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Beauty is the transformation of the world into pattern.

Sōetsu Yanagi

Contents

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1 | General introduction

Art, ornament and decoration are important parts of human culture, and archaeological evidence suggests that this has been true for tens of thousands of years. The aesthetic drive underlying the production and perception of visually pleasing objects seems to be universal in human societies, yet much remains unknown about why we engage in aesthetic practices. The study of aesthetics has changed profoundly since its beginnings as a philosophical discipline. Today, it is an active and multi-faceted field of research, including philosophy, art history, psychology, neuroscience, evolution, biology and more. The function of aesthetics and its role in humans' evolutionary history more generally has been speculated upon since Darwin [Darwin, 1874; Menninghaus, 2011]. Recently, scientists have begun to combine evolutionary approaches and neurological studies to shed light on these complex phenomena [Nadal et al., 2008; Zaidel, 2010; Zaidel et al., 2013], which requires expertise in multiple disparate fields. As the field of empirical aesthetics continues to grow, predictive models including the multiple facets of aesthetics will become increasingly important in guiding experiments with high potential for interdisciplinary study and reducing the potentially unlimited lines of inquiry [Chatterjee, 2003; Leder et al., 2004; Leder, 2013; Fitch et al., 2009].

One very active area in empirical aesthetics that has gained much recent attention is "neuroaesthetics" [Ramachandran and Hirstein, 1999; Skov and Vartanian, 2009; Chatterjee, 2010], which aims to understand how the brain processes art. Neuroscientist Semir Zeki maintains that "it is my conviction that no theory of aesthetics is likely to be complete, let alone profound, unless it is based on an understanding of the workings of the brain"[Zeki and Bartels, 1998, p.17].

The major challenge for empirical aesthetics is that a natural aesthetic experience bundles a complex set of phenomena, including conscious and unconscious cognitive processes but also emotional and motivational processes. Such complex interactions make it challenging to study aesthetics as a whole in general and help to explain why finding specific or unique brain activation patterns in the context of aesthetic appreciation is proving to be exceedingly difficult. Given the complexity of the brain and its activation patterns, it is vital for neuroimaging work to have a precisely defined object of study. As Conway and Rehding [2013] point out, there is a danger of simply conflating beauty and art. Many things that are beautiful are not art (e.g. flowers and sunsets), and not all art is necessarily beautiful (e.g. Picasso's 'Guernica'). In a functional magnetic resonance imaging (fMRI) study, Ishizu and Zeki [2011] showed participants paintings and

music excerpts and asked them to categorise them as either "beautiful", "ugly" or "indifferent". They found that when compared to ugly and neutral exemplars, exemplars in both modalities that were judged to be beautiful activated a particular brain region, the medial orbitofrontal cortex. Based on this finding, they claim to have found a "faculty of beauty". However, other studies showed that this region is involved with monetary value judgements, assignment of worth and moral decision making in general, and is not specific to aesthetic valuation [Conway and Rehding, 2013; Kable and Glimcher, 2009].

In a meta-analysis of imaging studies of brain activation during aesthetic appraisal of artworks, Brown et al. [2011] suggest that the appraisal process recruits regions related to multi-modal food appraisal, that is, judging whether or not food is good to eat based on taste, smell and texture (anterior insula) as well as general object appraisal (orbitofrontal cortex), and conclude that there is no specific or special neural circuitry associated exclusively with the appreciation of art versus non-art. Such pathways are shared with other species which presumably use them primarily for food appraisal, but possibly also for mate choice. Such studies rely on participants making explicit judgements about visual stimuli, which may not be an accurate reflection of the usual aesthetic process in real life, since aesthetic artefacts can be, and often are, enjoyed without explicit judging and rating.

Although some progress is thus being made on the connection between art judgement and brain activation, I would like to begin this thesis by exploring the underlying issue how beauty, artworks, aesthetics and judgement came to be so closely intertwined in current research and to explore routes to circumvent the potential confounds this might introduce to a broader understanding of aesthetics.

Historically, most interest in aesthetics has focussed on the relatively small subsection of aesthetic phenomena comprising so-called "high" Western art. Immanuel Kant proposed in his influential 1790 treatise *"Kritik der Urteilskraft"* (Critique of Judgement) [Kant, 1963] that a full appreciation of an artwork, a 'pure' judgement in Kant's terms, can only be achieved from a disinterested viewpoint, where the viewer has no personal desire or interest in the artwork.

It is important to note that Kant uses the term *art* in the very general sense of *Geschicklichkeit des Menschen*, that is, general human skill and dexterity, [Kant, 1963, p.230]). This meaning is rather close to the Latin *ars*, root of the English word "art", meaning "any human skill" [Shiner, 2001, p.5]. He distinguishes between so-called mechanical art or art that is made for payment (*Lohnkunst*) on the one hand and aesthetic art on the other, which is again subdivided into pleasant art and beautiful art. Mechanical art is viewed by Kant as inherently unpleasant to make, and produced solely for the financial rewards that it brings, while beautiful art is free and inherently rewarding to produce. This latter category corresponds to what we generally think of as "art" today.

Pleasant art centres on beautiful objects and pleasant experiences (a nicely laid out dinner table or pleasant background music, for example [Kant, 1963, p.233]), which have the sole purpose of eliciting pleasant feelings. According to Kant, truly beautiful art is about the beauty of the reflective process it triggers in the viewer, rather than the properties of the object observed. Indeed, a personal interest in the object is thought by

Figure 1.1: In his very influential philosophical treatise *Critique of Judgement*, first published in 1790, Immanuel Kant (1724-1804) advocated a disinterested stance during art appreciation.

Kant to be incompatible with the true appreciation process. In contrast, this reflective process is said to be absent in pleasant art. Thus, beautiful and pleasant art can be distinguished in Kant's approach by the degree to which the reflective process is necessary for the appreciation of an object's beauty. Furthermore, beautiful art cannot be produced according to predefined rules [Kant, 1963, p.236], while the production of pleasant art is thought to be mainly guided by cultural conventions. Kant calls the productive force underlying beautiful art, but not other categories of art, *'genius'*. Because beautiful art requires creative genius and cannot be derived from preexisting rules and conventions like pleasant art can, the creation of beautiful art, according to Kant, cannot be achieved by instruction or imitation alone, but must arise spontaneously through a creative and original spark in the artist [Kant, 1963, p.237-241].

It is important to realise that the concept of "high art" and the "artist" was a relatively new one when Kant was writing his treatise. To modern readers, the idea of artists expressing independent, creative and novel ideas is not particularly surprising. However, prior to the 18th century, there was no strong distinction between artists and craftspeople in Europe [Shiner, 2001; Kristeller, 1990]: artists often learned and practised crafts and had rich benefactors who ordered specific artworks and had considerable influence on the contents produced [Shiner, 2001, p. 35-6]. An understanding of the artist as Kant presents it, expressing unique, creative ideas, unfettered by the constrictions of convention or finances, and a concomitant ideal viewer, with a detached and disinterested view of the artwork would have been a radical departure from the conventional roles of producer and perceiver until then, and may have been an idealised vision, rather than an attempt to document reality. Kant's framework at the time was a significant contribution towards a means to formalise the refined aesthetic processes associated with paintings and music that had emerged only recently.

Kant's ideas were built mainly around the perceiver. Minimally, the cognitive process underlying aesthetics must have two dimensions: production, i.e. the planning and execution of actions that create an aesthetic object, and perception, meaning the processes through which the object is perceived, and the subsequent associations it triggers. In practice, producers must also use perceptual processes during production to monitor their own actions, but little is currently known about this potentially complex real-time interaction between perception and production.

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Almost a hundred years later, Friedrich Nietzsche [2012, p.688-9] criticises Kant's approach for being too focussed on the producer in the aesthetic process:

> [W]as ich allein unterstreichen will, ist dass Kant, gleich allen Philosophen, statt von den Erfahrungen des Künstlers (des Schaffenden) aus das ästhetische Problem zu visieren, allein vom "Zuschauer" aus über die Kunst und das Schöne nachgedacht und dabei unbemerkt den "Zuschauer" selber in den Begriff "schön" hineinbekommen hat.

> *What I only would like to emphasise is that Kant, like all philosophers, thought about art and beauty only from the position of the "spectator" when viewing the aesthetic problem, instead of from the experiences of the artist (the maker), and thus inadvertently introduced the "spectator" into the term "beautiful".* [my translation]

Nietzsche makes a good point. Because most philosophers (like most contemporary scientists) have extensive experience in perceiving, but not producing artworks, it is not surprising that philosophical discussion has centred mainly on the perception side of the aesthetic process.

An exception to this generalisation is Adolf Loos (1870-1933), a well-known Austrian architect and an admirer of Immanuel Kant [Loos, 2012, p. 174], who had strong views on aesthetics that incorporate production, perhaps because as an architect he himself took on an aesthetically productive role.

While Kant to my knowledge did not explicitly state that one type of art is better or more advanced than others, Loos clearly envisioned a "great chain of being" in aesthetics, with visual art shedding ornament as it evolves. In his manifesto *"Ornament und Verbrechen"* ("Ornament and crime"), originally published in 1908, Loos [2012] posits that ornament is the source of all art: 'Der Drang, sein Gesicht und alles, was einem erreichbar ist, zu ornamentieren, ist der Uranfang der bildenden Kunst" ("The urge to cover one's face and everything that is within reach with ornament is the very beginning of the visual arts") [Loos, 2012, p. 95]. Loos advocates a strict dichotomy between artworks and useful objects [Loos, 2012, p. 173] and he only allows ornament as an acceptable form of creative expression for humans who are either a) not part of Western culture and thus in his opinion occupy a 'lower" cultural level or b) are Western but on a lower cultural level by virtue of having a menial job, living in a rural area or being uneducated. For cultured, metropolitan Westerners however, gratuitous use of ornament is "criminal" (a kinder but less memorable term would have been "inauthentic"), because its use would be incongruous with the level of cultural evolution of its producer [Loos, 2012, p.95]: "Evolution der Kultur ist gleichbedeutend mit dem Entfernen des Ornamentes aus dem Gebrauchsgegenstande" ("The evolution of culture is equivalent to the removal of ornament from objects of use").

With these strongly worded statements Loos was criticising the Viennese branch of the Arts and Crafts movement, whose views on aesthetics were diametrically opposed to Loos' and Kant's understanding of aesthetic behaviours, including in particular the

separation of art and craft into distinct categories. We now turn to this alternative perspective on art and aesthetics.

1.1   Arts, crafts and aesthetics

The Arts and Crafts movement began in the United Kingdom in the second half of the nineteenth century [Blakesley, 2006]. Famous associates include Charles Rennie Mackintosh, William Morris and Stephen Crane, building on the previous ideas of John Ruskin. The movement lasted roughly until the first World War. As the name suggests, its aim was to erase the distinction between art and craft, making everyday objects and materials from cutlery to fabrics, and indeed entire houses, as valued as "high art" and as worthy of artistic treatment and elaboration as conventional artworks. Arts and Crafts emerged in the context of increasingly industrialised production of craft objects. As machines were introduced to the production process, objects that would previously have been very laborious to make could now be constructed in large numbers with a previously inconceivable degree of perfection. While there were clear benefits to industrialisation (better quality control, lower prices, reproducibility, etc), there was also a growing sense of potential loss of expertise, quality, and ultimately jobs, among artists, craftspeople and intellectuals alike [Blakesley, 2006].

Going beyond theoretical aesthetics, the Arts and Crafts movement particularly in Britain had an appreciable political agenda, with the rights and working conditions of artisans being one of their central issues.

The British Arts and Crafts movement inspired similar projects in the German-speaking world. Beginning in Munich in 1892, artists distanced themselves from existing artist's societies and founding new 'Secessions' that focussed on workmanship and materials, rather than artistic personae [Blakesley, 2006]. The art world in Vienna was also undergoing an upheaval, with artists such as Gustav Klimt, Oskar Kokoschka and Joseph Hoffmann leaving the traditional Viennese artist association to found the *"Wiener Secession"* in 1897. In the first edition of their journal *"Ver Sacrum"*, the Wiener Secession programmatically and idealistically state: "Wir kennen keine Unterscheidung zwischen 'hoher Kunst' und 'Kleinkunst', zwischen Kunst für die Reichen und Kunst für die Armen. Kunst ist Allgemeingut." ("We do not differentiate between 'high art' and 'small art', between art for the rich and art for the poor. Art is a common good.") [VerSacrum, 1898, p.6].

Here, the writers are attempting to re-unify what Kant's philosophy of aesthetics had previously cleanly split. Their efforts went beyond abstract declarations: Artists and artisans founded the *"Wiener Werkstätte"* ("Viennese Workshop") in 1903, which produced and sold furniture, fabrics, ceramics, jewellery etc, with a similar appreciation of hand crafted traditions to the British Arts and Crafts movement.

In Japan, a similar folk art movement developed in the 1920s: Sōetsu Yanagi, who was familiar with Morris' and Ruskin's writings and was friends with the renowned British Arts and Craft potter Bernhard Leach, coined the term *mingei* ("art of the people"), and founded the Japanese Folk Crafts Museum in 1936. Yanagi (Fig. 1.2),

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Figure 1.2: Sōetsu Yanagi (1889-1961), founder of the Japanese *mingei* (folk art) movement and promoter of traditional crafts.

also advocated studying crafts, rather than focussing exclusively on high art:

> It is my belief that while the high level of culture of any country can be found in its fine arts, it is also vital that we should be able to examine and enjoy the proofs of the culture of the great mass of the people, which we call folk art. The former are made by a few for a few, but the latter, made by the many for the many, are *a truer test.* [Yanagi, 2011, p.103, my emphasis]

Yanagi is essentially saying that numbers matter: if most people make crafts, and look at crafts more often than at art, why not focus on this area? Berlyne [1971, p.75] has a somewhat cynical answer to this question:

> Aestheticians have always been loath to identify artistic value with the greatest pleasure of the greatest number, since, if they did so, they would have to rate the latest popular song or grade-B film higher than the acknowledged masterpieces of artistic creation.

But this is not necessarily true since over time it is likely that many more people have appreciated Michelangelo's David than the latest Madonna song. Thus, it may not even be straightforward to define "greatest number", which would depend on whether one takes cumulative numbers over time into account (where older artworks would have an advantage), or numbers at a single point in time (in which case the most popular item at the time would prevail).

These details aside, I predict that as aesthetics moves from a purely philosophical discipline to include empirical approaches it will aim to produce generalisable findings rather than isolated judgements of specific artworks. If findings are to hold for humans in general, aesthetic behaviours as expressed by a wide circle of people, beyond accomplished artists and educated viewers, will gain importance for reasons of methodological validity and repeatability.

Interestingly, the views expressed by Yanagi [2011] are reminiscent of those of the philosopher Arthur Schopenhauer with regard to aesthetics. Yanagi states that the production of aesthetic objects involves discovering and capturing the unchanging, essential core of a subsection of the world: "A pattern is a picture of the essence of an object, an object's very life; its beauty is of that life" [Yanagi, 2011, p. 114]. Schopenhauer
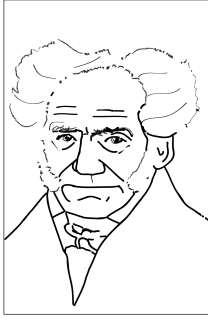
Figure 1.3: Arthur Schopenhauer (1788-1860) recognised the potential for beauty in all objects, given the right circumstances and viewing mode.

[2009] expresses a similar sentiment in *"Die Welt als Wille und Vorstellung"* (The World as Will and Representation), originally published in 1819: "Sie [die Kunst] wiederholt die durch reine Kontemplation aufgefaßten Ideen, das Wesentliche und Bleibende aller Erscheinungen der Welt (...)" ("It [art] repeats those ideas gathered through pure contemplation, and that which is essential and unchanging in all phenomena of the world (...)" [Schopenhauer, 2009, p.173]). Both describe art as a way to capture an unchanging essence of transient objects and phenomena in the real world. Beauty in Schopenhauer's model is a product of this capturing process, and can in principle be elicited by *any* object that a person encounters, given the right perceptual context and, unlike Kant's framework, independently of the maker's intentions and circumstances:

> "Da nun einerseits jedes vorhandene Ding rein objektiv und ausser Relation betrachtet werden kann; da ferner auch andrerseits in jedem Ding der Wille, auf irgend einer Stufe seiner Objektität, erscheint und dasselbe sonach Ausdruck einer Idee ist; so ist auch jedes Ding *schön* [Schopenhauer, 2009, p.194].

> *Since on the one hand every existing thing can be viewed purely objectively and without relation [to other things] and since on the other hand the will appears in each thing, at some level of its "Objektität" [manifestation of the will], and hence is an expression of an idea; therefore every thing is* beautiful.[my translation]

Similarly, the importance of a viewer's active engagement is also recognised by Yanagi, who posits that natural objects acquire a dimension of beauty by virtue of being observed and reproduced by an agent with the capacity for aesthetic sensation. He gives the example of a symmetrical pattern based on a bamboo plant:

> Where lies the essential difference between the plant and the pattern? The plant is a product of nature. The pattern is this plus a human viewpoint. The original plant is still "raw", nothing more than the given material. The viewpoint is what gives it content. (...) Beauty only emerges in the plant with the addition of a viewpoint that sees it as beautiful. Bamboo grass pattern is, in a sense, bamboo grass provided with order by a viewpoint [Yanagi, 2011, p.113].

Both Yanagi and Schopenhauer emphasise the unchanging essential core of an object, and the beauty that is bestowed on it by the cognitive processes at work in the human mind during production and perception alike, rather than being inherent in the object itself. Beauty thus can be found in a wide variety of things, and at the same time is highly personal, depending on a perceiver's viewpoint, or in Yanagi's terms, "makes an artist of the viewer" [Yanagi, 2011, p.124]. Both the productive and the perceptual side of aesthetics in this view are thus active, creative processes.

So far, I have laid out two seemingly unreconcilable positions on aesthetics: first, that art is distinct from craft and hence requires a special type of cognitive processing centering on judgement (Kant) and that it evolved from but is more advanced than craft (Loos). This remains the premise today for much current research on art perception. The assumption of a special status of "high art" and its judgement has, as we have seen, influenced methods in neuroaesthetics quite strongly. The second position maintains that art and craft are essentially the same (Secession) and that craft, because it is made and used by more people than "high" art, is actually more characteristic and revealing of the human aesthetic sense (Yanagi).

Neither of these philosophical positions can easily be disproven through empirical methods: the distinction between art and crafts that these positions are based on are artificial, and hence there is no objective way of distinguishing an object that was created as an artwork from one that was created as craft. Furthermore, given their different premises, these viewpoints may not be mutually exclusive: it could be true that a distinct mode of processing is applied when appreciating certain kinds of art, but that does not detract from the point that it may not be the mode that is usually used by most people.

A third, more practically useful approach, remains agnostic concerning the putative distinction between arts and crafts, but instead attempts to map out a way to study aesthetics empirically.

1.2 Studying aesthetics empirically

Gustav Fechner [1865, 1871, 1876] (Fig. 1.4) was the first scientist to attempt to study aesthetics empirically. He advocated a multipronged approach, including research on the production process (*Methode der Herstellung*, method of production), as well as preferences (*Methode der Wahl*, method of choice), and also analysing the properties of real-life objects (*Methode der Verwendung*, method of use) when studying aesthetics [Fechner, 1871, p.48]. Fechner was a highly influential figure in empirical aesthetics; in particular his notion of using simple stimuli rather than artworks to study a phenomenon as complex as aesthetics in a controlled laboratory environment (he called this approach "aesthetics from below", [Fechner, 1876]), is still used today, for example [McManus, 1980]. The method of production, in particular in conjunction with patterns is rarely employed in aesthetics research; some experiments were conducted in the 1950s-1970s on pattern memory and production which had a focus on information theory, rather than aesthetics *per se* [Attneave, 1955; Dörner and Vehrs, 1975; Szilagyi and Baird, 1977]. Furthermore, Fechner's proposal of studying a phenomenon by combining multiple
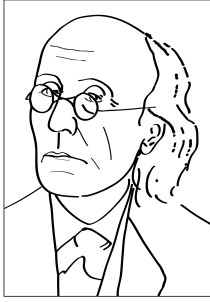
Figure 1.4: Gustav Fechner (1801-1887) was the founding father of empirical aesthetics. He advocated the use of multiple complementary research methods and introduced the distinction between direct and associative factors.

methods has not been widely adopted (though there are some exceptions, e.g. [McManus et al., 2011]).

It may seem curious to seek regularities and predictable outcomes in aesthetics, since received wisdom is that art relies on taste and individual creativity, and *"de gustibus non est disputandum"*("There's no point in arguing about matters of taste."). For Fechner, the way out of this quandary was to separate the general aesthetic appeal of an artwork into those elements that are objectively present in the object (such as the symmetry or width/height ratio of a cross), as distinct from those that arise through associations that a participant may have, and which thus may vary considerably between individuals (e.g. the cultural knowledge that a cross symbolises Christianity). He calls the former components "direct factors" and the latter "associative factors". In Kant's paradigm, associative factors are the primary criteria in arriving at a judgement during aesthetic appreciation of beautiful art.

Regarding direct factors, Fechner argues that the regularities in human perception and production in aesthetics can be studied better in non-representational patterns than in "high" art, since much of the appeal of abstract patterns relies not on associative, but on direct factors:

> Kann man hiernach dem Faktor directer Wohlgefälligkeit selbst in den höhern Künsten der Sichtbarkeit seine wichtige Bedeutung nicht absprechen, so wächst doch dieselbe, wenn wir von Plastik und Malerei zur Architektur und von dieser zur Kunstindustrie oder den sog. technischen Künsten und der Ornamentik herabgehen; indem nach Massgabe dieses Herabgehens einerseits der assoziative Faktor selbst an Bedeutung im Verhältniss zum directen verliert, andererseits Conflikte des directen mit dem assoziativen minder leicht eintreten. Namentlich gewinnt in diesen Kunstgebieten die anschaulich verknüpfte Mannichfaltigkeit eine erhöhte Wichtigkeit, wohin die Symmetrie, der goldne Schnitt, das regelmäßige Muster, die Wellenlinie, die Volute, der Mäander u.s.w. gehören, was Alles in den höhern Künsten der Sichtbarkeit leichter fehlen kann, und aus angegebenen Gründen meist fehlen muss, weil man darin für die anschauliche Verknüpfung die associative durch die Idee hat [Fechner, 1876, p.183].

