80
	Bottom	10	40	10	40	10	10	80	40
2.00	Top	80	20	10	10	40	40	10	20
	Mid$_{\text{(Top)}}$	20	40	40	80	10	20	20	10
	Mid$_{\text{(Bottom)}}$	80	10	20	20	80	80	80	80
	Bottom	10	80	80	40	20	10	40	40

Appendix C

All Possible Entropy by Symmetric Arrangements for Experiment 2.2

Entropy	Arrangement	Sym/Asym	Left	Mid Left	Middle	Mid	Right
0.00	1	Asym	A	A	A	A	A
0.72	1	Asym	A	B	B	B	B
	2	Asym	B	A	B	B	B
	3	Sym	B	B	A	B	B
	4	Asym	B	B	B	A	B
	5	Asym	B	B	B	B	A
0.97	1	Asym	A	A	B	B	B
	2	Asym	A	B	A	B	B
	3	Asym	A	B	B	A	B
	4	Sym	A	B	B	B	A
	5	Asym	B	A	A	B	B
	6	Sym	B	A	B	A	B
	7	Asym	B	A	B	B	A
	8	Asym	B	B	A	A	B
	9	Asym	B	B	A	B	A
	10	Asym	B	B	B	A	A
1.37	1	Asym	A	A	A	B	C
	2	Asym	A	A	A	C	B
	3	Asym	A	A	B	A	C
	4	Asym	A	A	B	C	A
	5	Asym	A	A	C	A	B
	6	Asym	A	A	C	B	A
	7	Asym	A	B	A	A	C
	8	Sym	A	B	A	C	A
	9	Asym	A	B	C	A	A
	10	Asym	A	C	A	A	B
	11	Sym	A	C	A	B	A
	12	Asym	A	C	B	A	A
	13	Sym	B	A	A	A	C
	14	Asym	B	A	A	C	A
	15	Asym	B	A	C	A	A
	16	Asym	B	C	A	A	A

	17	Sym	C	A	A	A	B
	18	Asym	C	A	A	B	A
	19	Asym	C	A	B	A	A
	20	Asym	C	B	A	A	A
1.52	1	Asym	A	A	B	B	C
	2	Asym	A	A	B	C	B
	3	Sym	A	A	C	B	B
	4	Sym	A	B	A	B	C
	5	Asym	A	B	A	C	B
	6	Asym	A	B	B	A	C
	7	Asym	A	B	B	C	A
	8	Asym	A	B	C	A	B
	9	Sym	A	B	C	B	A
	10	Asym	A	C	A	B	B
	11	Asym	A	C	B	A	B
	12	Asym	A	C	B	B	A
	13	Asym	B	A	A	B	C
	14	Asym	B	A	A	C	B
	15	Asym	B	A	B	A	C
	16	Asym	B	A	B	C	A
	17	Sym	B	A	C	A	B
	18	Asym	B	A	C	B	A
	19	Asym	B	B	A	A	C
	20	Asym	B	B	A	C	A
	21	Asym	B	B	C	A	A
	22	Asym	B	C	A	A	B
	23	Asym	B	C	A	B	A
	24	Asym	B	C	B	A	A
	25	Asym	C	A	A	B	B
	26	Asym	C	A	B	A	B
	27	Asym	C	A	B	B	A
	28	Asym	C	B	A	A	B
	29	Asym	C	B	A	B	A
	30	Asym	C	B	B	A	A
1.92	1	Asym	A	A	B	C	D
	2	Asym	A	A	B	D	C
	3	Asym	A	A	C	B	D