> *While one cannot deny that the factor of direct pleasingness has a fundamental importance in the higher visual arts, the importance grows when we move*

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down from sculpture and painting to architecture, and from there to crafts or to the so called technical arts and ornament. For one, as we go down, the importance of the associative factor also declines compared to the direct [factor] and furthermore, conflicts between direct and associative [factors] occur less easily. In particular, the clear connection of diverse elements gains importance, which is shared with symmetry, the golden section, regular patterns, the sinuous line, the volute, the meander etc, and which can be absent more easily in the higher visual arts, and for the aforementioned reasons often must be absent, because one has the [artistic] idea as the associative [factor] to establish the clear connections.[my translation]

In sum, Fechner suggests that ornaments are the clearest manifestations of direct organisational principles that humans generally utilise when creating visual aesthetic artefacts. With abstract geometrical patterns, we are in an unusual and fortunate situation that the principles underlying their perception can be studied with minimal interference by associations and semantic meaning. This would be akin to studying purely syntactic structures in language that naturally occur with no semantics, something linguists can only dream of.

The art historian Ernst Gombrich makes a similar distinction between visual semantics and perceptual concerning the value of studying non-representational art in 1979:

> I would therefore propose to distinguish between our perception of meaning and our perception of order. It appears that these basic categories play their part throughout the range of the visual arts. Needless to say the perception of meaning can never be switched off, but for the understanding of decoration we have initially to concern ourselves with the perception of order [Gombrich, 1984, p.2].

With myriad examples from around the world, Gombrich demonstrates that ordering principles are present in everyday ornamental objects and patterns, and suggests that they are worth studying from a psychological angle for this reason. Gombrich goes so far as to say the urge to surround ourselves with ordered ornament and patterns stems from a very basic human "sense of order", akin to other senses such as vision or audition. Gombrich postulates that the sense of order is active both during perception and production:

> The pleasure we experience in creating complex orders and the exploration of such orders (whatever their origin) must be two sides of the same coin [Gombrich, 1984, p.12].

In an interesting parallel line of reasoning, Rupert Riedl, a biologist, also notes that humans have a strong tendency to detect order and suggests that not only does the human mind impose order on its perceptions of the world, but the world must have imposed order on the mind over evolutionary time [Riedl, 1975, p. 331]. Hence, the human sense of order, according to Riedl, would be a natural product of evolutionary constraints imposed on our species.
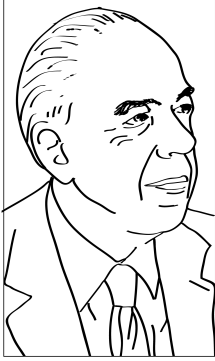
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Figure 1.5: Ernst Gombrich (1909-2001) suggested that humans have a strong "sense of order" that is the driving force behind the creation and appreciation of ornaments and decorations in cultures around the world.

Along parallel lines to Fechner's aesthetics from below, Gestalt psychology, which also arose at the end of the nineteenth century, attempted to determine the organising principles underlying general visual perception, such as figure/ground separation, grouping by proximity similarity and so forth [Mach, 1922; Koffka, 1935; Rubin, 1921]. The Gestalt enterprise is still ongoing today [Gepshtein and Kubovy, 2005; Quinn and Bhatt, 2005; Claessens and Wagemans, 2005; Nucci and Wagemans, 2007; Kubovy and van den Berg, 2008]. However, aesthetics has never been a focal point of this research field, although it might make valuable contributions to our understanding and definition of direct factors. Nonetheless, there is a certain similarity in Fechner's approach and the Gestalt approach in that simple mechanisms and rules are stipulated to account for broad regularities in complex phenomena such as natural visual scenes, in the case of Gestalt psychology, or aesthetic appreciation, in Fechner's approach.

Of course, uncovering organising principles and direct factors in aesthetic appreciation will never be the whole story in aesthetics. Understanding the combinatorial principles underlying patterns, and why we like them and produce them, is not enough to understand art. Part of the magic of art is precisely the associative, and unpredictable nature of aesthetic appreciation. Nonetheless, it may well be that such associative, cultural factors have been overemphasised in the past, and without a thorough understanding of the nature and extent of direct organising principles, a complete picture of aesthetics cannot be constructed. The aim of this thesis is to take some steps in exploring aesthetics from an empirical perspective using visual stimuli that maximise the contribution of direct, rather than associative factors.

1.3   Outline of the thesis

In chapter 2, a book chapter currently in review for publication, I give a broad overview of the historical and theoretical background issues driving my research. It is intended as more extensive introduction to the thesis topics and to the empirical work reported in subsequent chapters. The empirical component of the thesis comprises three peer-reviewed journal articles (chapters 3 and 4, published, and chapter 5, in press). In chapter 3, several perception and production experiments are presented that contain

data from individuals with Autism Spectrum Disorder (ASD), children, and pigeons, as well as normal adults. Chapter 4 reports findings on production and choice data, including cross-cultural comparisons. In chapter 5, a spatial analysis of real-life patterns in craft objects (quilts) is presented.

Methodologically, my approach is to focus on abstract geometrical patterns, studied with a complete Fechnerian toolkit, using each of his proposed three methods (production, choice and use) and additionally implementing a fourth method of my own ('parsing'). I focus on the role that the structural properties of patterns play in both productive and perceptual processes in aesthetics. Associative factors, although fascinating in their own right, will not be addressed here.

1.3.1 Method of production

The main question to be addressed when employing the method of production concerns the properties and regularities of patterns produced by adult humans, in the present case with no art or art history training (chapters 3 and 4). The stimuli consist of patterns displayed on a computer screen, which consist of simple square patterned elements ('tiles') in square matrices. Participants can change the orientation of individual tiles, with a mouse click rotating a tile successively by 90°. Hence, not the location of elements, but only the orientation of the tiles within the matrix gives rise to various two-dimensional patterns. The aim will be to analyse the structural properties of the patterns produced by humans with little to no formal art education. Three extreme results are possible, namely that a) individuals always produce the same rigid and fully predictable orders, or that b) the patterns produced by individuals differ greatly, with no discernible consistency, or c) that the products are random, which would not allow generalisations at all, neither within nor across individuals. If however the results show that there are general patterns across individuals, with enough variation in them to suggest some level of creativity rather than randomness or rote rule application, then this would lend credence to Fechner's idea that despite their relative simplicity, geometrical patterns are a good way of studying creativity and aesthetics in the lab in a well defined and constrained environment. Furthermore, because ordered rectangular patterns are used extensively in many societies (e.g. quilts, tiles), there is a real-world relevance of the production process and resulting patterns to aesthetics.

1.3.2 Method of choice

The attractiveness and orderliness of geometrical patterns can be readily assessed, even by people with no art background. Because such patterns are not typically identified as art, even laypeople have little hesitancy in expressing their opinion, with no fear of seeming uneducated or unsophisticated. Additionally, geometric patterns are simple enough and constrained enough to be produced by the average person. This means it is possible to study production and preferences in the same person with roughly equal levels of proficiency. In contrast, attempting this in representational art would be more difficult: the artistic talent of normal participants is variable. To avoid this, the participant

pool would need to be restricted to artists, designers, etcetera, who are both proficient in producing representational art as well as indicating their preferences. As a proxy for judgement, a two-choice method will be implemented here, which entails choosing the more favourable of two alternatives (chapter 4). By conducting full comparisons between pattern variants, the main goal will be to investigate participants' preferences for various pattern variants as a proxy for aesthetic evaluation. Preference rankings for each participant will be generated from a participant's decisions, which will allow an analysis of the consistency of choices within participants, and also comparisons between participants. Furthermore, the similarity of patterns produced and patterns chosen will be investigated. The more traditional Likert scale will also be used as a simpler way to measure preferences applicable to one image at a time.

1.3.3 Method of use

Fechner's method of use will be implemented by analysing the spatial properties of actual patterns used in traditional styles of patchwork. Real-life patterns are a crucial part of studying the aesthetic phenomenon of pattern-based ornament because their analysis allows us to link effects found in artificial laboratory situations with naturally occurring behaviours. Geometrical patterns that are used for decorative and ornamental purposes, regardless of cultural origin, can typically be described with a symmetry system using only four basic operations: reflect, rotate, glide and translate, which leads to seven possible production rules in one dimension (so-called frieze patterns), and seventeen basic rules in two dimensions (plane patterns or wallpaper patterns) [Washburn and Crowe, 1988; Grünbaum and Shephard, 1987]. Regular decorative patterns from around the world and throughout history can be classified with this system. This makes the comparison of pattern structures across cultures and history far easier than syntactic descriptions of music and language: because of the huge variation in musical and linguistic structures, their syntactic descriptions are extremely complex and varied and no definitive general descriptive method or "metagrammar" has been agreed on to date.

In chapter 5, I compare the spatial properties of so-called 'crazy quilts' to quilts with traditional patchwork patterns. Crazy quilts are quilts which contain carefully executed patchwork that rather unusually does not follow any obvious geometrical regularity and cannot be classified according to the conventional symmetry system just described. Such quilts enjoyed a brief heyday in the Victorian age, and provide a rare potential example of a random style of ornamental object.

With the goal of gaining a better understanding of these patterns, a detailed spatial analysis of several exemplars of crazy quilts will presented, contrasting crazy quilts with quilts containing patterns that are highly symmetrical. More precisely, the aim will be to determine whether the apparent randomness of crazy quilt patterns is indeed supported by statistical models usually used to describe truly random phenomena.

1.3.4 Parsing and deviant detection

In addition to Fechner's three methods, I will use a fourth approach based on perception without choice ('parsing'), presented in chapter 3. This method entails testing whether a participant can extract regularities from visual input without instruction and is assessed by the speed and accuracy with which they can detect items that deviate from this regular pattern. This method is reminiscent of the artificial grammar learning (AGL) paradigm which has been used to show that humans are sensitive to statistical regularities in auditory and visual input, spontaneously deriving rules that allow the parsing of novel strings in generalisation tests [Reber, 1967]. Stimuli used in AGL studies are typically one dimensional, and unfold over time in the case of auditory studies. Parsing also goes beyond well-known visual search tasks in the tradition of Treisman and Gelade [1980], which require the detection of an "odd one out" based on a single feature or a conjunction of features in elements within an array. In order to detect structural deviations (which is characterised by a deviation of the orientation of a pattern element from the general production rule) in any but the simplest patterns, it is not enough to detect elements that differ by a single feature or combination of features, for example symmetry deviation within a figure. Such local features may rely on relatively simple detection mechanisms based on spatial harmonics (see for example Osorio [1996]). In contrast, a relational deviation can only be detected because an element's properties are not correct in relation to its neighbours, which necessitates a sensitivity to multiple long distance, rather than local, dependencies (an example of a real tiling with a structural deviant is given in figure 1.6).

In my experiment, participants do not have to be able to describe or point out a deviation, but merely have to decide whether or not a deviation is present in the stimulus. The parsing task entails being able to distinguish differences between elements in their orientation which is based on a rule from those differences in orientation that do not conform to a rule, regardless of the local internal properties of individual elements. The elements themselves may have further internal regularities (note for example the symmetrical nature of the tiles that constitute the pattern in Fig. 1.6). The advantage of the parsing approach (though it does not directly test for aesthetic sensitivities) is that it helps to account for low level processing difficulty of inter-item relationships that may propagate up to production and preference differences for patterns of varying complexity. Hence, a dispreference against a pattern could be at least in part accounted for by parsing difficulty, for example if the underlying rule is not obvious or easy to derive. Furthermore, this approach is one in which cross-species comparisons can be conducted relatively straightforwardly, in contrast to Fechner's three suggested methods.

In relation to more complex artworks, these patterns are situated at a relatively simple level of appreciation, yet they already represent a higher level of structural complexity, the processing of which requires a sensitivity to longer distance spatial relations and low, rather than high, spatial frequencies. While much research has been conducted on features within items that can be detected by animals, the question whether animals can extract rule-based regularity from patterns with low spatial frequencies that require sensitivity to interelement relationships is a relatively new one. However, there
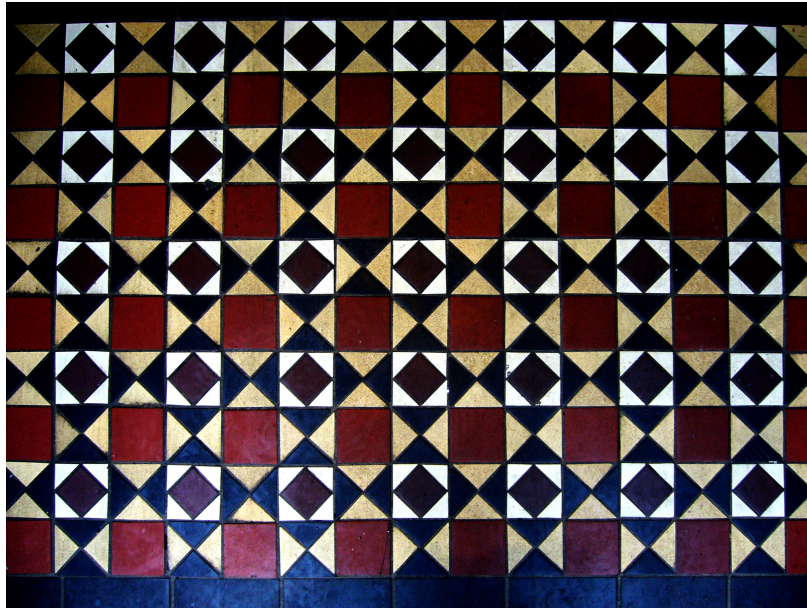
Figure 1.6: A real-life illustration of the parsing task. In this floor tiling, one black and white tile has an incorrect orientation for its position in the pattern. Detecting the deviation requires sensitivity to the rule governed repetition of tiles in the array. ANSWER: The black and white tile in question is third from the top, fourth from the left. Photo: Gesche Westphal-Fitch

is a growing body of literature on rule learning in animals in AGL paradigms [Fitch and Hauser, 2004; Gentner et al., 2006; Stobbe et al., 2012], which require animals to establish structural rules between elements in a sound stream [Fitch and Hauser, 2004; Gentner et al., 2006], or in visual one-dimensional arrays [Stobbe et al., 2012] suggesting that while aesthetic preferences or production are extremely difficult to test with animals, their ability to detect the statistical regularity of elements in two dimensional patterns (as in the parsing approach presented here), should, in principle, be feasible. The parsing approach will be put to test with pigeons and results are reported in chapter 3.

2 | Towards a comparative approach to empirical aesthetics

Towards a comparative approach to empirical aesthetics

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Abstract

Because aesthetic traditions are a pan-human phenomenon, aesthetic proclivities should be studied across human cultures if we are to describe the shared building blocks of human aesthetic experience. Furthermore, comparisons with animals are crucial to determine which elements of our aesthetic experience are shared with other species and which evolved uniquely in humans.

We argue that abstract geometric patterns have a special status in the evolution of human visual art, predating representational art considerably and being less complicated by issues of iconic or symbolic meaning. We review the literature concerning abstract visual patterns and discuss possible mechanisms by which abstract patterns emerged as aesthetic phenomena.

We then review the literature on aesthetic-like phenomena in animals, in particular nest-building and symmetry perception. We argue that both the perceptual abilities and the ecology and socio-biology of a species are crucial in the evolution of behaviours that have the potential for gaining aesthetic dimensions.

The human aesthetic capacity is argued to be a cognitive complex with interesting parallels to music and language. The generative process underlying geometric patterns may be described with the same formalisms as musical and linguistic syntax, raising the intriguing possibility that the production of visual patterns depends on cognitive resources that also underlie the generation of complex hierarchical structures in music and language.

1 Introduction

Aesthetic traditions are ubiquitous in human societies and seem to be a human cultural universal, akin to language and music. Empirical aesthetics is emerging as an area of cognitive research on a par with musicology and linguistics in its potential to reveal fundamental properties of the human mind. Empirical aesthetics as we understand it focusses on the processes underlying the interaction of one or more individuals with an aesthetic stimulus (often visual), during both perception and production of the object. An important aim of this research should be to describe and understand the worldwide human drive to create and surround ourselves with objects that are pleasing to one or more of the senses, in a way that goes beyond their immediate utilitarian function.

There is a rich potential for comparative work in aesthetics. First, differentiating cultural specific features from universally shared elements necessitates studying aesthetic traditions in a wide range of human cultures. This is analogous to searching for and defining universal features present in all languages (e.g. different word classes such as verbs and nouns), versus language specific features, such as the Chinese tone system.

In addition to cross-cultural comparisons, comparisons across species are required to distinguish those components of the aesthetic process that are uniquely human from those shared with other species and to discover possible examples of convergent evolution.

In this chapter, we consider some common features of human aesthetic traditions with a particular emphasis on early artefacts incorporating non-representational patterns, and discuss their possible evolutionary origins. Non-representational patterns and ornaments are present in most, if not all, human cultures. However, they are not a typical research focus in empirical aesthetics, where the main focus has been on Western "high art". From a cross-cultural view, however, it makes sense to study abstract ornamental patterns due to their ubiquity and relative simplicity, (cf. Westphal-Fitch, Huber, Gómez & Fitch 2012, Westphal-Fitch, Oh & Fitch 2013). We therefore emphasize the importance of geometrical and non-representational patterns here.

Biologically, it seems likely that many low-level perceptual components of the aesthetic process are shared with other species, while certain aspects (e.g. production of repeated hierarchically organised patterns) may well be unique to our species. Such features may also be present in other human domains such as music or language, with important implications for our understanding of the nature of the human mind. In this chapter, we review literature on symmetry perception and on nest-building in birds, bees and primates, two areas where we think known similarities and differences between humans and animals concerning aesthetics can be usefully pursued. It is vital to study not only chimpanzees and other primates (Zaidel, Nadal, Flexas & Munar 2013), but also species that may have evolved traits convergently, e.g. birds. In particular, we highlight the need to take the ecology and socio-biology of a species into account to understand the mechanisms by which pre-existing traits can become exaggerated and gain social importance beyond their immediate function.

2   Pervasive issues in aesthetic inquiry

We begin with a short discussion of the historical development of aesthetics, observing that the sharp distinction between ornament and "high art" is a relatively new phenomenon idiosyncratic to Western European cultures. We also consider a tension at the heart of all aesthetic inquiry, namely that between the broad pan-human universality of aesthetic activity and the wide variety of superficial fashions and traditions that may change rapidly in individual cultures and time periods.

2.1   Natural and acquired aesthetics: Beyond Kant

Aesthetics began as a purely philosophical discipline. With the advent of Gustav Fechner's writings introducing an empirical approach to aesthetics (Fechner 1871, Fechner 1876) scientists began to gather data on aesthetic behaviours. This makes empirical aesthetics one of the oldest branches of psychology, dating back to the 1870s.

Our modern Western conception of the fine arts as "high art" phenomena, distinct from ornament and craft, is a relatively new one which emerged in 18th century Europe (Kristeller 1990, Shiner 2001). Prior to that, and hence for the vast majority of human history, no strict distinction was made

between art and craft, and in many cultures this distinction does not exist (Anderson 1979). The concept of "aesthetics" as a distinctive kind of appreciation specific to art (as opposed to "good taste" that might apply to any number of things) arose at roughly the same time in Europe.

The word "aesthetics" derives from the Greek "aisthetiko", meaning sentient or sensory (cf. the medical term "anaesthetic"). Aesthetics was first used as a term to describe appreciation of beauty in 1750 by Alexander Baumgarten (Gregor 1983, Shiner 2001). Baumgarten proposed aesthetics as a second cognitive mode that relies on the senses (*cognitio sensitiva*), in addition to rational thought. In his model, rational thought is independent of sensory input, but *cognitio sensitiva* relies mainly on input through the senses. Additionally, Baumgartner differentiates between the natural and artificial (acquired) aesthetic sense. While humans are born with a natural aesthetic sense (Baumgarten calls it a natural disposition of the soul for beautiful thought: *dispositio naturalis animi ad pulcre cogitandum* (Groß 2001, p.97), enculturation leads to a refinement of this sense. We interpret this natural aesthetic sense that Baumgarten describes as the aesthetic sense that is shared between all humans, regardless of cultural surroundings, while traits specific to a culture are acquired in a later enculturation process (or refinement, in Baumgarten's terms) during ontogeny.

Beauty for Baumgarten is a cognitive phenomenon in an aesthetically minded perceiver – beauty is perfect perception, and *not* a property of the object being viewed (Groß 2001). This is reminiscent of David Hume's famous statement (Hume 1757): "Beauty is no quality in things themselves: It exists merely in the mind that contemplates them; and each mind perceives a different beauty."

Baumgarten's original concept of aesthetics crucially attributes the capacity for aesthetic perception to all humans, with the proviso that enculturation can refine this ubiquitous natural aesthetic sense. This contrasts sharply with the very influential concept of aesthetics proposed by Immanuel Kant, presented in *Kritik der Urtheilskraft* (Critique of Judgement)(Kant 1872). The key concept for Kant is "disinterested contemplation". Kant posits that a perceiver needs to lack all interest in the object (for example, the desire to possess it) for a pure aesthetic judgement of the object to be possible (Kant 1872, p.50):

> "[...] so sagt Jedermann: Hunger ist der beste Koch, und Leuten
> von gesundem Appetit schmeckt Alles, was nur essbar ist; mithin

beweist ein solches Wohlgefallen keine Wahl nach Geschmack. Nur wenn das Bedürfnis befriedigt ist, kann man unterscheiden, wer unter Vielen Geschmack habe oder nicht [. . .] Geschmack ist das Beurtheilungsvermögen eines Gegenstandes oder einer Vorstellungsart durch ein Wohlgefallen oder Missfallen ohne alles Interesse. Der Gegenstand eines solchen Wohlgefallens heisst schön."

our translation: ... *people say that hunger is the best cook, and people with a healthy appetite enjoy everything that is edible. Such pleasure does not evidence a choice based on taste. Only when the needs are satisfied can one discern who amongst the many has taste or not. [. . .] Taste is the ability to judge an object or a performance with pleasure or displeasure without any interest. The object of such a pleasure is called 'beautiful'.*

Kant's view takes a highly restrictive position on aesthetic judgement, differentiating between "pure" (what we today might call "objective") and "unpure" judgements, effectively excluding most perceivers. It is also elitist: if such a pure and disinterested judgement is only available to the few people on this planet whose needs are met entirely, then aesthetic judgement is not available to the majority of humans. For an empirical approach to aesthetics seeking broad commonalities between humans, Kant's view implies an overly restricted working model, and Baumgarten's previous, more inclusive approach is preferable.

A later movement, influenced by the reports of explorers and adventurers describing the art practices of other cultures from around the world, explicitly argued that the aesthetic capacity is fully shared by all humans, as stated by Franz Boas: "In one way or another esthetic pleasure is felt by all members of mankind. No matter how diverse the ideals of beauty may be, the general character of the enjoyment of beauty is of the same order everywhere (. . .). The very existence of song, dance, painting and sculpture among all the tribes known to us is proof of the craving to produce things that are felt as satisfying through their form, and of the capability of man to enjoy them.' (Boas 1955, p.9). Indeed, the pervasiveness of ornamental objects and patterns and their similarities in symmetry, repetition and structure gave rise to the notion that common, describable elements might underlie ornament and that ornament could usefully be described in "grammars", e.g. (Jones 1856). This approach has been greatly expanded in more recent work by Washburn & Crowe (1988).

2.2 The multiple purposes of art

Alois Riegl, a Viennese professor of art history, in his posthumously published *Historische Grammatik der bildenden Künste* (Historical grammar of the visual arts) (Riegl 1966) emphasised that humans naturally possess a *Kunstschaffenstrieb* (a drive to create art) (Riegl 1966, p.217). Riegl differentiates between three purposes ("Zweck") characterizing all human artefacts: 1. *Schmückungszweck* (decoration), 2. *Gebrauchszweck* (use), 3. *Vorstellungszweck* (imaginative purpose) (Riegl 1966, p.217). There may be mainly functional creations with little artistic content, for example an arrowhead, and almost purely artistic creations with no actual functional purpose other than decoration and/or representation. The intertwining of function and aesthetics in tools is particularly interesting. Some quite early hominid tools, so-called bifacial tools (or hand axes), first produced about 1.4 million years ago (Mithen 1996), have a high degree of bilateral symmetry, which would have required a considerable planning and careful execution. The largest specimens weigh well over a kilogramme and are 30 cm long (Wenban-Smith 2004), and it is not clear that they could have functioned usefully as tools. Both the size and symmetry of these Achulean hand axes have spurred discussion about aesthetic or social functions (Kohn & Mithen 1999, Mithen 2003, Nowell & Chang 2009) and the concomitant cognitive abilities required to create them (Mithen 1996) early on in human cultural development.

2.3 Fechner and non-representational art

Fechner (1876) distinguished between direct and associative factors in aesthetics. Associative factors correspond roughly to Riegl's *Vorstellungszweck*, i.e. the ideas and associations that an object triggers in the perceiver's mind. Direct factors are more closely tied to properties inherent in the object, such as symmetry, color and other formal or material properties. Associative factors can potentially intensify or counteract the effect of the direct factors. Therefore, Fechner suggested that in order to identify aesthetic principles, non-representational ornament may be more useful than representational art, because the associative factors in the objects portrayed in representational art can occlude or override the more subtle organising principles. This is not the case in ornament, where formal organising principles take center stage. The associations that a portrayed object triggers are very specific to a certain place and time, and thus hinder a comprehensive historical and cross-cultural

study of aesthetics. Furthermore, direct factors are likely to be the only ones that can be meaningfully studied across species.

Concerning data collection, Fechner proposed three different methods for empirical inquiry in aesthetics: *Wahl* (Choice), *Herstellung* (Production) and *Verwendung* (Usage in the real world). The underlying assumption is again that aesthetic proclivities can be active in multiple modalities, and thus can potentially be broken down into component parts, some of which are shared across all cultures and potentially across species (though to our knowledge Fechner does not discuss the latter possibility). Fechner's three-way approach takes into account that aesthetics is not a simple stimulus/response activity captured by a sender/receiver model. Inevitably, the producer(s) of an artwork/aesthetic object also engage their perceptual proclivities during production. Very often, the finished product differs from what was originally envisioned, presumably due to the effects of feedback from perception influencing production, leading to unexpected results and "happy accidents".

Biological approaches to aesthetics have only recently been proposed and empirical data from animals is rarely included. Eibl-Eibesfeldt (1988), writing about the biological underpinnings of aesthetics, distinguishes between three layers of perceptual biases that we might find: those that are shared with other species, specifically other vertebrates (level 1), those that are unique to the human species but shared across humans (level 2) and those that are unique to a certain human culture (level 3). These are important distinctions worth keeping in mind when developing a comparative approach in aesthetics and can, in our opinion, be usefully extended to production biases as well. We hypothesise that Fechner's associative factors are located at level 3, while direct factors are situated at level 2. If true, this alignment again underscores the relevance of non-representational abstract art to cross-cultural and cross-species inquiry.

The contents of level 1 (aesthetic proclivities shared with other species), remain little studied and poorly understood. However, an increasing body of research on birds, insects and primates (reviewed below), allows us to form tentative hypotheses about what may be shared among animals.

3 Some implications of non-representational human artefacts

Some of the oldest human aesthetic artefacts known are patterned markings on ochre dating back about 70,000 years (Henshilwood, d'Errico, Yates et al. 2002, Kuhn & Stiner 2007). Contemporaneous perforated marine shells seem to have been collected and worn specifically for their visual appeal (Henshilwood, d'Errico, Vanhaeren, van Niekerk & Jacobs 2004, Vanhaeren, d'Errico, Stringer, James, Todd & Mienis 2006, Bouzouggar, Barton, Vanhaeren et al. 2007). Both predate paleolithic representations of humans or animals by roughly 30,000 years (Hodgson 2006, Verpooten & Nelissen 2010). This is surprising, because geometric patterns are far rarer than animate beings in the natural world, and animals and fellow humans would have had a high relevance for early human artists. The fact that abstract patterns and ornaments can be found across cultures, including those that have not developed representational art, further supports the idea that decorative abstraction is a basic and direct outlet for the human aesthetic drive, with no general need for representation.

Ochre has been used by humans for at least 100,000 years: quite sophisticated ochre-processing tools from that time have been found at Blombos cave, South Africa, including an abalone shell containing a well-fitting grindstone (Henshilwood, d'Errico, van Niekerk et al. 2011). This "toolkit" contained a residue of the mixture used, consisting of ochre, bone and marrow, charcoal and other minerals, indicating that these humans were experienced in producing pigments. Ochre can be used for body painting (and still is in many cultures), but also for tanning, hafting, etc., so its presence alone does not demonstrate aesthetic activities.

Gastropod shells were used very early on as body decorations, some of the oldest examples known date back 70,000-82,000 years (Henshilwood et al. 2004, Vanhaeren et al. 2006, Bouzouggar et al. 2007). Some of these oldest examples show evidence of having been covered with or come into contact with ochre (Henshilwood et al. 2004, Bouzouggar et al. 2007). Wear marks around perforations in the shell suggest that the shells were suspended from cords, like beads (Bouzouggar et al. 2007). Ornamental shells have been found in locations several kilometres from the nearest beach, and due to their small size they were unlikely to represent a food source. Unlike the shells of molluscs that were used for food, shells used as beads show abrasion

marks suggesting that they were collected after they washed up on the beach, rather than caught fresh (Kuhn, Stiner, Reese & Güleç 2001).

Around 30,000-19,500 years ago, beads began to be fashioned from teeth, bone, stones etc, with further embellishments and patterns engraved into the surface (Dubin 1997). Beads from 38,000-10,000 years ago have been found in Australia, Africa, Russia, India, China and Europe. Even today, beads are popular as jewellery, continuing one of the oldest aesthetic traditions of humankind.

Darwin (1874) discussed body ornament as the most basic form of art in "The Descent of Man", and interprets it mainly as a means to enhance physical features and to increase physical beauty. (Darwin 1874, p.577) noted the universality of ornament, suggesting that it is due to a shared cognitive architecture:

> "Lastly, it is a remarkable fact (. . .) that the same fashions (. . .) now prevail, and have long prevailed, in the most distant quarters of the world. It is extremely improbable that these practices, followed by so many nations, should be due to tradition from any common source. They indicate the close similarity of the mind of man, to whatever race he may belong."

Ornaments are produced and appreciated by men and women alike. In contrast, most famous painters, sculptors, architects, musicians and poets in Western culture were men, which has led some to hypothesise that art production is mainly a male trait (Voland 2003). However, a male preponderance in the arts is most likely due to socio-historical factors specific to Western cultures, where the aesthetic objects produced by women occupied the less valued domestic and craft domains. Everyday objects that may be subject to aesthetic modification such as weaving, carving, sewing are produced by both sexes (Shiner 2001), though the allocation may vary from culture to culture.

Decorating the body with beads, tattoos, scars and paint is extremely common (Gröning 1997, Dubin 1997) and is found in men and women alike, as well as in children. Interestingly, symmetrical paintings on the face increase the perceived attractiveness of faces (Cárdenas & Harris 2006). Swaddle & Cuthill (1995) have shown that artificial manipulations of photographs of individual faces to make them symmetrical actually decreases their attractiveness. However, symmetry is preferred in faces created from many averaged faces (Perrett, Burt, Penton-Voak, Lee, Rowland & Edwards 1999). It may
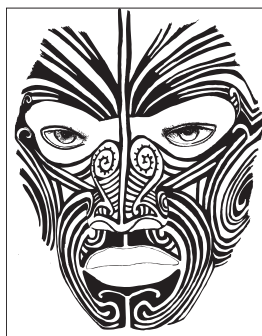
Figure 1: An example of the intricate and highly symmetrical facial tattoos typical of Maori tradition in New Zealand.

be the case that symmetrical face markings are a means to make a perceiver focus on a general global symmetry (akin to averaging facial properties as in (Perrett et al. 1999)), while drawing away the attention from characteristics that define an individual face, and individual facial asymmetries. Cárdenas & Harris (2007) found that women do not rate symmetry of the face or face decorations more highly during the fertile phase of their cycle, suggesting that at least symmetrical ornamentation of the face does not act as a straightforward cue allowing females to assess mate quality or good genes. In addition to looking attractive, body decoration probably always has been a social activity (it's difficult to tattoo or scar yourself, particularly when symmetry and regularity is the goal, see for example figure 1), thus weakening the obvious parallel between body ornament and animal courtship displays. Ornaments may thus serve a group cohesion function, see figure 2, or as a means to rapidly broadcast diverse social information to a large number of people beyond immediate associates (Kuhn & Stiner 2007).

Verpooten & Nelissen (2010) have proposed sensory exploitation in combination with social learning as a mechanism by which representational art evolved in humans. Sensory exploitation is a mechanism on the part of the sender of a signal, manipulating the signal to heighten its salience to the receiver due to pre-existing perceptual biases (Ryan 1998). Verpooten and Nelissen argue that the early rise of non-representational art and geometric patterns can be explained by stimulation of lower (e.g. primary visual cortex) visual areas. It required social learning and rituals, in addition to
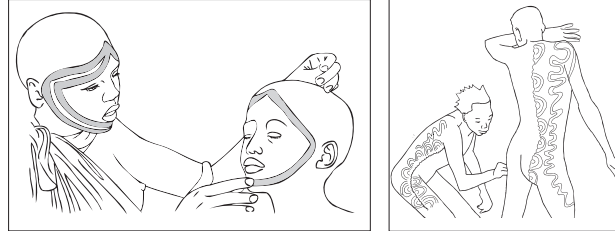
Figure 2: Body ornament is often by necessity applied in a social setting, e.g. between mothers and offspring (left) or same sex dyads, suggesting that aesthetics has a strong social core.

an emerging mental bias for iconic images (e.g. readiness to detect faces or figures in inanimate matter), for iconic art to emerge in human society. They thus attempt to map the cultural evolution of artistic tradition onto neural processing in the visual system, with abstract patterns being both earlier in history and lower in the hierarchy.

Though intriguing, we find this argument unconvincing. Not only has it been shown that symmetry perception does not primarily activate early visual cortex (Sasaki, Vanduffel, Knutsen, Tyler & Tootell 2005), but as already observed, abstract art is often a social art form. The postulated 'basic' manifestations of aesthetic behaviours may be more sophisticated than previously thought, and already involve higher level visual processing and social interactions. Research with animals, whose basic visual system closely resembles that of humans, provides one way to evaluate this hypothesis.

In another attempt to understand the origins of art, entoptic phenomena have been proposed as the trigger for early non-representational art (Lewis-Williams & Dowson 1988, Dronfield 1996). These are visual phenomena that arise not from stimulation of the retina by light, but from activity within the visual system itself, for example the flashes and geometrical patterns perceived when pressure is applied to the eyeballs, during exposure to stroboscopic flicker, or the visual aura perceived by many migraine sufferers prior to an attack. Given the similarities in the visual systems across species, this would predict that entoptic phenomena are not unique to humans (though testing this prediction is not trivial). Thus the question why only humans have developed the urge to produce abstract geometrical patterns remains

open.

Taking a broader view on the motivation to produce aesthetic objects, Deacon (2006) suggests that aesthetics may be part of a general novel cognitive style that evolved in humans, involving a modified motivational system. Such an internal reward system would make it inherently enjoyable to perceive and manipulate certain visual stimuli in a manner that may also apply to music and language. Additionally, Deacon (2006, p.30) posits that humans have a unique 'representational stance' which biases perception towards detecting a symbolic relation between an object and another referent (e.g. interpreting cloud shapes as objects). This would explain the origin of representational art.

Certainly, aesthetic experiences are rewarding, and it seems likely that the brain's reward system has a reinforcing effect on the production and perception systems underlying aesthetics. However, we suspect that the representational stance did not play an important role initially, given that geometrical patterns seem to be the oldest art forms, and lack any obvious iconic representational function (though symbolic reference may arise later, e.g. meander patterns standing for Greek culture).

While it may be impossible to fully reconstruct the pathways by which geometrical patterns arose, the fact that they are expressed so ubiquitously in contemporary humans as well as in the oldest artefacts, suggests that they are part of our core aesthetic sense, and thus make them a good departure point for considering research in other species.

4   Animal aesthetics?

At least since the 1950s, claims have been made that chimpanzees and other primates produce "artistic" paintings when provided with paper, paints and brushes. Other animals which have been claimed to paint include elephants, horses, dolphins and rhinoceros. We see these performances as having limited relevance. Animal paintings are only produced in a captive or domesticated setting, with human encouragement and provisioning of materials, suggesting that these paintings are more likely due to encouragement and rewards by humans than a natural artistic or aesthetic inclination of the animals.

Unfortunately, little solid empirical work in the lab has been done specifically on the aesthetic perception of animals. Using training and food rewards, Watanabe, Sakamoto & Wakita (1995) have shown that pigeons can discrim-

inate between Monet and Picasso paintings and generalise the distinction to new paintings by different painters in the same style. Pigeons can also be trained to distinguish between children's drawings that have been classified as good or bad by humans, and generalise to further examples of these categories (Watanabe 2010). However, there is no indication that the birds are enjoying these experiences beyond the immediate food reward they receive for successful answers or that they preferred 'good' over 'bad' paintings. Indicators of enjoyment might be longer staying times of the animal in the vicinity of art without reward and extensive visual inspection of art, or physiological measures such as lower cortisol levels or lower heart rates when exposed to art. Nonetheless, because pigeons have excellent vision, this research is valuable in showing what perceptual tasks can be accomplished on artworks without requiring aesthetic appreciation.

Perhaps more convincingly, Watanabe & Nemoto (1998) provided Java sparrows (*Padda oryzivora*) a choice between perches which either elicited playbacks of Bach and Schönberg or silence. Two of the four birds spontaneously spent more time on the perch that triggered Bach. Accepting that this may reflect some preference on the birds' part, the question of what aspect of the stimulus is preferred (loudness, tempo, pitch, range, etc.) remains open, see (Fitch 2006)).

Early evidence suggested that nonhuman primates prefer regular over irregular visual shapes. Rensch (1957) studied visual preferences in a capuchin (*Cebus apella*) and a vervet monkey (*Cercopithecus aethiops*, now *Chlorocebus aethiops*) with stimuli that either contained symmetry on one or two axes ("regular") or were asymmetrical ("irregular"), and reported a bias in both species towards the symmetrical shape. Anderson, Kuwahata, Kuroshima, Leighty & Fujita (2005) later conducted a similar study with four capuchin and four squirrel monkeys (*Saimiri sciureus*) with additional stimuli including a) images of bilaterally symmetrical versus scrambled faces and b) geometrical shapes that were arranged regularly but not in a bilaterally symmetrical fashion versus scrambled shape arrangements. Regular or irregular images were pasted on cards and several of them presented simultaneously to the animal. The first card to be picked up was interpreted as the preferred image. The animals did not receive food rewards. There was a slight preference for regular over irregular patterns, which however was not consistent for all individuals of a species and not always statistically significant. However, even when not significant, the trend tended to be against irregular and for regular patterns. Again, it is not clear that the animals

gained any aesthetic pleasure from this task, and there is no evidence that these species produce such regular patterns. Nonetheless these results may indicate a subtle perceptual bias for regularity in other primates that might be utilized and reinforced in human aesthetic artefacts.

Walker (1970) exposed rats to backgrounds ranging from monochromatic grey to black and white geometric patterns of varying complexity and found "a general tendency for the animals to move from less complex to more complex stimuli during the day" (Walker 1970, p.643). As the order of the backgrounds was not counterbalanced, this effect may have merely been due to familiarity or novelty seeking behaviour in the animals.

Artificial body ornaments in the form of leg bands change preferences for conspecifics in zebra finches *(Taeniopygia guttata)* and can have a positive effect on both males and females. Zebra finches have orange-red beaks, and males additionally have orange-red patches in the face. Females prefer males with red bands over unbanded individuals or those with blue and green bands, while males prefer females with black or pink bands (Burley, Krantzberg & Radman 1982). When males are kept in dyads, those equipped with red bands monopolised food sources and displaced individuals with green bands (Cuthill, Hunt, Cleary & Clark 1997). Recently, Pariser, Mariette & Griffith (2010) reported that when wild caught zebra finches were kept in male-only aviaries, those individuals with red bands gained more weight and sang more than those individuals with green or neutral bands. Seguin & Forstmeier (2012) however failed to replicate this effect with zebra finches bred in captivity. We note that ultraviolet light seems to play a crucial role in the preference for red, and that artificial lighting may distort the UV information available to the birds (Hunt, Cuthill, Swaddle & Bennett 1997). This may explain the difference in these two studies.

Studying the aesthetic experience as a monolithic whole in animals and comparing it to that of humans can only provide the coarsest insights into the biology and evolution of the aesthetic sense. Particular species may have similar abilities and proclivities in some parts of the aesthetic process, but not others. We suggest a modular approach: in the visual domain, perception can be broken down into perception of colour, symmetry (reflectional, rotational, translational), repetition, Gestalt principles (for an early study see (Hertz 1928)) and so on. Production could be broken down into production contexts, production self- reward systems (i.e. the effect that producing something has on the producer itself), demonstrating the ability to manipulate objects and use tools, self-adornment versus object adornment etc. We now explore some

commonalities and differences between bees, birds and primates concerning production (nest-building) and symmetry perception.

4.1   Nest-building

Nest-building is an intriguing behaviour to examine in the context of aesthetics because it characterizes all great apes, most birds and many bees and wasps. Not only does nest construction entail a sophisticated use of external material, but in many species cooperation and quality assessment by perceivers play a role as well.

Bees produce a wide range of nests, using sand, leaves, clay, feathers or wax (von Frisch 1974). The honeycomb produced by honeybees (*Apis mellifera*) is particularly pleasing to our eye because of its astonishingly regular hexagonal pattern. Many bees work together to produce the comb; a single cell may be constructed by multiple bees by placing wax chips at 120 degrees to each other to form the walls of the cell (von Frisch 1974). The entire comb structure is independently aligned by many bees along a line determined by the earth's magnetic field. The production of the comb cells is dependent on motor-sensory feedback from bristles on the side of the bee's neck, and ceases when these are immobilised (von Frisch 1974). The hexagonal shape of the cells can also be found in other species of bees and wasps, which use non-wax building materials, so that the hexagons are unlikely to be due to properties of the wax, contra (Pirk, Hepburn, Radloff & Tautz 2004).These facts refute the oft repeated myth, originating with D'Arcy Thompson (Thompson 1948), that regular hexagonal cells emerge automatically due to physical principles – instead, these structures require active, precise control of the insect builders themselves.

The majority of bird species build nests and use them for parental care, though the complexity and materials of the structure as well as the social dynamics involved in nest-building and courtship vary considerably (Hansell 2000). While females are typically involved in nest-building, either alone or together with the male, there are some cases where females assess and choose between nests built by males, for example in weaver birds (Ploceidae). Male Village weaver birds (*Ploceus cucullatus*), native to Africa, constructs nests later inspected by females. The nests are attached to branches and consist of interwoven blades of grass. If the female approves, she will line it with grass and mate with the male (Hansell 2000). Thus, the female chooses her mate partially on the basis of the quality of the nest he can construct. Walsh,

Figure 3: Male weaver birds (left) construct elaborate nests that are inspected by the female prior to mating. Male bower birds (right) build bowers that do not function as nests, but serve to attract females. The construction is enhanced with attractive, colourful objects, and the male performs a display for the female, holding objects in his beak.

Hansell, Borello & Healy (2011) have shown that male Southern Masked weaver birds (*Ploceus velatus*) become more efficient over time. Nests of both species built late in the season are shorter and lighter than early ones (Walsh, Hansell, Borello & Healy 2010). This suggests that experience interacts with the birds' inherent drive to build nests, demonstrating that males are not merely performing an invariant fixed action pattern. Nest quality may thus reflect not only dexterity and physical prowess, but also the learning ability of the builder.