	4	Asym	A	A	C	D	B
	5	Asym	A	A	D	B	C
	6	Asym	A	A	D	C	B
	7	Asym	A	B	A	C	D
	8	Asym	A	B	A	D	C
	9	Asym	A	B	C	A	D
	10	Sym	A	B	C	D	A
	11	Asym	A	B	D	A	C
	12	Sym	A	B	D	C	A
	13	Asym	A	C	A	B	D
	14	Asym	A	C	A	D	B
	15	Asym	A	C	B	A	D
	16	Sym	A	C	B	D	A
	17	Asym	A	C	D	A	B
	18	Sym	A	C	D	B	A
	19	Asym	A	D	A	B	C
	20	Asym	A	D	A	C	B
	21	Asym	A	D	B	A	C
	22	Sym	A	D	B	C	A
	23	Asym	A	D	C	A	B
	24	Sym	A	D	C	B	A
	25	Asym	B	A	A	C	D
	26	Asym	B	A	A	D	C
	27	Sym	B	A	C	A	D
	28	Asym	B	A	C	D	A
	29	Sym	B	A	D	A	C
	30	Asym	B	A	D	C	A
	31	Asym	B	C	A	A	D
	32	Asym	B	C	A	D	A
	33	Asym	B	C	D	A	A
	34	Asym	B	D	A	A	C
	35	Asym	B	D	A	C	A
	36	Asym	B	D	C	A	A
	37	Asym	C	A	A	B	D
	38	Asym	C	A	A	D	B
	39	Sym	C	A	B	A	D
	40	Asym	C	A	B	D	A

	41	Sym	C	A	D	A	B
	42	Asym	C	A	D	B	A
	43	Asym	C	B	A	A	D
	44	Asym	C	B	A	D	A
	45	Asym	C	B	D	A	A
	46	Asym	C	D	A	A	B
	47	Asym	C	D	A	B	A
	48	Asym	C	D	B	A	A
	49	Asym	D	A	A	B	C
	50	Asym	D	A	A	C	B
	51	Sym	D	A	B	A	C
	52	Asym	D	A	B	C	A
	53	Sym	D	A	C	A	B
	54	Asym	D	A	C	B	A
	55	Asym	D	B	A	A	C
	56	Asym	D	B	A	C	A
	57	Asym	D	B	C	A	A
	58	Asym	D	C	A	A	B
	59	Asym	D	C	A	B	A
	60	Asym	D	C	B	A	A
2.32	1	Asym	A	B	C	D	E

Appendix D

Final Environment Entropy and Symmetry Presentation Order for Experiment 2.2

Trial	Left Entropy	Right Entropy	Left	Right
1	Control	Control	Control	Control
2	0.00	1.52	S	A
3	0.97	0.00	A	S
4	2.32	1.52	A	A
5	1.92	2.32	S	A
6	0.97	1.92	S	A
7	Control	Control	Control	Control
8	0.00	2.32	S	A
9	1.52	1.92	A	S
10	2.32	0.97	A	S
11	1.52	0.97	A	A
12	1.92	0.00	S	S
13	Control	Control	Control	Control
14	0.97	1.52	S	A
15	2.32	1.92	A	S
16	1.52	2.32	S	A
17	2.32	0.00	A	S
18	0.97	2.32	A	A
19	Control	Control	Control	Control
20	1.92	0.97	A	A
21	1.52	0.00	S	S
22	0.00	1.92	S	S
23	1.92	1.52	S	S
2	0.00	0.97	S	A
25	Control	Control	Control	Control
26	0.97	0.00	S	S
27	2.32	1.92	A	A
28	0.00	2.32	S	A
29	1.52	0.97	S	S
30	0.00	1.52	S	S
31	Control	Control	Control	Control

32	2.32	1.52	A	S
33	1.92	0.00	A	S
34	0.97	1.92	A	S
35	1.52	1.92	S	A
36	2.32	0.97	A	A
37	Control	Control	Control	Control
36	1.92	0.97	S	S
39	0.97	2.32	S	A
40	1.52	0.00	A	S
41	0.00	1.92	S	A
42	1.92	1.52	A	A
43	Control	Control	Control	Control
44	0.00	0.97	S	S
45	1.52	2.32	A	A
46	0.97	1.52	A	S
47	2.32	0.00	A	S
48	1.92	2.32	A	A