While nest structures are typically used to incubate eggs, in some cases, the male construction is not related at all to incubation. Bower birds are a small family of birds (Ptilonorhynchidae) native to New Guinea and Australia (Borgia 1986, Diamond 1982), consisting of roughly 20 species. In fifteen of these species (Hansell 2000), males construct bowers in specially cleared courts in the forest. The bower, together with physical displays of the males, serves to attract females (their use or *Gebrauchszweck*, in Riegl's

terms). A bower is a large structure made from grass and twigs, somewhat reminiscent of a nest, that is built on the forest floor and decorated with various, typically brightly coloured, objects. The preferred colours of the objects and construction style of the bower varies widely between species. The bowers are not used as nests; these are built by the female after mating. Rather, bowers are a component of the courtship display, serving to entice and impress the female (Riegl's *Schmückungszweck*). There is also competition between males: neighbouring males often try to steal objects from rivals' bowers and/or destroy the bower structure. The dimensions and construction principles of the bowers vary between species, as do the types and colours of the objects used to decorate the bowers.

While bower birds are famous for a behaviour that appears ornamental, it is not unique. Other bird species are known to clear courts for their displays (Hansell 2000), and some species such as the superb lyrebird (*Menura novaehollandiae*) additionally modify the centre of the clearing with a mound of earth (superb lyrebird) or a grass tuft (Jackson's widowbird (*Euplectes jacksonii*)). In the bird-of-paradise species Lawe's parotia (*Parotia lawesii*), males place selected objects in the clearings, reminiscent of bowerbirds, with the difference that females subsequently remove the objects from the clearings (Pruett-Jones & Pruett-Jones 1988).

All adult great apes (gorillas, chimpanzees, bonobos and orang-utans) build nests every night, and use them for sleeping and sometimes for social interactions such as grooming (Sabater Pi, Vea & Serrallonga 1997). The nests also offer protection against predation and wet ground. Individuals build nests that they rarely share with others, with the exception of mothers sharing nests with their infants. Nests are rarely reused and are built anew each evening. As these nests are mostly arboreal (with the exception of gorillas who usually build terrestrial nests (Tutin, Parnell, White & Fernandez 1995)), the nests need to be sturdily constructed. An analysis of orang-utan nests showed that the structures are complex, with sturdy branches used preferentially for support, and thinner branches used for interweaving (van Casteren, Sellers, Thorpe et al. 2012). Nest construction in chimps and bonobos is rapid, taking about a minute for day nests (used during midday rest) and no more than five minutes for night nests. Juveniles begin constructing nests in a playful manner, in preparation for their own 'solo' nests that they must construct after weaning (Fruth & Hohmann 1996).

To summarise, nest-building is a behaviour that in birds has the potential to be a crystallisation point for the emergence of aesthetic production and

perception due to its dual productive/perceptive nature, with competition in males driven by female perceptual judgement. In great apes, although nest-building is a universal trait, there is little social pressure for this behaviour to become more elaborate or fulfil a courtship function because each individual builds their own nest. In bees, we see that the collaborative construction by many individuals biases the group towards a unified production process, leaving no room for individual variation or innovation if the combined effort is to converge on a well-formed structure. Each of these examples shows certain points of contact with human artistic practices, but none possesses all of the relevant features.

4.2   Symmetry perception

Symmetry, in particular reflectional symmetry, is an important element in many visual designs and is a highly salient cue for humans (for an extensive review on human symmetry perception see (Treder 2010)).

It has been hypothesised (Møller 1992, Penton-Voak, Perrett, Castles et al. 1999) that symmetrical features and markings can act as indicators of high genetic fitness in humans and other animals (usually in males), with few deviations from a symmetrical ideal ("fluctuating asymmetry") being indicative of "good genes", meaning a high ability to deal with developmental stress and hence most desirable to females. However, fluctuating asymmetry has been criticised, for example by Palmer & Strobeck (2003), since the measurement of symmetry may be very sensitive to small measurement errors (especially in small traits) and asymmetries may arise for reasons other than developmental anomalies. Furthermore, Johnstone (1994) argues that a preference for symmetry in females can arise in the absence of a link between symmetry in males and genetic fitness. Neural networks have been implemented to test whether a visual signalling process might inherently be biased towards symmetrical signals, similar to the symmetrical markings often found in animals (Enquist & Arak 1994, Enquist & Johnstone 1997). While bilateral reflectional symmetry does tend to emerge in these models with repeated iterations of initially random visual signals, critics have noted that this effect may be a byproduct of the simplified perceptual models implemented (Dawkins & Guilford 1995, Bullock & Cliff 1997, Kamo, Kubo & Yoh 1998). Both biological approaches make interesting and valid points, but fall short of capturing (human) symmetry processing in its full generality.

In animals, symmetry preferences have been studied extensively in the

context of mate choice and sexual selection (Møller & Thornhill 1998). Far fewer studies have been published that examine symmetry preferences outside of a mate selection context. Since symmetry preferences in humans can be found in many contexts and feature prominently in many if not most human artefacts, we review research on symmetry perception in animals beyond the mate selection context to see whether clues can be found in other species concerning the socio-ecological pressures that might have led to such an expansion of symmetry use in humans.

Honeybees can be trained to discriminate bilaterally symmetrical visual stimuli from asymmetrical stimuli and can generalise to new exemplars (Giurfa, Eichmann & Menzel 1996, Giurfa & Menzel 1997). Although there was no initial preference for symmetrical images, after exposure, those trained to approach symmetrical stimuli performed consistently better and hovered longer and nearer to the stimuli than those trained to approach asymmetrical stimuli. Bees can also distinguish a vertical axis of symmetry from other orientations in bilateral symmetry (Horridge 1996). Bumblebees raised with no exposure to flowers or other symmetrical visual stimuli nonetheless show a marked preference (measured by approaches and staying times on the stimulus) for bilaterally symmetrical over asymmetrical images (Rodríguez, Gumbert, Hempel de Ibarra, Kunze & Giurfa 2004). Given that these species obtain food from flowers, which are typically highly symmetrical, with more symmetrical flowers containing more nectar than less symmetrical flowers (Møller 1995), it is not surprising that symmetry is a salient cue to these insect species in a foraging context.

Turning to birds, extensive studies have been carried out on symmetry perception in both pigeons and starlings, with contradictory results.

Pigeons can distinguish bilaterally symmetrical (with a vertical symmetry axis) from asymmetrical stimuli and generalise to new exemplars (Delius & Habers 1978, Delius & Nowak 1982). However, Huber, Aust, Michelbach, Olzant, Loidolt & Nowotny (1999) call into question whether this discrimination was based on an abstract concept of symmetry. Using three types of stimuli classes, they show that pigeons can learn to discriminate between symmetrical and asymmetrical items in two out of three stimuli classes. However in the successful cases, the birds do not seem to acquire a general concept of symmetry to differentiate the two types of images. Instead, the authors suggest that pigeons use alternative discrimination strategies, the main one being rote learning. Results indicate that pigeons store each training exemplar together with the reward contingency. When viewing novel stimuli, the

birds seem to compare the stored exemplars with the novel ones and respond according to a threshold based on stimulus similarity.

A mixed picture is also emerging for starlings. Starlings have a speckled breast, and the difference between the number of dots on each side averages about 9% (Swaddle & Witter 1995). The birds can differentiate between artificial symmetrical and asymmetrical dot patterns where the asymmetry is achieved by moving the dots of one side of a bilaterally symmetrical pattern around randomly without removing them, that is, the number of spots on either side remains the same (Swaddle & Pruett-Jones 2001). However, if the number of dots is increased and the asymmetry is brought about by randomly removing dots from one side of a bilaterally symmetrical image and placing them randomly on the other side (the number of spots on either side differs) birds fail to discriminate between symmetrical and asymmetrical (Swaddle & Ruff 2004), corroborating the findings of (Huber et al. 1999) with pigeons. Similarly, young chicks (*Gallus gallus*) can be trained to discriminate bilaterally symmetrical stimuli from asymmetrical stimuli (Mascalzoni, Osorio, Regolin & Vallortigara 2012) but have a preference for asymmetrical stimuli right after hatching Furthermore, they preferentially peck on irregular dot arrays deviating from a straight line rather than arrays that are spaced alonga straight line (Elliott, Salva, Mulcahy & Regolin 2012), suggesting that a capacity to perceive mirror symmetry is not necessarily an indicator of a general preference for regularity and order.

Taken together, the studies for pigeons, starlings and chickens tell a cautionary tale: symmetry detection can be achieved with training and positive feedback under some circumstances, but it is not a robust capacity as in humans. The detection of symmetry, if present in a species, may be confined to narrowly delineated circumstances and stimuli types, e.g. mate choice or foraging, rather than indicating a generalised perceptual principle, as it seems to be in humans.

The literature on nonhuman primate symmetry perception is surprisingly sparse. A brain imaging study conducted by Sasaki et al. (2005) while participants were viewing radially symmetrical and asymmetrical dot patterns showed that the same areas of extrastriate visual cortex are activated in both humans and macaques, (regions V3a, V4d), but that the activation was stronger in humans. There was little to no symmetry-specific activation in primary visual cortex (V1 and V2). These findings suggest that the visual processing of symmetrical stimuli in humans uses similar visual pathways as other primates.

Waitt & Little (2006) showed macaques symmetrical and asymmetrical versions of conspecific faces, and the animals looked longer at symmetrical faces , which, at least in humans, is usually interpreted as a sign of preference (Langlois, Roggman, Casey, Hart, Rieser-Danner & Jenkins 1987, Quinsey, Kesetzis, Earls & Karamanoukian 1996). In an eye-tracking study, Kano & Tomonaga (2009) showed chimpanzees and humans images of humans, chimpanzees and other mammals. The basic scan patterns of images were very similar, focussing mainly on the head and face regions of the images and spending little time on the background. This again suggests that perceptual similarities exist between humans and other primates. To our knowledge no face preference studies have yet been conducted in chimpanzees. However, there is evidence that chimpanzees have no preference for symmetrical versus asymmetrical images of perineal swellings in female conspecifics (Breaux, Watson & Fontenot 2012).

Based on the scant data available, one possibility is that the basic perceptual processes involved in symmetry perception may be quite similar in humans and other primates. So far, in all animal species studied symmetry recognition is restricted to particular symmetry types (typically reflectional symmetry) and contexts (mate selection in birds or foraging in bees), which may reflect a shared "canonical neural substrate" (Cohen & Zaidi 2013, p.2) that relies on relatively simple perceptual mechanisms (Osorio 1996, Cohen & Zaidi 2013) that possibly evolved due to the biological relevance of symmetrical input in certain circumstances. The very broad appreciation of multiple types of symmetry that humans show, particularly involving both the perception and production of geometrical patterns, is to our knowledge unparalleled in the animal kingdom.

Despite the rarity of flexibly generated, creative geometrical patterns in the animal kingdom, and their ubiquity in human society, surprisingly little empirical research has focused on human pattern production (though cf. Westphal-Fitch et al. 2012, Westphal-Fitch et al. 2013), and we think that the ability and proclivity of ordinary humans to generate structured and attractive patterns should be an important focus of future work in empirical aesthetics.

5 Discussion

Over its long history, aesthetics has grappled with the distinction between a "natural" aesthetic appreciation and further development (or refinement) of aesthetic sensitivities through cultural input.

The aesthetic traditions of a culture may vary over historical time, but while fashions come and go, we suggest that there are some core fundamental biases and proclivities of natural aesthetics that drive humans to produce aesthetic objects and remain unchanged. In particular, a very general ability to both perceive and produce symmetrical stimuli appears to be a stable, and biologically unusual, feature of our species. Production of highly ordered but also extremely varied abstract geometrical patterns is, by current knowledge, unique to our species, as is the production of representational art.

Although there are phenomena reminiscent of aesthetic behaviour (e.g. bower building) in the animal kingdom, these nonetheless differ in important ways from those of humans (restriction to certain contexts, males only).The development of symmetrical signals in the animal kingdom is frequent, but again typically restricted to specific contexts and forms. Little is known to what extent abstract patterns are perceived in animals, but it seems clear that patterns are not generated in a creative, flexible and open-ended fashion in non-human species.

5.1 Music, language and art as a cognitive triad

Art, music and language are cultural phenomena that have a strong social component: language facilitates communication between humans and is typically used in a social setting (there are exceptions such as babbling and self-directed speech). Music is often played or sung in a group, and an audience may be present. Art is less obviously social: although artefacts may be produced and perceived in a solitary setting, often they are produced in a group, particularly in traditional societies. In particular, body art is highly social both in its production and in its later intended perception.

Besides their social functions, we suggest that a further common feature at the heart of the music/language/art triad is the ability to iteratively apply generative rules during their production (i.e. a generative syntax). In the case of visual art, we refer here in particular to abstract geometric patterns. Syntactic rules that govern the combinatorics of words are studied extensively in language, and it is a promising research field in musicology (Temperley 2010).
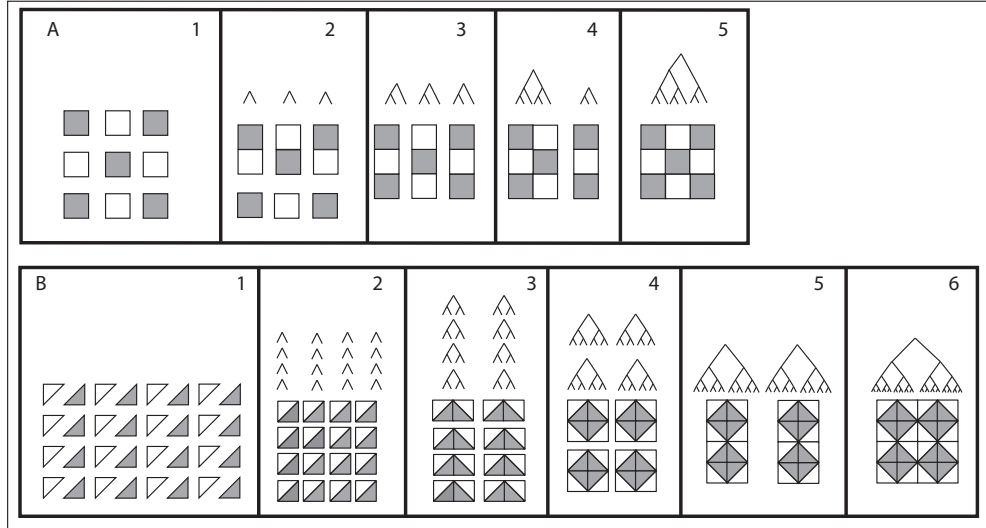
Figure 4: The production process underlying two visual patterns produced from basic shapes (squares, triangles) using a rule that only two edges may be joined at each step, as when sewing patchwork. The repeated application of the generative rule results in binary branching structures that show multiple levels of hierarchical embedding. A: The number of nodes is odd, leading to an asymmetrical binary tree, while the nodes in B are even, resulting in a symmetrical, recursive structure. The branching direction in A is arbitrary, but is kept consistent in the diagram for clarity.

We argue that some sizeable subset of aesthetic behaviours involving abstract patterns in the visual domain also involve repeated application of generative rules with parallels to musical and linguistic structure (for examples see figure 4).

Art, music and language have in common that they are produced over time and the generative rules are applied serially during production. The ordering in the visual domain is less strict than in the auditory domain. Production may be restricted to a serial "one element at a time" production style, for example during sewing or beading, when only one joining operation can be executed at a time, but the order in which elements are joined is typically flexible.

A more striking difference between visual art on the one hand and music

and language on the other becomes obvious during perception. While listening to speech or music, the stream must be parsed serially over time. So the perceptual process must closely track the production process of the speaker or performer temporally. However, eye-tracking studies show that this is clearly not the case in visual art: perceivers can scan the two-dimensional array (or three dimensions in the case of sculptures) any way and in any order they like, without temporal restrictions. Humans (disregarding certain clinical groups) have a strong tendency to globally scan an artwork or stimulus first, focussing on details at a later stage. Also, the perceiver can return their attention to regions that have already been looked at as often as they like. This relatively unconstrained aspect of visual perception versus the temporally bound perception of music and language offers a noteworthy freedom to the perceiver. Of course, this applies to static artwork but not to film or dance, which share the temporal flow of music or speech. It may be that such oppositions between visual and auditory, or static and temporally dynamic input have a profound effect on our aesthetic experience. However, it is also possible that all aesthetic experience shares certain common organizing principles, for example an 'aesthetic trajectory' of recognition/surprise and resolution regardless of the medium or temporal dynamics (Fitch, von Graevenitz & Nicolas 2009). Both possibilities provide issues for exploration in future empirical work.

Language is limited in its generativity by pragmatics and semantics. While it is possible to utter sentences such as "Colourless green ideas sleep furiously", meaningless sentences are not conducive to successful communication, which is usually the goal of speaking. Music and abstract art are not similarly limited by semantics. Music is the most abstract case, and art can be representational (i.e. convey representational meanings) or abstract. Abstract patterns are particularly visually striking, have the longer developmental history (as we have argued above), and are much more widespread across cultures than representational art. Both music and visual art have an additional dimension of flexibility due to the freedom from semantic content (optional in the case of visual art) that language does not typically enjoy outside the narrow domains of linguistic examples or Dadaist poetry.

5.2 Outlook

Precisely because of the vast variance in the types of artwork that humans produce, empirical aesthetics needs to cast a wide net to achieve a compre-

hensive picture of the human aesthetic drive, and to discover features that all cultures have in common. Therefore, we maintain that in the future, empirical aesthetics should in principle incorporate the aesthetic judgements and activities of humans from a wide variety of cultures, and include manifestations of the aesthetic drive that can feasibly be studied in the lab. In particular, we strongly question the notion that it takes special knowledge or formal education to have a fully fledged aesthetic experience (Fitch & Westphal-Fitch 2013).

In the same way that linguistics, and more recently, musicology have rejected traditional prescriptivist approaches to what is good or bad or right or wrong, empirical aesthetic needs to embrace a non-elitist, cross-cultural approach which recognises and explores the aesthetic capacity of ordinary humans.

A broad comparative approach to aesthetics both across different human cultures and cross-species comparisons will allow the field to benefit from methodologies and research questions of linguistics and musicology, which have already mostly transitioned from a prescriptivist (i.e. normative) to a descriptivist approach, (e.g. (Honing 2011)). We suggest that a wholehearted embrace of such a broadly comparative perspective has rich insights to offer into aesthetics, and the intriguing hidden structural similarities of the human cognitive triad of music, language and art.

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3 | Parsing and production of visual patterns

Research

Production and perception rules underlying visual patterns: effects of symmetry and hierarchy

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Formal language theory has been extended to two-dimensional patterns, but little is known about two-dimensional pattern perception. We first examined spontaneous two-dimensional visual pattern production by humans, gathered using a novel touch screen approach. Both spontaneous creative production and subsequent aesthetic ratings show that humans prefer ordered, symmetrical patterns over random patterns. We then further explored pattern-parsing abilities in different human groups, and compared them with pigeons. We generated visual plane patterns based on rules varying in complexity. All human groups tested, including children and individuals diagnosed with autism spectrum disorder (ASD), were able to detect violations of all production rules tested. Our ASD participants detected pattern violations with the same speed and accuracy as matched controls. Children's ability to detect violations of a relatively complex rotational rule correlated with age, whereas their ability to detect violations of a simple translational rule did not. By contrast, even with extensive training, pigeons were unable to detect orientation-based structural violations, suggesting that, unlike humans, they did not learn the underlying structural rules. Visual two-dimensional patterns offer a promising new formally-grounded way to investigate pattern production and perception in general, widely applicable across species and age groups.

Keywords: symmetry; plane patterns; hierarchy; pattern perception; pigeons; autism spectrum disorder

1. INTRODUCTION

Abstract, non-representational visual patterns, such as those used in weaving, patchwork, embroidery, jewellery, etc., are produced in most, if not all, human cultures. Similar to music and language, such patterns seem to be a human cultural universal, not found in other species. The earliest artefacts with abstract geometrical patterns, found at Blombos cave in South Africa, predate representational art considerably [1], and archaeological findings at Avdeevo in Russia show that a Palaeolithic culture that developed representational art continued to use geometrical patterns to embellish tools and jewellery, as do modern cultures [2]. As already pointed out by Franz Boas [3] in 1927,

the presence of symmetry in art is not limited to any particular culture or region.

Geometrical patterns as we understand them here are characterized by structured repetitions of elements in a two-dimensional plane. While the symmetries in patterns can be easily classified [4], the principles underlying the perception and production of geometrical patterns remain poorly studied. As Gombrich [5] noted in his classic book '*The sense of order*', it is precisely because of the predictability and regularity of patterns, and also their pervasiveness in everyday culture that they are an 'unregarded art', often derogated to the 'lower arts' or 'crafts'. Nonetheless, humans clearly like to surround themselves with visual patterns that follow some kind of structural order.

Visual patterns have in common with music and language that they are governed by a set of combinatorial principles—'grammars'—that constrain the arrangement of units into groups on multiple hierarchical levels. Although formal language theory is most typically used in the context of linear sequences or strings (e.g. in linguistics, computer programming and molecular biology), it can be naturally extended

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to cover two-dimensional patterns as well [6]. These lesser-known two-dimensional extensions of formal language theory include picture grammars [7] and picture languages [8] as well as L-systems [9] and picture-processing grammars [10]. Two-dimensional variants of both regular grammars and context-free grammars are reasonably well understood [7,11], and such grammars have applications as tools for image processing [9] and as models of plant development [12]. Current research is focused on two-dimensional patterns at the finite-state level [7]. However, two-dimensional artificial grammars, and the patterns that they generate, have received little attention from psychologists interested in the production, perception and appreciation of visual patterns.

The research presented here provides a first look into this potentially rich domain, by testing various aspects of two-dimensional pattern perception, allowing people to generate their own two-dimensional patterns and analysing the output, and by comparing human two-dimensional pattern perception with that of pigeons—a highly visual bird species.

We suggest that the methods of artificial grammar learning can be fruitfully applied to the perception of visual patterns, using patterns to probe perception of structure of different sorts, preferences for different levels of structural complexity and effects of the presence or absence of hierarchy. By studying which structural manipulations make a pattern easily detected, we hope to shed light on what kind of (unconscious) knowledge a perceiver acquires concerning the regularities underlying the pattern. We can thus think of geometrical patterns as reflecting naturally occurring visual grammars. Artificial grammars based on similar principles can then be used to empirically evaluate structural parsing abilities in the visual domain.

2. VISUAL PATTERN PRODUCTION AND AESTHETICS

One feature that sets everyday geometrical patterns apart from conventional 'high' art is that they can be appreciated equally by everyone, regardless of levels of artistic proficiency, cultural background or education. Similarly, the production of such patterns requires no formal art education or special artistic talents. Hence, we will first investigate what kind of patterns normal humans spontaneously create, without instructions or time constraints, reviving a neglected branch of a research programme in aesthetics outlined in 1876 by Fechner [13]. Fechner advocated that, in addition to gathering preference ratings, psychologists should also investigate material created by subjects in a controlled laboratory setting ('Method of production: one lets many people create by themselves that which is pleasing to them'; our translation, p. 190).

While considerable research has explored the perception of symmetry and the detection of deviations from symmetry—especially bilateral symmetry—by humans and some animal species [14–18], little research has been performed to explore what kinds of symmetry and order humans produce spontaneously. Producing unstructured outputs may be difficult for humans: participants instructed to create random number sequences

nonetheless produce structured sequences that deviate significantly from true randomness [19–22]. But what structures are favoured? The types of regular pattern types that are produced most, and the cultural or structural factors that determine this, remain little studied. In one pioneering study which found that humans tend to produce symmetrical patterns rather than asymmetrical patterns, participants were probably biased towards symmetry because they were instructed to produce 'pleasing patterns' [23]. In experiment 1, we will present a pattern production study where no such instruction biasing was present, but which still provides very similar results.

3. PATTERN PERCEPTION AND GESTALT PRINCIPLES

Gestalt psychologists searching for factors that affected the 'goodness' of a form [24,25] noted the influence of symmetry on figure/ground relations: a symmetrical shape is more likely to be interpreted as a figure than as background. However, these grouping principles were not explicitly formalized at the time. The concept of figural goodness was revitalized in the 1950s, in attempts to combine the intuitive understanding of symmetry with information theory [26,27]. Current Gestalt research focusing on perceptual grouping mainly explores the effects of proximity and similarity on perceptual grouping in artificial Gabor lattices, and not the more typical, everyday patterns of the type we investigate here [28,29].

We conducted several perceptual tasks to explore the perception of order in two-dimensional patterns. The main goal of our experiments was to determine which structural features help or hinder the perception of the regularity in patterns. In particular, we looked at the effects of hierarchy and symmetry within the patterns and pattern elements in discrimination efficacy. We also contrasted two patterns that differed only in one aspect of their production rule: the presence or absence of an intermediate level of structural hierarchy. We initially examined normal adults, to establish baseline values (experiment 1), and went on to test individuals with autism spectrum disorder (ASD), and children aged 5–12. ASD individuals often outperform control groups in visual search tasks, both in speed and accuracy [30–33], and there is some evidence that they give local information priority over global information when processing complex visual stimuli [34]. We explored this possibility by comparing their performance with patterns that required processing either global or local relations.

Finally, to lay the groundwork for a comparative investigation of the human 'sense of order', we tested whether pigeons are able to process visual patterns such as those used in our human experiments, comprising either colour or orientation features. Pigeons are interesting in this context because they are able to discriminate regular, repetitive patterns such as stripes and checkerboards from random visual patterns made of the same basic elements [35]. Although pigeons are thus able to differentiate randomness from order, it remains unclear whether they can detect minor *violations* of regular orderings and if so,

FLEXTILES software interface

initial random
starting configuration

various final configurations

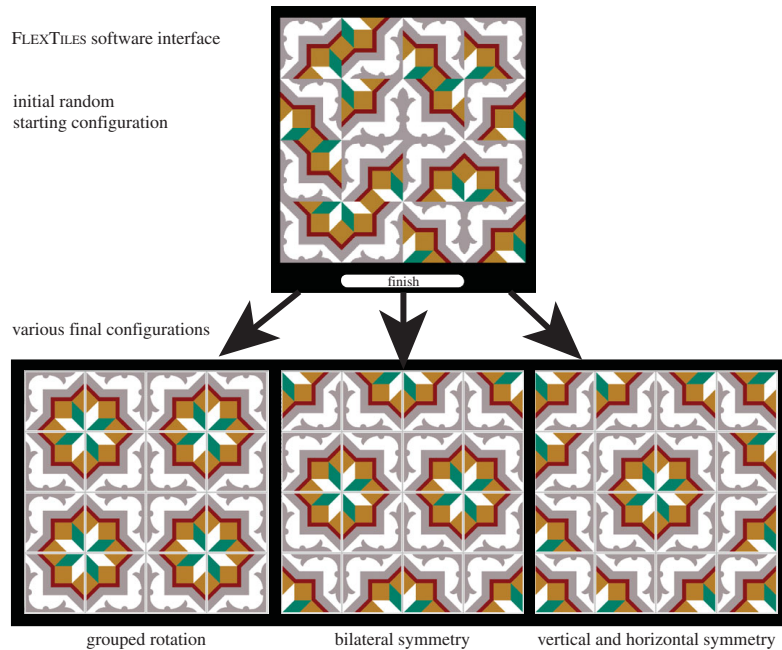grouped rotation   bilateral symmetry   vertical and horizontal symmetry

Figure 1. Overview of FLEXTILES software interface with initial random configuration and various ordered final configurations. Tile image taken from '*Havana tile designs*' published by The Pepin Press.

which violations are most readily detectable. Pigeons are known to have a bias towards local featural processing (as opposed to global, relational processing) and we thus compared human and pigeon processing on a uniform translational pattern and a hierarchical grouped pattern—a local parsing style would enable flaw detection in the translational pattern, but not in the grouped pattern. This experiment thus begins to investigate the degree to which the perceptual mechanisms humans employ in processing abstract visual patterns are shared with other species.

4. EXPERIMENT 1. SPONTANEOUS PATTERN PRODUCTION

(a) *Introduction*
The aim of our first experiment was to investigate the types of patterns humans spontaneously produce, when free to change the array as much or as little as they like, with no further instructions. We also investigated the effect of repeated exposure to a single particular pattern element, to see whether familiarity (or boredom) sparks creativity, by presenting each array three times in succession to each participant.

(b) *Participants*
We recruited 10 adult participants (seven female, mean age: 29.3, age range: 18–51) at the University of Vienna. All participants were right-handed. None of the participants were artists or worked in creative

professions. All gave their written informed consent prior to participating and were paid for participating.

(c) *Material and methods*
Patterns consisted of identical 'tiles' arranged on a square grid. Tiles were semi-realistic depictions of actual artisanal tiles from Havana and Barcelona [36,37]. Three tile categories were used: (i) either possessing symmetry along one of the diagonals, (ii) symmetry along either the vertical or horizontal axis and/or (iii) with no internal symmetry. We used four tiles of each 'symmetry' type, yielding 12 tiles, each repeated three times.

Using FLEXTILES, a custom-written image manipulation program, each tile was repeated 36 times on a 6×6 matrix; initially, each tile (100×100 pixels) was randomly assigned to one of four possible orientations ($0°$, $90°$, $180°$ or $270°$). The matrices were displayed on a touch screen (Elo Intellitouch $17''$). Every time a tile was touched, the tile rotated $90°$ clockwise. Participants were told that they could change the array as much or as little as they liked, and that there were no right or wrong choices. To finish their activities for each particular array (one 'production trial'), participants touched a button on the screen below the array labelled 'Finish'. See figure 1 for an overview of the software, in this case using tiles with diagonal symmetry. Each of the 12 individual tiles was shown in the array three times in succession. The starting arrays were always newly randomized and varied
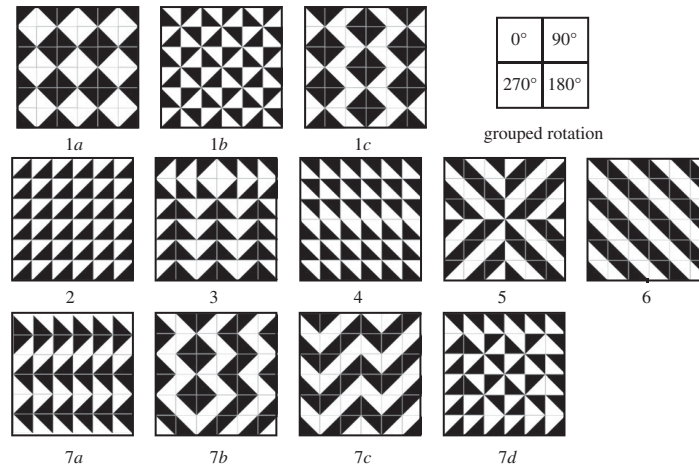
Figure 2. Pattern types spontaneously produced in experiment 1, recreated in black and white: (1) grouped rotation with diamond figure (1*a*), windmill figure (1*b*) or offset diamonds (1*c*). (2) Translational symmetry, (3) bilateral symmetry along vertical axis, (4) 180° rotational symmetry, (5) 180° and 90° rotational symmetry, (6) symmetry along diagonal axis. (7) examples of 'local linear' groupings of two tiles, with no overall global symmetry.

between trials. The order in which each tile was shown was also randomized. There were 36 production trials in total, split into two sessions. All instructions were given to the participants in writing and did not contain any words that alluded to beauty, aesthetics, patterns or symmetry.

In addition to the production task, each participant completed a rating task. After 18 trials, and again after all 36 production trials were completed, the participants rated single pattern arrays on a Likert scale from one to seven (1, like; 7, dislike). Rating sessions either included participants' own versus random arrays (six of each), or random arrays versus patterns made by other humans (six each). Session order was counterbalanced across subjects, and image order within sessions was randomized. Regardless of provenance, two examples of each of the three tile symmetry classes were shown.

(d) Results
All participants spent a considerable amount of time spontaneously ordering the random tile arrays; the typical duration of the experiment was an hour and on average, participants clicked 68 times in the array before submitting it as 'finished'. The majority of patterns (72%) submitted contained at least one type of symmetry, whereas 28% did not, or only incomplete symmetry. If a pattern deviated from symmetry by more than one tile, then we did not classify it as symmetrical. The 'non-symmetrical' patterns nonetheless often had a high degree of order as the examples in figure 2(7*a*–*d*) show, so these measures are conservative.

One order was particularly common (shown in figure 2, top row), which we call 'grouped rotation': this is a special instance of symmetry along the horizontal and vertical axes. This pattern is hierarchical and has

an intermediate level of organization above that of the tile element: four tiles are grouped to create a diamond-shaped figure (1*a*), a windmill-shaped (1*b*) or offset diamonds (1*c*). By contrast, translational patterns (figure 2(2), though symmetrical, have no intermediate level of organization.

We developed PYTHON-based software to automatically compute entropy [38] and symmetry values for the patterns. Entropy values of the human-produced patterns were significantly lower than those of randomly produced patterns (human mean: 1.58, random mean: 1.94 Mann–Whitney *U*-test: $p = 0.038$, $Z = -2.07$). The maximum entropy possible in our rotational framework is 2.0 (when each of the four orientations occurs equally often in the matrix), and a pattern with full translational symmetry (only one tile orientation present) has the lowest possible entropy of 0. An analysis of entropy values however does not reveal hierarchically ordered structure—image 1*a* from figure 2 also has the maximum entropy value 2.0, because all orientations occur with equal probability. Grouped rotation is thus indistinguishable from randomness by this measure.

We thus extended our code to analyse specific symmetries in the patterns, automatically detecting the following symmetry categories (figure 2): translation, grouped rotation, diagonal, 180° rotation (including 180° + 90° rotation), horizontal and vertical symmetry (H + V). Additionally, we manually included patterns that contained only one mistake (10 images, 2.78% of the data), as well as patterns that contained local regularities but not consistent global groupings ('local linear'; e.g. images 7*a*–*d*).

The only type of symmetry that was produced by every participant was 'grouped rotation' and was the most frequent pattern overall (figure 3). Grouped rotations made with tiles from the vertical/horizontal category
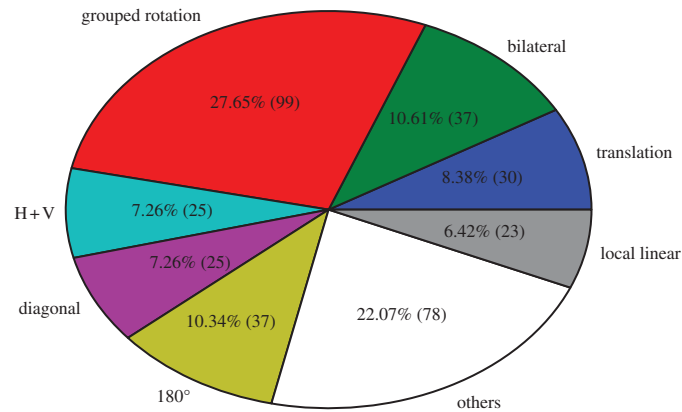
Figure 3. Percentages of patterns produced, with maximally one error in the patterns.
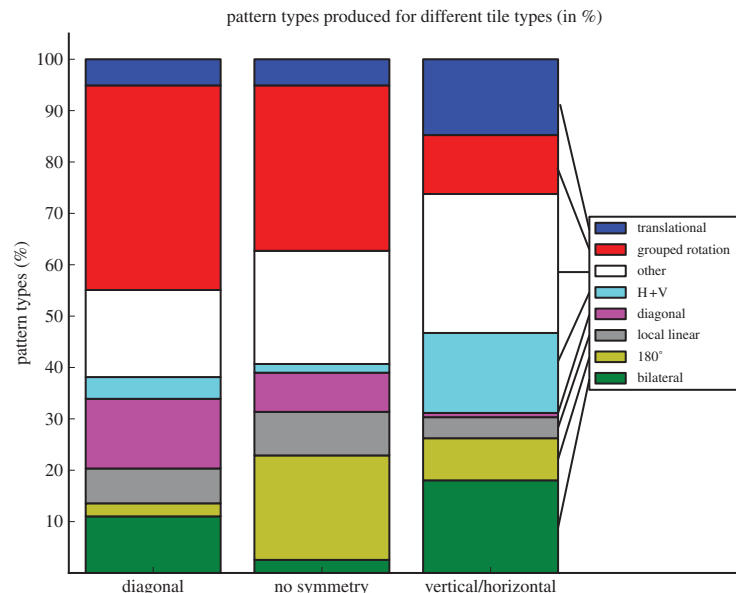

Figure 4. Frequencies of patterns produced for different tile types.

were rare (11.6%), but the most frequent symmetrical pattern for tiles with diagonal symmetry (39.2%) or those containing no symmetry (31.6%; figure 4).

Regarding creativity, participants used the grouped rotation most frequently (31.9% and 32.7% of patterns produced), in the first two passes at a tile. Only with the third pass did grouped rotation frequency drop down to 18.3% (figure 5) and other symmetries, particularly bilateral symmetry along the diagonal axis increase (diagonal symmetry: 6 instances (first iteration), 7 (second iteration), 13 (third iteration)).

Subjects also rated patterns on a Likert scale (1–7, with 7 indicating 'dislike'). Participants significantly preferred human-made patterns over random patterns, but showed no preference for their own or others' patterns (table 1; one-way ANOVA: $p < 0.001$, $F = 30.182$, d.f. = 2).

(e) *Discussion*

Our results confirm that humans spontaneously produce highly ordered visual patterns in the absence of instructions to do so. Our participants were also creative, producing many different patterns, and producing different patterns when exposed to the same element repeatedly. Those patterns that do not adhere to classical

pattern types produced on first, second and third presentation of a tile, in %
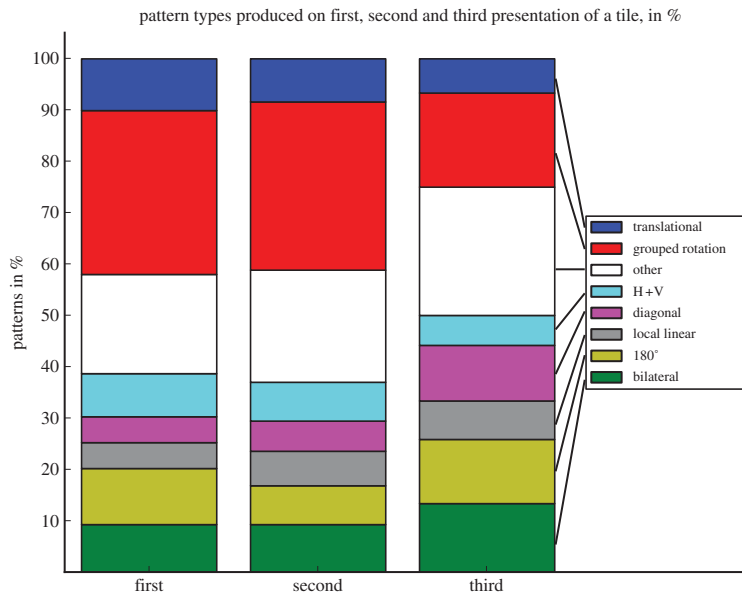

Figure 5. Frequencies of patterns for first, second and third presentations of the tile.

Table 1. Mean ratings on a Likert scale (1, 'I like it'; 7, 'I do not like it') for random patterns, other- and own-produced patterns.

image type	mean	n	s.d.
unknown (symmetrical)	2.81	54	1.97
unknown (random)	5.00	60	2.17
own	2.77	114	1.69

symmetries still tend to display a high degree of order and organization (see examples in figure 2, images 7*a*–*c*). The local symmetry present in the tile element had an effect on the type of patterns produced (figure 4). Our rates of symmetrical pattern production are somewhat lower than reported by reference [2] (72% versus their 85%). However, those authors used only one type of pattern element (a black dot on a white square), whereas we used three different tile types, which may have promoted the production of a wider variety of symmetries.

This experiment confirms that humans spontaneously impose order on visual arrays, using various generative rules. However, it remains unclear what kinds of structural rules underlying such ordered visual arrays can be perceived. We addressed this question in a series of perceptual experiments, using a 'spot the flaw' paradigm described below.

5. EXPERIMENT 2. 'SPOT THE FLAW': DETECTION OF PATTERN VIOLATIONS BY UNDERGRADUATES

In the next set of experiments, we studied the perception of plane patterns. We exposed participants to

ordered visual patterns, giving them no verbal information about the underlying structural rules. We reasoned that if participants were able to detect violations of the underlying order, or 'flaws', then they must have developed some understanding of the regularity of the pattern, even if imperfect. Moreover, we hypothesized that if a pattern type was difficult to perceive or process, aberrations in patterns of that type would be correspondingly more difficult to detect.

(a) Participants
Sixteen University of St Andrews undergraduates (12 female, mean age: 21.8 years, age range: 18–35) took part in this experiment. All gave their written informed consent prior to participating and were paid for their participation. Participants attested to normal, or corrected to normal, visual acuity, as well as normal colour vision, as a condition of participation. This experiment and experiments 3–5 were approved by the ethics board of the School of Psychology, University of St Andrews.

(b) Materials
Five sets of images were shown to each participant (figure 6). In all sets, the grid size varied from a 3 × 3 to a 6 × 6 matrix. The tiles measured 120 × 120 pixels, hence the stimulus size varied from 360 × 360 to 720 × 720 pixels. Each image was shown in a flawed and an unflawed version to each participant, leading to a 50/50 distribution for flawed and unflawed stimuli. In the 'colour' task (set A; 64 trials) matrices were of uniform coloured tiles, and flaws consisted of one tile that had different colours. In the 'orientation' task (set B; 64 trials), all tiles had the same
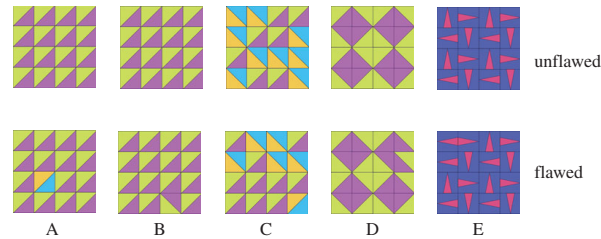
Figure 6. Examples of stimuli used in the five sessions of experiment 2. (A) Colour feature target, (B) orientation feature target, (C) conjunction of colour and orientation features, (D) grouped rotation with tiles that have symmetry on one diagonal axis (E) grouped rotation with tiles that have symmetry on the vertical or horizontal axis.

orientation, and flaws consisted of one tile that had a different orientation. Set C (64 trials) was a 'conjunction' task: the matrix contained two tiles with different colours and orientations. A flaw consisted of a tile that had the orientation of one tile type, but the colour of the other tile type (figure 6). Because we expected the following 'grouped rotation' tasks to be harder than these single feature tasks, but had no expectation about how much harder, we added the conjunction task as a well-studied point of reference [39,40]. In classical visual search, search times for targets defined by conjunctions typically rise with the number of distractors [39].

The final class of stimuli were generated using a 'grouped rotation' rule (64 trials). The tiles were arranged in an orderly hierarchical fashion such that the orientations of the tiles resulted in global shapes consisting of four tiles in the matrix. We split this class into two sets based on tile symmetry: with 'diagonal symmetry' tiles (set D; 32 trials) well-formed Gestalt groups were formed. In contrast, the 'non-diagonal' tile that made up set E (32 trials) had either a horizontal or vertical symmetry, but no diagonal symmetry, rendering the global shapes less coherent than set D.

The basic tile elements were generated in INKSCAPE (www.inkscape.org), and then assembled into matrices with PYTHON software implemented in NODEBOX (www.nodebox.net). Images were displayed on an LCD monitor; presentation and data collection used custom experiment running software written in PYTHON (Experimenter 1.11). Participants responded via an IOLAB button box (www.iolab.co.uk), allowing millisecond reaction time (RT) accuracy.

(c) Methods

The participants underwent a short interactive training session, during which verbal feedback was given, and all pattern types were shown once. The tiles differed from those used in the test phase. In the test phase, no feedback was given to the participants to indicate whether their decisions were correct or incorrect.

Pilot data showed that class E was more difficult, particularly if combined with images of class D in a single session. Then, class E images were likely to be erroneously classified as flawed, probably owing to the absence of continuation cues between the tiles. Hence, we separated these two image types into two sessions, to avoid confusion as to the cues for the

presence of flaws in the images. The order of the sets A–D was randomized for each participant except that set E was always shown last to all participants. Each participant was shown both the flawed and unflawed versions of each stimulus, and the order of the stimuli was randomized within a session.

A two-alternative forced-choice procedure was used. In each test trial, one image was shown on a computer monitor, and participants pressed one of two buttons on the button box to indicate whether or not the presented image contained a flaw (e.g. if an image contained a flaw, the participant had to press the left button, whereas unflawed images required a right button press). Button assignment was constant for each participant, but counterbalanced across participants. A black screen was presented for 1 s between trials. If the participant did not press a button within 10 s, then the trial timed out and the image disappeared from the monitor. Trials that timed out were not repeated and were excluded from the analysis. Participants had an opportunity to take a short break after every 50 trials, as well as between image sets. Response and RT were recorded. Trials with RTs less than 200 ms were excluded, as such short RTs were typically due to inadvertent button presses. Statistical analyses were conducted in SPSS 17.

(d) Results

Participants performed at very high levels (correct responses for A: 98%, B: 98%, C: 87%, D: 88%, E: 86%); however, the difficulty of tasks C, D and E was reflected in longer RTs (mean RTs in milliseconds A: 877, B: 970, C: 3110, D: 2227, E: 4318; figure 7). To test whether RTs were different between sessions, we calculated the mean RTs for each session and participant. A Kolmogorov–Smirnov test confirmed that the means were normally distributed for all tasks (all $Z > 0.6$, all $p > 0.278$). Using a repeated-measures ANOVA with a Greenhouse–Geisser correction, the mean RTs differed between tasks ($p < 0.001$, d.f. = 2.568, $F = 125.57$). Pairwise post hoc comparisons showed that tasks A and B did not differ ($p > 0.99$), but that all other tasks differed significantly from each other ($p < 0.001$).

(e) Discussion

These results demonstrate that adults can easily recognize patterns of various sorts, and correctly identify
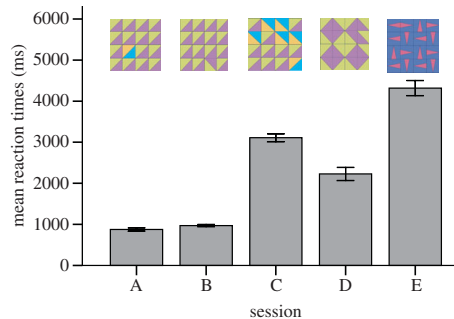
Figure 7. Mean reaction times (milliseconds) for the five tasks in experiment 2. (A) Colour flaw, (B) orientation flaw, (C) conjunction, (D) grouped rotation with tiles that were symmetrical on one diagonal axis, (E) grouped rotation with tiles with vertical/horizontal symmetry. Error bars represent 95% CIs.
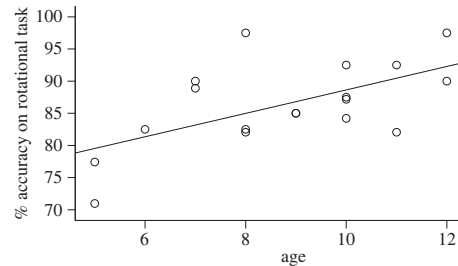

Figure 8. Correlation of percentages of correct responses in grouped rotational patterns and age in children (r^2 linear: 0.358).

violations of these patterns. Very simple 'popout' tasks were trivial, and had high accuracy (98%) and fast reactions. RTs and accuracies for the novel grouped rotation tasks (D and E) were comparable to those in our conjunction task (C). The differences between classes D and E are striking—the presence or absence of continuation or Gestalt grouping cues has a strong effect on RTs (class E responses take about 2 s longer than class D images), but the overall accuracy remains at the same level (88% (D) versus 86% (E)).

6. EXPERIMENT 3. 'SPOT THE FLAW': DETECTION OF PATTERN VIOLATIONS BY CHILDREN

Experiment 2 showed that violations in ordered patterns were easily detected by adults. To determine at what age this skill sets in, we conducted an experiment in the same paradigm with children aged 5–12 years. We focused on the two rotation-based tasks from the previous experiment—a simple translational pattern and the hierarchical grouped rotation pattern. We used the more naturalistic tile elements of experiment 1 for more attractive and interesting stimuli.

(a) *Participants*
Eighteen children (seven female, mean age 8.76, age range 5–12) and 18 additional university undergraduates (16 female, mean age 21.11, age range 18–35) were tested using a 'spot the flaw' task. The undergraduates gave their written informed consent and were paid for participating. A parent or guardian of the child gave their written informed consent, and the children gave their verbal consent and received a small toy for participating.

(b) *Materials*
As in experiment 1, digital reproductions of Spanish, Cuban and Portuguese tiles were used. Five different tile images were used. Tiles were repeated on four sizes of square matrix ranging from 3×3 to 6×6, in both a translational or a rotational pattern (corresponding to task A and D in experiment 2). For each

of these 40 images, a corresponding flawed version was created, in which one tile was rotated an additional 90°, yielding 80 stimuli in total. Only tile images with an internal symmetry along one diagonal axis were used, yielding well-formed Gestalt groups. As in previous experiments, each participant saw all stimuli.

(c) *Methods*
The experimental session began with a short practice session consisting of 6 stimuli made from different tiles than in the main experiment, but which followed the rules and violations to be tested. Participants received verbal feedback from the experimenter as to whether they had pressed the correct button during the practice session, but not during testing. Images were shown one at a time, and the participants again had to indicate whether or not an image contained a flaw by pressing one of two buttons on a button box. The assignment of buttons was counterbalanced between participants. The participants had to make a decision within 7 s, or the image went away and the screen went black for 1 s. After participant response, the image disappeared and the screen went black for one second. Time-out trials were not repeated, and were excluded from analysis. The participants could optionally take a break after 40 trials.

The experiment used custom-written PYTHON software running on an Apple Mac Mini with an IOLAB button box to record responses.

(d) *Results*
Both adults and children performed at high levels of accuracy for both translational and grouped rotational patterns. Adults had 92 per cent correct responses for rotational and 89 per cent for translational patterns, whereas children had 87 per cent correct for rotational and 83 per cent correct for translational patterns. Children's performance was positively correlated with age in the case of rotational patterns (Kendall's Tau-b: $p = 0.026$, $r^2 = 0.358$; figure 8), but not for translational patterns (Kendall's Tau-b: $p = 0.124$, $r^2 = 0.2$). No age/performance correlation was found in the adults.

(e) *Discussion*
We found that even young children were able to perceive both types of pattern organization without

difficulty. Performance when detecting flaws in the simplest rule, translational symmetry, showed no significant improvement with age, whereas the hierarchical grouped rotation rule did. Naturally, it would be intriguing to run a pattern production study such as experiment 1 with children of various age groups to see whether production shows similar development during ontogeny.

7. EXPERIMENT 4. 'SPOT THE FLAW': DETECTION OF PATTERN VIOLATIONS IN INDIVIDUALS WITH AUTISM SPECTRUM DISORDER

Individuals diagnosed with ASD often perform differently in visual tasks [41–43]. Various theories have proposed different processing styles or mechanisms as explanations. The theory of Weak Central Coherence [44–46] maintains that information processing in the visual domain is fundamentally different in individuals with ASD, because the local information is not integrated to a global whole in the same way as in normal individuals, leading to superior performance in tasks that demand a focus on local features, such as embedded figures. Another theory [47–49] posits that a local bias underlies the visual perception in individuals with ASD leading to superior performance in certain visual tasks because there is less distraction from the global information of the stimuli presented. According to this theory, sometimes termed 'enhanced discrimination', global perception is intact, though not as dominant as in normal individuals. Not all studies have consistently shown visual search superiority effect in ASD [50], and in fact some have found diminished performance [51]. A recent experiment reports increased sensitivity detecting displays with mirror symmetry in autism compared with typical individuals, which the authors interpret as an ability to access local and global information in parallel [52]. This variety of results and interpretations may stem from high variability between individuals diagnosed with ASD, and suggests that the differences in performance are probably due to multiple factors, rather than any one single factor.

In the next experiment, we compared performance on the 'spot the flaw' task used in experiment 2 between ASD individuals and age and IQ-matched controls.

(a) Methods
Materials and methods were identical to those described in experiment 2.

(b) Participants
Ten adults diagnosed with ASD (three female, mean age: 22.90, age range: 20–33) and 11 neurotypical adults from the local community (eight female, mean age: 25.36, age range: 20–33) participated in this experiment. All participants, and their guardians if appropriate, gave their informed consent. Participants were paid for their participation. Mean IQ score (as determined by Wechsler Abbreviated Scale of Intelligence test) for the ASD group was 90.8 (s.d. : 19.12) and 101.4 (s.d. : 12.68) for the control group. No significant differences were found between the groups
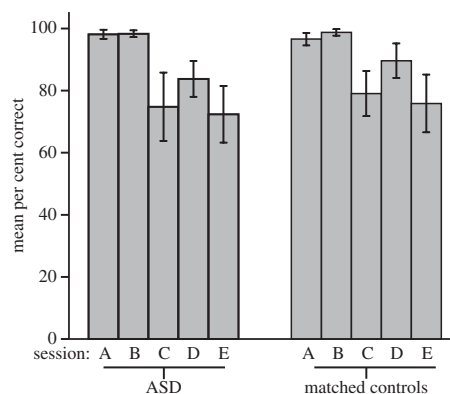
Figure 9. Mean correct responses in per cent for autism spectrum disorder and matched control participants for five flaw detection tasks. (A) Colour flaw, (B) orientation flaw, (C) conjunction, (D) grouped rotation with tiles that were symmetrical on one diagonal axis, (E) grouped rotation with tiles with vertical/horizontal symmetry. Error bars represent 95% CIs.

for IQ scores (Mann–Whitney U-test: $p = 0.148$, $Z = -1.446$) or age (Mann–Whitney U-test: $p = 0.267$, $Z = -1.109$). Furthermore, the differences in IQ scores between males and females were not statistically significant (Mann–Whitney U-test: $p = 0.972$, $Z = -0.35$).

(c) Results
Both groups mastered the tasks with no problems and intuitively understood what counted as a 'flaw' in the pattern. An overview of the mean percentages of correct responses and mean RTs for both groups is shown in figure 9, broken down by stimulus type.

We calculated the mean percentage of correct response for both groups in the different sessions. These values were normally distributed. (Kolmogorov–Smirnov tests, all $p > 0.169$, all $Z > 0.755$.) A mixed-model ANOVA with *stimulus type* (i.e. sessions A–E) as a within subjects factor and *group* as a between subjects factor showed that per cent correct for the different tasks did not differ significantly between the groups (test of within subject effects for session and group affiliation with Greenhouse–Geisser correction: $p = 0.483$, $F = 0.784$, d.f. = 2.380). Mean RTs for each task and participant were normally distributed for all tasks (Kolmogorov–Smirnov, all $p > 0.223$, all $Z > 0.571$). A mixed-model ANOVA showed no significant differences between the groups for the mean RTs for each session (within subject effects for session and group affiliation with Greenhouse–Geisser correction: $p = 0.352$, $F = 1.068$, d.f. = 1.914).

Pairwise comparisons of mean correct responses for each individual group showed significant differences in accuracy between the tasks within groups (repeated measures ANOVA with Greenhouse–Geisser correction, ASD: $p < 0.001$, $F = 22.843$, d.f. = 2.329; controls: $p < 0.001$, $F = 21.762$, d.f. = 1.995). Session C and E did not differ significantly from each

other for either group (ASD: $p = 0.586$, controls: $p = 0.225$), suggesting that the conjunction task and grouped rotation with good Gestalt figures were similarly challenging for both groups. RTs also showed significant differences between the sessions (within subject effect, Greenhouse–Geisser correction: ASD: $p = 0.001$, $F = 14.707$, d.f. $= 1.461$; controls: $p < 0.001$, $F = 63.16$, d.f. $= 2.43$; figure 9). The mean RTs for session E were significantly higher than all other tasks in the control group (all pairwise $p < 0.04$). For the ASD group, the mean RT for session E differed from all sessions (all $p < 0.05$) except session C, the conjunction task ($p = 0.845$).

(d) Discussion

In contrast to previous research on visual search in ASD individuals, we did not find consistently higher rates of accuracy or faster RTs for our ASD group. The control group did show slower RTs in task E than in the other tasks, whereas the ASD group did not show such an effect. Yet, because the percentage of correct responses did not differ between tasks C and E for either group, the apparent speed advantage that the ASD group showed for this, the most difficult task, did not coincide with higher accuracy. However, given that correct responses were all well above chance level, it is not surprising that this possible slight advantage for the ASD group is reflected in RTs rather than differences in response accuracy. Overall, this data reveal no appreciable differences between ASD and control groups in solving our tasks presented to them.

8. EXPERIMENT 5. SERIAL VERSUS HIERARCHICAL ROTATION

(a) Introduction

Experiments 2–4 showed that human participants readily detect violations of rule-based patterns. In this experiment, we initiated a more systematic investigation of the specific types of patterns that can be more or less easily parsed. We used two minimally different production rules. The first implements the most frequently produced pattern in experiment 1 ('grouped rotation'). This hierarchical pattern, made up of sub-units of four tiles, is not affected by changes in grid size, because the four orientations are relative to a fixed point, which leads to mid-level visual groupings of four tiles. If the matrix size is odd, then these groupings are incomplete on the edge, but the overall pattern remains unchanged. The production rule underlying the second, 'sequential' pattern entails that the tiles are rotated by $90°$ when serially progressing along the grid in a Western reading fashion (from top left to bottom right), with no fixed point around which the rotation occurs. Despite their simplicity, patterns with serial rotation were never produced spontaneously in experiment 1. Unlike the grouped rotation, the pattern that is produced with a serial rotation depends strongly on the overall matrix size. Obviously, we cannot know whether the patterns are necessarily perceived using these rules. Indeed, we cannot, at present, speculate about what the rules underlying the parsing of patterns by humans are. However, the

production rules explicitly describe how the patterns were generated computationally.

(b) Materials

We used 13 images of Spanish and Portuguese tiles from the same sources as experiment 3 and arranged them on five matrix sizes, ranging from 2×2 to 6×6, with custom-written NODEBOX software according to both the hierarchical and the sequential rules. Each image was generated in a flawed and unflawed version, yielding a total of 260 images. The tiles were 120×120 pixels, hence the stimulus size varied from 240×240 to 720×720 pixels. As the matrix size increases, the composite structures that emerge in patterns using the serial rotation rule are very different: 4×4 and 6×6 matrices contain structures that repeat along the vertical and horizontal axes, whereas 3×3 and 5×5 matrices contain structures that repeat along the diagonals (see figure 10 for examples). Generally, structures on a diagonal are often more difficult to perceive (oblique effect), most likely due to a diminished neural representation compared with horizontal and vertical structures [53].

(c) Participants

Twelve university undergraduates (nine female, mean age: 20.9, age range: 21–40) took part in this study. They gave their written informed consent prior to the experiment and were paid for their participation.

(d) Methods

The order of all images was randomized. Images were shown one by one on a computer monitor, and the participants had to indicate by pressing one of two mouse buttons whether they found a flaw in the image or not. The assignment of mouse buttons to flawed or unflawed images was counterbalanced across participants. There was no time limit for responding. The software was run with custom-written PYTHON software on an Apple Mac Mini.

(e) Results

Trials with RTs shorter than 200 ms were excluded, as these were most likely accidental button presses (nine out of 3120 trials). Across all grid sizes, participants responded much faster and more accurately for hierarchical 'grouped rotation' than sequential patterns, with RTs roughly twice as long for images with serial rotation (mean RT for serial rotation: 1.66 s, grouped rotation: 3.21). This difference in mean RTs was significant (Mann–Whitney U-test: $p = 0.013$, U: 29).

Accuracy was high for hierarchical patterns for all grid sizes (table 2). Grid size affected accuracy in different ways in the two patterns. In hierarchical patterns, participants were significantly better in the 2×2 images than all other grid sizes (two-way ANOVA, $F_{1,4} = 15.48$, for *matrix size × pattern*: $p < 0.001$, Tukey pairwise comparisons $p < 0.001$) with the exception of 4×4 ($p = 0.09$), whereas in the sequential rotation, participants were significantly better at 4×4 images than all other grid sizes (all pairwise comparisons $p < 0.001$). Differences in performance between grid sizes for the sequential patterns do not
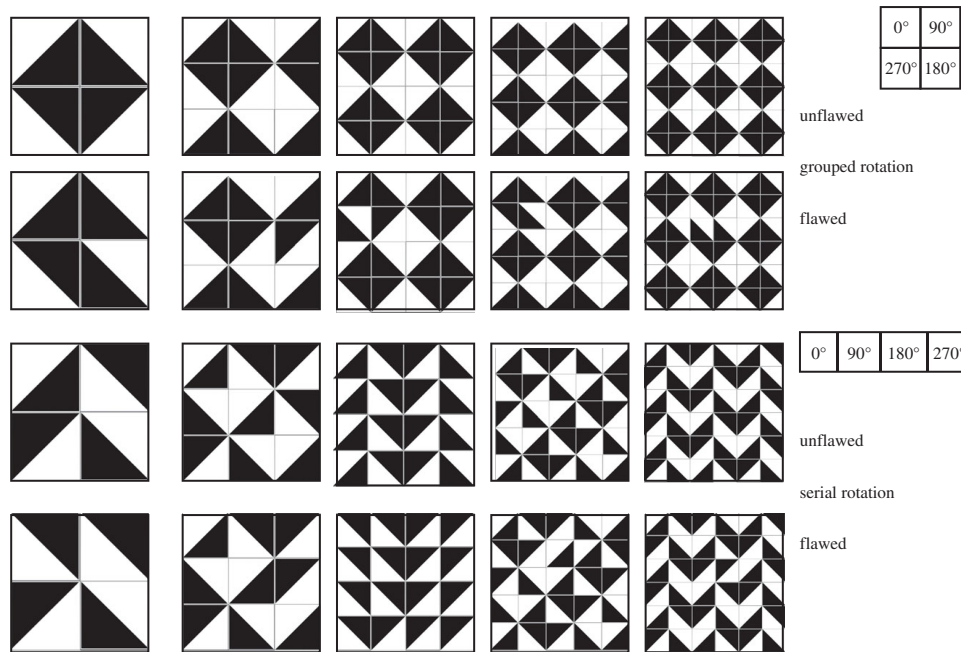
Figure 10. Examples of stimuli generated in matrices ranging from 2×2 to 6×6, in hierarchical grouped and serial rotations, and in flawed and unflawed versions (recreated in black and white).

Table 2. Accuracy (in %) for hierarchical and sequential patterns.

pattern	2×2	3×3	4×4	5×5	6×6
hierarchical	98.4	87.8	92.6	85.9	87.5
sequential	59.5	65.9	88.4	62.1	66.2

appear to reflect an oblique effect, as there is no statistical difference between 5×5 grids (diagonal repetition) and 6×6 grids (vertical repetition), $p = 0.96$. Accuracy was lower in the serial rotation task but still above chance. We computed d'-values as a measure of sensitivity to flaws in patterns [54,55]. D'-values were higher for all participants on grouped rotation (mean d' for grouped: 3.01, for sequential: 1.03), and in total were significantly higher for this pattern (Wilcoxon-signed rank test: $p = 0.002$, $Z = -3.059$). We conclude that the production preference for hierarchically grouped patterns, observed in experiment 1, is closely mirrored by perceptual performance. Participants found a computationally simple but visually non-intuitive pattern quite difficult to parse but performed above chance, even though they were unlikely to have encountered such patterns earlier.

(f) Discussion
Results from experiments 2–5 provide strong evidence that humans intuitively understand a concept of orderedness in visual patterns and use it to reliably

detect violations in patterns of varying levels of complexity. Whether animals detect such rules in two-dimensional patterns remains unclear. Testing these questions is not easy—the animal in question has to be highly visual (using vision either for foraging or navigation, or both) and trainable in a laboratory setting. We decided to use pigeons as a first species to test on our patterns, as their visual system is well understood and a large body of research shows that they can be excellent visual learners.

9. EXPERIMENT 6. 'SPOT THE FLAW': DETECTION OF PATTERN VIOLATIONS IN PIGEONS
(a) Introduction
Visual perception is well studied in pigeons [56], and it seems clear that in many ways their perception is different from humans. For example, when presented with stimuli that are hierarchically organized, with information available on the local and global level, typical humans give precedence to global-level information rather than local [57]. Studies on pigeons reached conflicting conclusions concerning their global parsing abilities. Cavoto & Cook [58] found that pigeons learned to discriminate between shapes based on local information more readily, suggesting that local information takes precedence in their visual processing. By contrast, Goto *et al.* [59] found that global-feature properties were acquired faster than local features, as in humans.

Rotational violations of translational patterns (see experiment 2, task B) could be detected using only local perception, i.e. spotting the one tile that has a different orientation than any neighbours. However, solving the same task with a hierarchically grouped pattern requires processing beyond the strictly local level, as the 'flawed' tile does not have a unique orientation in the array. Thus, recognizing a flaw requires that the orientation of each tile be checked against its neighbours to see whether or not the orientation fits.

In this experiment, we tested orientation flaws in both translational patterns and grouped rotational patterns, and included a simple control task consisting of detecting a colour flaw.

Pigeons outperform humans on tasks that involve judging whether complex geometrical shapes are identical in various rotations [60], but perform worse than humans on tasks that require them to judge whether or not an object contains bilateral symmetry. Delius and co-workers found some evidence for bilateral symmetry recognition in pigeons [61,62], whereas Huber *et al.* [63] did not.

(b) Subjects
Eight pigeons (*Columba livia*) participated. All birds were socially housed in outdoor aviaries in Vienna. The experiment was conducted in accordance with Austrian animal protection laws; see Huber [64] for animal housing and care procedures. The birds were trained 5 days a week, and had free access to water and grit in their aviaries. On days when experiments were conducted, food was available only during or immediately after the experimental sessions.

(c) Materials
We used square 4×4 matrices. Four tiles with different internal features and four colours (red, blue, yellow and green) were used. The tiles were divided along the diagonal, with the colour division being roughly equal between the two halves. Each tile consisted of two colours. All possible colour combinations were used in the tiles, and the tiles either had $0°$ or $90°$ initial orientations, leading to 96 flawed and unflawed image pairs in total. The stimuli measured 3.7×3.7 cm on screen—the tiles were squares of 0.7×0.7 cm, with 2.5 mm black borders between the tiles. The tiles were arranged either in a translational or a rotational pattern (figure 11). The stimuli were generated with custom-written NODEBOX software.

In the colour control task, the target consisted of one tile that had the correct orientation, but a different colour combination than the other tiles. The target was randomly located in the matrix. For both rotational and translational patterns, the violation was unique in the array only due to its distinctive colour features. In the structure task, the target was one tile which had an orientation that did not follow the pattern, but had the same colours as the rest of the array. Crucially, the violation was unique in the matrix in the translational pattern only. In the rotational pattern, the target was not unique in the array and could only be detected if the relation of the tile to its neighbours was taken into account.
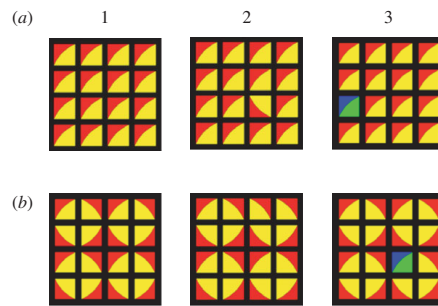
Figure 11. Examples of patterns used in experiment 5. (*a*) Translation and (*b*) grouped rotation: (1) unflawed, (2) with orientation and (3) colour flaws.

(d) Apparatus
The pigeons were individually placed in an experimental chamber, equipped with an infrared touch screen (CarrollTouch, 15″). Underneath the touch screen was an opening through which a feeding device provided grain rewards after a correct response. The feeder tray was raised and illuminated for 3 s to provide a food reward. The experiment, including the apparatus, stimulus presentation and data recording was run using the software COGLABLIGHT, v. 1.9 (Michael Steurer).

(e) Methods
One group of experimentally naive birds ($n = 4$) were trained on a colour task, and one group of experienced birds ($n = 4$) were trained on both the colour and structure targets in a Go/No-Go paradigm (see [65] for an extensive description of the apparatus and paradigm). One image, either flawed or not, was presented at a time. Within each group, half the birds were trained to peck on images with a flaw to get a food reward, whereas the other half were trained to peck on images with no flaw.

The number and timing of the bird's pecks in the first 10 s of stimulus presentation were recorded for analysis. After a varying time interval (VI) of 10–30 s, the pecks were again counted to trigger the reward. In this final phase of the trial, the bird had to peck at least five times, and three times within 3 s on an S+ or 'Go' image to get a food reward. If a negative (S−) image was shown, the bird had to withhold pecking for at least 8 s after the VI (No-Go). No reward was given for withholding pecking. Pecking on a No-Go stimulus was not penalized, except that the image did not go away and the trial did not finish until pecking was withheld for the requisite time period. The order of trials was randomized. The criterion for passing the task was five successive sessions with ρ-values significantly above chance ($\rho > 0.726$). The ρ-value is derived from the U-value in a Mann–Whitney test, and is commonly used in categorization experiments [66,67]. The training was aborted if the bird did not reach this criterion after 165 sessions (3960 trials).
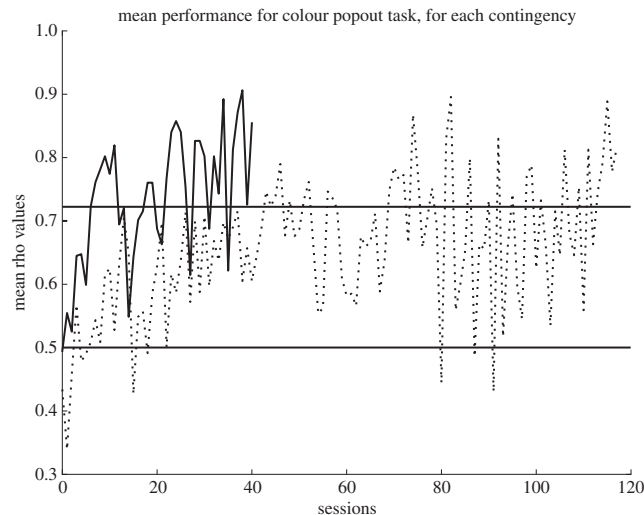
Figure 12. Training progress of pigeons ($n = 4$) on the colour flaw task. Dotted line, flawed image is S−; solid line, flawed image is S+. The upper horizontal line represents the significance threshold ($\rho = 0.72$), whereas the lower line represents chance level ($\rho = 0.5$).

In addition to the colour control task, the four experienced birds were also trained to distinguish between images that did or did not contain a structural flaw. All birds were tested on both patterns (two starting with translational and then rotational, and two birds in the reverse order). For half the birds, the flawed image was (S+).

(f) Results

All eight birds mastered the colour task. Both naive and experienced birds showed a feature positive effect [68,69], i.e. those birds trained to peck on images that contained a colour flaw reached criterion significantly faster than birds trained to peck on images that did not contain a flaw (Mann–Whitney U-test: $p = 0.029$, $Z = −2.309$; figure 12).

Despite their success in the colour task, none of the birds managed to discriminate reliably between the two image classes in the orientation task regardless of whether the flaw was located in a translational or rotational pattern, or whether it was (S+) or (S−) (see electronic supplementary material). Training with structural flaws failed to reach criterion and was aborted after 165 sessions (3960 trials).

Thus, pigeons learned to detect a colour feature with relative ease, but a task that requires the detection of a structural feature, even a simple one, was not mastered by the birds in this experiment.

(g) Discussion

These results are surprising because, in principle, the unique structure feature in the translational pattern should be solvable by strictly local processing. The fact that the birds consistently failed the task suggests that rotational invariance may make orientation anomalies hard to detect. However, Cook *et al.* [70]

have shown that pigeons can differentiate vertical and horizontal orientations of the same object, and that performance is no worse and acquisition no slower for this orientation cue than for colour or size cues. The stimuli in that study also consisted of identical elements arranged on a square grid, but differed from ours in that the target was not one single element with a different orientation, but a square group of 7×6 elements with a different orientation than the rest of a 24×16 matrix, thus the orientation targets took up a larger portion of the matrix overall. The stark contrast in performance between the colour and orientation tasks suggests that our pigeons had severe difficulties processing the types of patterns that all groups of humans mastered in the preceding experiments.

10. SUMMARY AND GENERAL DISCUSSION

The picture that emerges from this suite of experiments is very clear: humans are excellent at parsing and creating ordered patterns. Patterns spontaneously created in experiment 1 are not only highly ordered, but also show symmetries of various types. Evidently, humans have a strong drive to impose order on random arrays, and do so without instruction. Furthermore, our participants gave ordered patterns higher preference ratings than random patterns, providing empirical support for Gombrich's assertion that humans prefer ordered visual arrays over random ones. In the patterns spontaneously produced, the most frequent pattern (grouped rotation) was observed most often in participants' first encounter with a new tile, and dropped off when the tile was encountered a third time, suggesting that there is a trade-off between reaching an 'obvious' default solution to the self-imposed task of

creating ordered arrays and exploring creative, but not necessarily symmetrical, tile arrangements

In our perceptual studies, we contrasted perception of a very simple pattern, translational symmetry, with the most frequent pattern from the pattern production experiment, grouped rotation, by normal adults, individuals diagnosed with ASD and children. All of our human participants intuitively understood what a pattern was and what counted as a violation. Performance for adults was at very high levels, and ASD individuals performed at the same levels of accuracy as age and IQ-matched neurotypical participants.

Finally, approaching the question of pattern perception from a comparative direction, we investigated which violations of patterns pigeons could detect. In sharp contrast to humans, the pigeons tested on structural violations clearly failed at the task, whereas succeeding on a comparable colour task. The universal mastery of the task in humans, contrasted with the pigeons' failure, suggests that visual patterns tap into cognitive skills that might be phylogenetically unusual: creating and parsing rule-governed structures that can be reiterated indefinitely seems trivially easy to humans. Surprisingly, pigeons—a highly visual bird species—could not master such structures.

Given that language, music and the visual arts are all typical aspects of human cultures worldwide, we might ask to what degree the cognitive resources that underlie these three domains are shared and general, versus domain-specific. A growing body of research suggests that music and language may share processing resources in the brain [71]. When we contrast abstract visual patterns with this pair, two immediate comparisons suggest themselves: hierarchy and symmetry.

Regarding hierarchy, both music and language are typified by hierarchical, tree-like structures, in which small constituents are combined into larger and larger components to create a multipart whole. Although abstract visual patterns do not need to display such hierarchy, we found that humans, left to their own devices, have a strong propensity to generate hierarchical patterns (the 'grouped rotation' pattern being the most common), and that perceivers find such patterns easy to process. Furthermore, discrimination over hierarchical patterns improves in children with age, implying that the underlying cognitive processes of these visual patterns develop increasing sophistication with maturity. In general, our results suggest that hierarchy represents an important similarity of decorative visual patterns with musical or linguistic patterns.

By contrast, symmetry seems to be a domain of difference between visual patterns and music or language—at least superficially. Syntactic structures in language tend to be asymmetrical [72], with tree structures branching either to the right or left depending on the language. By contrast, both artisanal decoration and the patterns generated in our experiments tend to show one or more axes of symmetry. However, this apparent dissimilarity may be an artefact of linearization in the acoustic domains, i.e. reducing dimensionality from a multi-dimensional (and more symmetrical) conceptual space down to a one-dimensional auditory/vocal stream. Visual patterns extending in a two-dimensional plane are not similarly constrained—unlike language,

their output entails no inherent structural asymmetry. If visual pattern perception relies upon processing resources that overlap with those of language and/or music, then the greater dimensional freedom of two-dimensional patterns may offer new insights into types of dependencies and symmetries that can be processed by these general perceptual mechanisms, including types that by definition cannot occur in music or language, such as multi-dimensional long-distance dependencies. We believe that applying the theoretical framework of formal language theory to two-dimensional patterns offers a rich new perspective on the human capacity for producing regular, hierarchically organized structures. Such visual patterns may actually prove more flexible than music or language for probing the full extent of human pattern processing abilities.

With the results presented here, we have taken the first steps in decoding the uniquely human fascination with visual patterns, what Gombrich termed our 'sense of order'.

Although the patterns we studied are most similar to tilings or mosaics, they are examples of a much broader type of abstract plane pattern, a type found in virtually all of the world's cultures [4]. Given that such abstract visual patterns seem to represent human universals, they have received astonishingly little attention from psychologists. This neglect is particularly unfortunate given their democratic nature, their popular appeal and the ease with which they can be generated and analysed in the laboratory. With the current research, we hope to spark renewed scientific interest in these 'unregarded arts', which we believe have much to teach us about the nature of the human mind.

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3.1 Supplementary material

Production and Perception Rules Underlying Visual Patterns: Effects of Symmetry and Hierarchy

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Experiment 4:

Concerning the nature of the deviation of the regularity (local or global), we attempted to address this question by analysing whether the differences in matrix size affected the performance of the groups differently. An uneven grid size necessarily leads to one row and column of incomplete 2x2 figures in grouped rotation patterns. Given that individuals with ASD are said to give precedence to local information, while individuals without this condition give precedence to global structure, it might be expected that the performance of participants with ASD are less affected by an odd matrix size (i.e. 3x3 or 5x5). For tiles with diagonal symmetries that do not form good Gestalten (Diagonal 2 in he table below), both groups perform slightly better on even matrix sizes than odd, but the differences are in the same direction for both groups.

	Diagonal1	Diagonal2	Horizontal	Vertical
ASD Even	56	78	46	56
ASD Odd	56	70	53	58
Control Even	67	86	57	76
Control Odd	72	81	54	77

Table 1: Percent correct for ASD and control groups for images with even and odd grid sizes and different tile types. Diagonal 1: tile withdiagonal symmetry that does not form a good Gestalt; Diagonal 2: tile with diagonal symmetry that forms a good Gestalt; Vertical: Tile with vertical symmetry;Horizontal: Tile with horizontal symmetry.
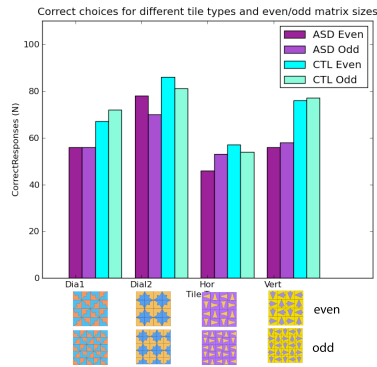
Figure 1: Mean percent correct for AS and control groups for images with even and odd grid sizes and different tile types

Experiment 6:

Methods

One group of experimentally naïve birds (n=4) were trained on a colour task, and one group of experienced birds (n=4) were trained on both the colour and structure targets in a Go/No- paradigm (see e.g. (53) for an extensive desciption of the laboratory setup and paradigm). Within each group, half the birds were trained to peck on images with a flaw to get a food reward, while the other half were trained to peck on images with no flaw.

The images were positioned in the centre of the screen on a black background. The number and timing of the bird's pecks in the first ten seconds of stimulus presentation were recorded for analysis, which was not perceptible to the birds. To avoid temporal cueing, a variable interval (VI) of 10 to 30 seconds followed, during which the bird's pecks were not counted. After the VI, the pecks were again counted to trigger the reward. Once the counter restarted in this final phase of the trial, the bird had to peck at least five times, and three times within 3 seconds on the image if a positive (S+) image was presented (Go). After the requisite number of pecks, the image disappeared and the birds had access to food for 5 seconds. If a negative (S-) image was shown, the bird had to withhold pecking for at least 8 seconds after the VI (No go) for the image to disappear from the screen and the next trial to begin. No reward was given for withholding pecking. The order of trials was randomised; however at most three images of the same contingency category were shown in succession, and the first image of a session was always positive (S+). The criterion for passing the task was five successive sessions with rho values significantly above chance (rho>.726). The rho value is derived from the U value in a Mann-Whitney test, and is commonly used in categorisation experiments; see (54, 55). The training was aborted if the bird did not reach this criterion after 165 sessions (3960 trials).

The four experienced birds were also trained to distinguish between images that did or did not contain a structural flaw. All four birds were tested on both

patterns (2 starting with translational and then rotational, and 2 birds in the reverse order.) For half the birds, the flawed image was (S+).
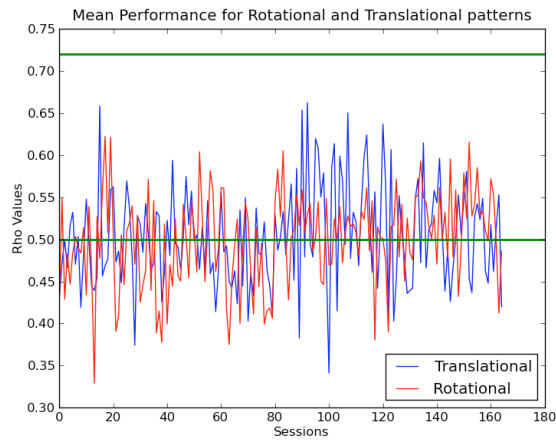*Results:*

Figure 2: Training progress on the orientation task for four birds trained on both rotational and translational patterns. Red line: grouped rotation; Blue line: translation. Upper line represents threshold for statistical significance (rho = 0.72), lower line represents chance level (rho =0.5)

4 | Further production and preference experiments

Studying Aesthetics With the Method of Production: Effects of Context and Local Symmetry

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We investigated the role of local and global context on visual patterns produced by normal participants, examining the effects of both top-down context (framing) and bottom-up content (element-internal symmetry) in a computer-based experimental framework. In the first study, we allowed participants to generate rectangles of arbitrary proportions and found an effect of framing on width-to-height ratios of rectangles produced, demonstrating the importance of taking visual framing into account when discussing human shape preferences. In a second study, using FlexTiles, an interactive pattern-generation framework, we showed that the patterns humans produce are influenced by local symmetrical properties of pattern elements. Participants also had to indicate preferences between pairs of pattern variants. We found that in some cases, pattern preferences and pattern production lead to different results. We conclude that visual context, either in the form of visual framing or local symmetries, changes aesthetic patterns that humans produce and prefer in predictable ways. These differences between the productive and perceptual preferences highlight the importance of using multiple methods when studying the human aesthetic sense.

Keywords: pattern, production, symmetry, preference, aesthetics

Gustav Fechner, the founding father of empirical aesthetics, proposed three different approaches to exploring human aesthetic sensibilities (Fechner, 1871). The first and most traditional he termed the "method of use." This entails simply observing aesthetic objects in the world, and attempting to analyze and evaluate patterns in these natural data. The second, and most typical of contemporary research, is termed the "method of choice." Here, stimuli created by the experimenter are presented to participants whose ratings or preferences are recorded and analyzed. Fechner termed his third, and most neglected, approach the "method of production." Here, participants create their own aesthetic objects in the laboratory. Fechner stressed that in order to gain meaningful insight into the nature of any particular aesthetic phenomenon, it is crucial that at least two of the three methods should be used to study it (Fechner, 1876). The advantage of the method of production is that it is less constrained by the experimenter's preconceptions and cultural norms, which inevitably influence the first two

methods. The typical disadvantage is, of course, directly linked to this freedom: In any but the simplest contexts, we expect an explosion of diversity and variability that would defy attempts at rigorous analysis. A group of participants given paper and crayons or paints and a blank canvas can hardly be expected to produce replicable results amenable to statistical analysis. Even if strong cultural biases were controlled for, too many individual factors would influence the resulting artwork, from mood and personality to artistic skill, for us to expect any profound or insightful analysis of the whole ensemble. This problem is intrinsic to the method of production. One way around it is to provide an extremely simple and constrained environment of production in which aesthetic preferences can nonetheless be elicited. For example, a considerable amount of work has examined simple rectangles that participants produce and prefer. The beauty of this approach is that the outcome can be appropriately summarized in a single number: the width/height ratio of the rectangle. Unfortunately, however, the results of this research are rather inconsistent, with Fechner's early finding of a strong preference for the classical "golden ratio" of about 1.6 (ϕ) being upheld in some studies, but failing in many others (see below).

In his book *The Sense of Order*, Ernst Gombrich put forth the hypothesis that humans have a strong drive to surround themselves with ordered, symmetrical objects and patterns. The decorative results of this "sense of order" are so pervasive, that, much like fish in water, we typically do not notice the constant presence of human ordering principles in our surroundings. This led Gombrich to dub ornament the "unregarded art" (Gombrich, 1984). Although real-life decorative patterns have been extensively studied (Grünbaum, 2006; Washburn & Crowe, 1988; Wichmann, 2008), little

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research has been conducted on how people produce such two-dimensional (2D) patterns.

We recently introduced such a method of production in Westphal-Fitch, Huber, Gómez, & Fitch (2012) using a computer interface to provide a relatively complex stimulus and an open-ended production task, with tightly constrained operation(s) available to the participant. Our first study in this vein used a software interface called FlexTiles, in which a matrix of square tile images can be manipulated by clicking them, which rotates the targeted tile by 90°. Participants in this study, presented with an initial random array, were very consistent in their behavior. Although they were instructed simply to click as often and wherever they wanted, and then to indicate when they were finished, virtually all subjects clicked in such a way as to produce highly ordered and structured stimuli. They thus reliably manifested Gombrich's sense of order in the laboratory. Furthermore, one particular pattern, typical of real-world tilings, was often produced first, and was produced at least once by all subjects. Despite this consistency, participants were not uncreative: When given the opportunity to produce a second or third pattern with the same tile array, they were creative and often generated quite different and more unusual arrangements. Thus, this novel approach to empirical aesthetics combines a desirable stimulus complexity and freedom of expression with constraints, leading to replicable results amenable to statistical analysis.

The studies reported here build on these initial findings in two ways, with the general goal of understanding the various factors that influence the patterns produced by normal participants. First we use a novel computer-graphics framework to investigate the role of global context on the production of a simple single-element pattern: a rectangle whose height and width could be freely varied. This experiment revisits the very old and controversial issue of the aesthetic significance of the golden section by allowing participants to generate rectangles by dragging a computer mouse. We analyze how visual context (specifically, the frame within which the rectangle appears) affects participants' productions.

In the second study, we take a bottom-up approach, examining the role of element-internal symmetry on global pattern production in the FlexTiles interface discussed above. Here, we explore the specific effect of tile-internal symmetry (diagonal, orthogonal, or none) on the patterns produced and preferred. Both of these studies clearly illustrate the value of production-based approaches to a richer understanding of basic aesthetic proclivities.

Experiment 1: Rectangle Production

In our first experiment, we used a simple computer interface to allow participants to draw rectangles of a size and proportion of their liking. The overall issue we hoped to explore was the preference (or lack thereof) for simple ratios, and particularly for the golden section ($\phi = 0.618$ or 1.618), which has attracted great attention in aesthetics since the ancient Greeks proposed it as an "ideal" and pleasing proportion. This "golden section hypothesis" has accumulated what is probably the largest literature in empirical aesthetics, dating from the seminal works by Fechner (1871, 1876), which report a strong preference for "golden rectangles" with width/height ratios around ϕ. Since then, interest in this topic has waxed and waned, but the overall literature is full of contradictory findings, with some studies reporting strong preferences

for golden rectangles (or other shapes), some finding weak preferences, and some finding none at all (for an authoritative review see Green, 1995). Although most of these studies were based on choice and/or preference ratings, several studies also used the method of production by having participants draw a rectangle on paper (e.g., Davis, 1933). Based on this prior literature, we developed hypotheses that might help explain this lack of consistency.

First and foremost, we hypothesized that the context in which the rectangles are presented and/or drawn may play a major role in determining the experimental outcome. For example, in drawing studies we may expect the proportions of the paper to influence the rectangle drawn, whereas for computer-based presentations, the screen dimensions might be important. When actual cardboard rectangles are presented, we may expect the proportions of the table upon which they are laid to play a role. Such contextual details are often omitted from the published reports, making this hypothesis difficult to evaluate in most of the literature. To test it, we asked our participants to generate rectangles in four different contexts: no frame, square frame, and either horizontal or vertical rectangular frames. Interestingly, a similar experiment was already proposed by Fechner in 1865, but to our knowledge, the effect of framing rectangles within larger rectangles has never been tested empirically.

The other issue we hoped to examine was the influence of culture, in a broad sense, on aesthetic preferences. Berlyne (1971) found some rather subtle differences in rectangular preferences between Japanese and Canadian schoolgirls, and in particular, found that the Japanese group tended to prefer squarish rectangles (and that both groups frequently chose squares as their best-liked shape). Canadians were about twice as likely as Japanese to initially choose the golden rectangle. Furthermore, there is some empirical evidence that East Asians tend to have a more holistic visual perception, for example paying more attention to background information in a scene than do Westerners (Ji, Peng, & Nisbett, 2000; Nisbett, 2003; Nisbett & Miyamoto, 2005). To gain first insights into the importance of this issue, our participants were roughly half Korean and half Western. There are of course many other possible contributing factors to context (see Discussion), some of which are easier to exclude or vary than others, but these two provide a start to evaluating the strength of these various contextual effects.

Method

Participants. We recruited 12 Korean (6 female, mean age 27.7 years, range: 25–31 years) and 11 Western participants (6 female, mean age 31.8 years, range: 24–44 years). The Western participants originated from Austria, Germany, Canada, Russia, Croatia and Italy and were recruited at the University of Vienna. On average, the Korean participants had spent 2.9 years in Austria (range: 0.1–7 years). The data of one Western participant had to be excluded due to a software problem. The Korean participants were recruited through informal connections to the Korean community in Vienna. A Korean native speaker was present before and after the experiment to provide clarifications for the Korean participants.

All participants gave their written informed consent prior to taking part. They received chocolate for participating. The Korean

participants also received €5 as compensation for traveling to the University of Vienna especially for the experiment.

Materials and procedure. This experiment had four conditions: (a) no frame, (b) square frame, (c) horizontal frame (1.6 width/height ratio), and (d) vertical frame (0.6 width/height ratio). The images were projected on a blank white wall (4.84 × 2.7 m) in an empty room. In the no-frame condition, the participant saw only a white starting point (5 × 5 pixels) on a black background, whereas in the other conditions, a gray frame (2 pixels in width, red, green, blue (RGB) values: 0.5, 0.5, 0.5) was shown on the center of the projector screen, within which the white starting point was centered. On an LCD projector, colors are projected with additive light (e.g., white is a mix of red, green and blue light). Black is shown by an absence of light, that is, black, when projected, blends into a white background with no visible boundary, in particular when the ambient light in the room is bright. Hence, the ceiling lights remained switched on during the experiment. The area of the shape that the participants could change was constrained by a visible frame in the case of the framed conditions, and by an invisible square boundary in the unframed condition. The available area for the rectangles was the same for the framed conditions, as closely as could be achieved using whole pixel units (see Table 1 below for an overview of the frame conditions). Each condition comprised 10 trials presented in a block, and the conditions were presented in random order. The unframed condition was shown twice in the course of the experiment, and all others were shown once, leading to a total of 50 trials per participant.

Participants were seated directly behind the projector, approximately 374 cm away from the wall. They used a wireless mouse to change the dimensions of the shape, which always remained centered on the screen. By pressing and holding the left mouse button, the dimensions of the rectangle (width and height) could be changed. For every pixel that the mouse moved, two pixels were added to the shape in the direction that the mouse moved. For example, if the mouse moved one pixel vertically, 2 pixels were added to the height of the shape, and the center of the shape was recalculated on the fly by the software, and aligned with the center of the screen. Consequently, regardless of how its dimensions were changed, the shape remained centered on the screen for the participants. To finish, the participants clicked on the right mouse button, which ended the trial, and they had to click an "OK" button on a pop-up window to continue to the next trial. The experimenter was present in the room and sat behind an opaque barrier so that neither the participant nor the projected image was visible to her.

The experiment was run on an Apple MacBookPro (Cupertino, CA) using custom Python software (Beaverton, OR; Version 2.6.4; www.python.org). The images were projected with a NEC NP-M350X projector (Tokyo, Japan) placed on a table, 293 cm from the wall, resulting in an overall screen size of 222.5 cm (width) × 166 cm (height), which, however was not visible to the participants. We used SPSS (Versions 17 and 19, Armonk, NY) and R (Version 2.15.1, Vienna, Austria, r-project.org) for statistical tests and graphs.

Results

To ensure that participants had made appreciable changes in both dimensions, we excluded those trials in which the height and/or width of the 5 × 5 pixel starting point had been changed by less than 5 pixels. Furthermore, we excluded those trials in which *both* parameters were at their maximum value (i.e., the participants had filled the available space completely) because this simply resulted in rectangle proportions identical to the frame, inevitably confirming our framing hypothesis. These two exclusions reduced the number of trials from 1100 to 919. The rectangles can be fully characterized by two values: size (area) and proportions (width/height ratio).

We found no significant differences between the mean area or width/height ratio for the two unframed conditions, area: paired-samples t test, $t(21) = -.48$, $p = .638$; width/height ratio: paired samples t test, $t(21) = .28$, $p = .78$, so we pooled the no-frame data.

We used an alpha level of .05 for all statistical tests, and applied a Bonferroni correction when multiple tests were conducted. As the histograms of the width/height ratios (Figure 1A) show, the distributions are spread widely. There were a nontrivial number of outliers with large ratios (horizontal stripes). Rather than excluding outliers based on an arbitrary cutoff point, we log-transformed the data, which reduced the influence of these outliers considerably (Figure 1B). Results are reported for both raw and log-transformed width/height ratios. In the histograms of the raw ratios, there are peaks around 1.5 and 1 width/height ratio for the horizontal frame; in contrast, there is a single clear peak around 0.6 for the vertical frame, demonstrating an effect of framing. To evaluate this rigorously, we conducted repeated-measures ANOVAs on the mean values of three measures: area, area fraction (proportion of the area of the produced shape relative to available area) and width/height ratio (see Table 2 for an overview). One Korean participant was excluded from the repeated-measures analysis because in one condition, he only produced stripes of less than 10 pixels width or height. By our exclusion criteria, these all had to be excluded, leaving no valid trials. For all ANOVAs performed, we found no significant main effect or interaction of ethnicity. Hence, except where explicitly noted, we report the results with Korean and Western participants pooled.

Table 1

Overview of the Four Frame Conditions in Experiment 1

Condition	Frame dimensions (Width × Height, in pixels)	Frame dimensions (Width × Height, in cm)	Frame area (in cm²)	Visual angle (width of stimulus)
No frame	800 × 800*	173 × 173*	29,929*	19.92*
Square	474 × 474	102 × 102	10,404	12.26
Horizontal	600 × 375	130 × 80	10,400	15.63
Vertical	375 × 600	80 × 130	10,400	26.67

* In the "no frame" condition, the specifications refer to the largest possible shape that could be produced.

A: Width/Height Ratio (untransformed, outliers not illustrated)
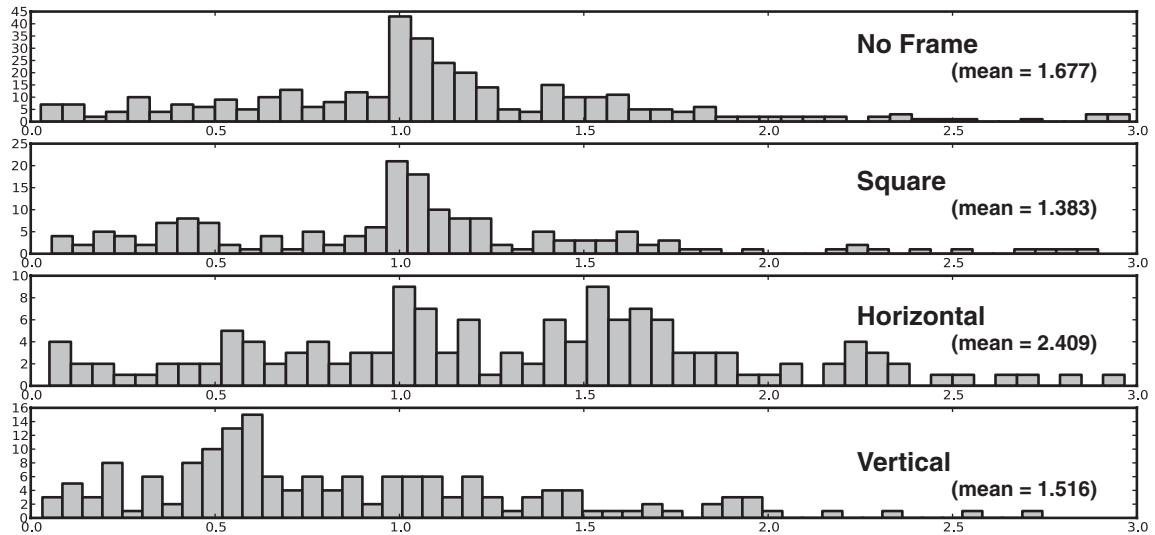
B: Width/Height Ratio (log transformed, outliers shown)
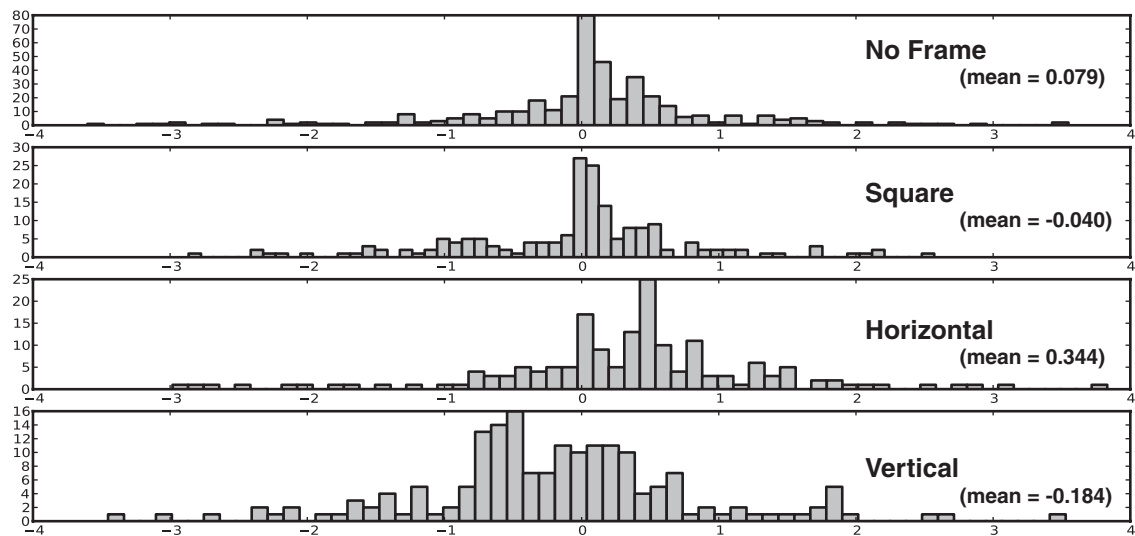
Figure 1. Histograms of width/height ratios (all participants included). A: Distribution of untransformed ratios. Because there were many large outliers, only ratios between 0 and 3.0 are shown; however, the means shown are for all data. B: Distribution of natural log-transformed ratios (all data are shown).

Area. We conducted a one-way repeated-measures ANOVA analysis with the frame conditions as a within-subjects factor. We found that that there were significant differences in the areas of the shapes produced, $F(1.23, 24.62) = 25.7$, $p < .001$, Greenhouse–Geisser correction for spherical data; the area of shapes for the unframed condition was significantly larger than the other three conditions, paired-samples t test, $t(20) = 5.08–5.67$, $p < .001$, Bonferroni-corrected significance threshold = .0083), and the

Table 2

Overview of the Mean Area, Mean Area Fraction, Width/Height Ratio of Shapes Produced in Experiment 1

Condition	Mean area (in total pixels)	Mean area fraction (in %)	Mean width/ height ratio
No frame	175,383	27.4	1.68
Square	54,044	24.1	1.38
Horizontal	64,013	28.5	2.41
Vertical	57,164	25.4	1.52

three framed conditions did not differ significantly from each other in area, paired sample t tests, $t(20) = -1.24$–1.42, $p > .17$. Bonferroni-corrected significance threshold = .0083.

Area fraction. However, this size difference between the unframed condition and the framed conditions might be due to the fact that the overall size available was constrained to a smaller area in the framed conditions. To evaluate this, we calculated the fraction of the total available area that the produced shape occupied and conducted a one-way repeated-measures ANOVA analysis on this, with frame type as a within-subjects factor. We found that there were no significant differences, $F(3, 60) = 0.83$, $p = .481$ in the area fractions between conditions, confirming our guess that larger shapes in the unframed condition are due to the fact that participants had a larger area to work with.

Width/height ratio. A repeated-measures ANOVA on untransformed ratios, with frame type as a within-subjects factor, showed that there were significant differences in the width/height ratios of shapes produced in the different conditions, $F(2.32, 46.31) = 5.13$, $p = .007$, Greenhouse–Geisser correction. Post hoc tests revealed a significant difference between the horizontal and square conditions: paired t test, $t(20) = -2.99$, $p = .007$. Though the difference between horizontal and vertical conditions approached significance, it was not below the Bonferroni-corrected threshold: paired-samples t test, $t(20) = 2.8$, $p = .011$. All other pairings did not differ significantly (all ps > .0083). Thus, there was a clear effect of frame condition, even with the untransformed data.

Based on the histograms, it seemed likely that a high number of outliers were obscuring differences between the conditions. We thus ran another repeated-measures ANOVA using logtransformed width/height ratios as the dependent variable. We again found a significant effect of frame condition: $F(2.23, 42.35) = 12.54$, $p < .001$, Greenhouse–Geisser correction. However, now post hoc tests showed that four of the six possible comparisons of the conditions differed significantly from each other, $t(20) = -3.98$–4.6, $p < .004$, with the exception of square versus vertical: paired-samples t test, $t(20) = 1.73$, $p = .1$ and square versus unframed: paired-samples t test, $t(20) = 2.1$, $p = .049$, not significant after Bonferroni correction. All other comparisons of framing contexts showed significant changes in the proportions of the rectangles produced.

Shape categories. We classified the shapes as either horizontal (width > height), vertical (height > width) or square (width ≈ height). Given the difficulty of matching height and width exactly by eye, we allowed up to 5% discrepancy between width and height in the square category. Horizontal shapes were the most frequent shape type for all conditions except the vertical frame condition, in which vertical shapes were most common (see Table 3).

The distribution of shape types for the various frame conditions deviated significantly from random: Pearson $\chi^2(6, N = 399) = 68.63$, $p < .001$. Our results also show that Koreans produced slightly higher numbers of squares than Westerners (69 vs. 39), providing some support for Berlyne's ethnicity findings. However, though the number of produced squares did depend on frame type—repeated-measures ANOVA with Greenhouse–Geisser correction, frame condition as within-subjects factor, ethnicity as between-subjects factor, $F(1.7, 32.24) = 10.07$, $p < .001$—there was no significant effect of ethnicity across conditions, $F(1.7, 32.24) = 2.34$, $p = .12$. That is, the same basic pattern is true for both cultural groups: Horizontal shapes are produced most frequently, with the exception of vertical frames, in which vertical shapes are most frequent, as Figure 2 shows.

Discussion

This study revealed a strong and consistent effect of framing on the rectangles that our participants produced. First and most obvious, significantly larger shapes were produced in the no–frame condition, but this seems to result simply from the interface allowing the possibility of larger rectangles in this condition. When looking at the area of the shape compared with the overall available area for the different conditions, we found that on average, between 24.1 and 28.5% of the area was filled (see Table 2). We interpret this as a somewhat trivial type of context dependence: The area of produced shapes is dependent on the area available.

More intriguing are the pronounced effects of frame context on proportions. First, we found an effect of framing between square and horizontal contexts using the raw ratios. Second, when logtransformed to diminish the effect of numerical outliers, the framing effect was even stronger, with four out of six condition pairs differing significantly from each other. One exception makes sense: The square versus unframed conditions did not differ significantly. Since the unframed condition was invisibly constrained by an 800×800 square, it is unsurprising that it did not differ from the square condition. The reason for the second exception, square versus vertical frame, is less obvious, but it may result from the multipeaked nature of vertical distribution, which creates difficulties for standard statistical techniques such as ANOVA or generalized linear models.

This robust effect of framing may help to explain the many inconsistent findings in the previous literature, since some implied frame always exists (even if only the viewer's own visual field), but the specific proportions of the framing context are rarely specified in previous work. In contrast, we found no significant effect of the cultural background of the participants (Korean vs.

Table 3

Influence of Frame on Proportions of Shapes: Percentages (Rounded to the Next Full %) of Vertical, Horizontal, and Square Shapes Produced in the Four Different Shape Conditions

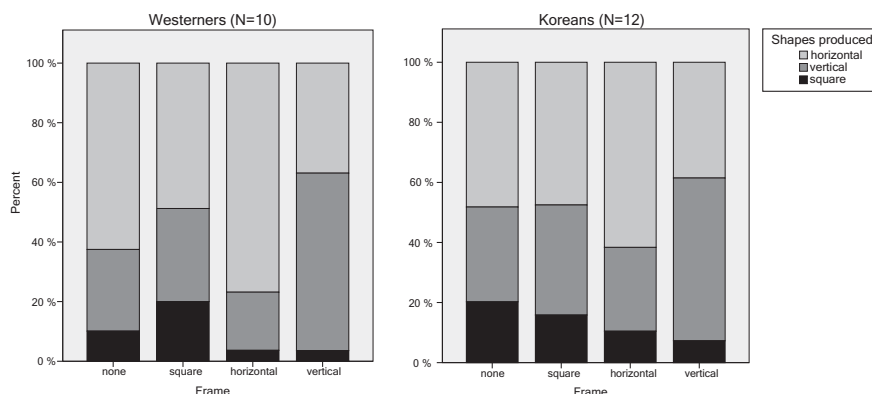| Condition	% Horizontal	% Vertical	% Square
No frame	54	30	16
Square	48	34	18
Horizontal	69	24	7
Vertical	37	57	5

Figure 2. Effect of cultural background: The percentage of vertical, horizontal, and square shapes produced in the four experimental conditions. The slightly higher occurrence of square shapes in the Korean group (right) compared with the Western group was not statistically significant.

European). Both groups showed an equally robust framing effect. The slightly higher occurrence of squares in the Korean group, though not statistically significant, remains intriguing. The effect size of cultural background, if it exists at all, may be very small, and presumably a much larger sample size would be required to reach significance.

Overall, our data are consistent with Fechner's original finding of a preference for golden rectangles with ratios at 0.618 or 1.618, but only in the context of rectangular framing. Consistent with the argument of McManus (1980) and many previous findings, we found dual preference peaks at the 1:1 (square) ratio and a broader peak near the golden rectangle. Green (2012) has recently shown with mathematical models that the distribution of length ratios is uniform, so peaks around these points seem to reflect an actual preference rather than a mathematical artifact. Based on a factor analysis of individual preference distributions, McManus found two consistent underlying factors: a preference for squares, and a rectangular preference with peaks roughly at ϕ. However, roughly 25% of his participants exhibited a *negative* loading on the "square" factor, meaning an active nonpreference for squares. More recently, McManus & Wu (2012) tested rectangle preferences in Western and Chinese participants and found no consistent preference pattern between the two cultural groups. Green (1995) suggested that much previous research had unfairly pitted 1:1 ratios against the golden ratio, as if a preference for squares would nullify Fechner's hypothesis. Instead, Green suggested that both gestalt approaches (e.g., Arnheim, 1954) or the broader Pythagorean approach to empirical aesthetics would incorporate the possibility of multiple preferences. Furthermore, he cited the possibility originally proposed by Davis (1933) that the frequent finding of a broad peak in the rough vicinity of 1.6 actually represents the summation of several independent peaks at other nearby complex ratios, such as $\sqrt{2}$ (= 1.414 . . .) and $\sqrt{3}$ (= 1.73 . . .) as well, possibly, ϕ itself.

After his painstaking analysis of all possible pairings of stimuli from a pregenerated stimulus set, McManus (1980) concluded that, despite "moderately good evidence" for Fechner's golden rectangle hypothesis, "techniques at present [are not] accurate enough"

(p. 523) to discriminate the golden section from other nearby ratios (such as 1.5 or 1.75). Our results show that the method of production presented here provides a potential solution to this problem, allowing any normal participant to easily generate a large number of rectangles (or any other simple figure) quickly and with pixel accuracy. With a larger number of trials than employed here, we can, in principle, discriminate between these hypothetically preferred ratios statistically. The key point from our results is that future work must control for, or experimentally evaluate, the effect of framing context for these accurate values to be meaningful.

Given the strong effect of rectangular framing found here, the most obvious next step in this line of research will be to evaluate the extent to which the specific ratio of the framing rectangle influences the rectangle produced. We used rectangles of 0.6/1.6, which is the proportion of many modern computer and TV screens and very close to ϕ, but providing a series of frame proportions around this ratio (e.g., $\sqrt{2}$, 1.5, ϕ, and $\sqrt{3}$) would allow us to evaluate the specificity (or lack thereof) of this effect. Given the powerful effect of framing, it would also be valuable to follow up the suggestion of Hintz and Nelson (1970) that individual differences in rectangle preferences may result from differences in the viewer's own visual field dimensions. An obvious example of this effect (again apparently ignored in previous work) would be to analyze the effect of wearing eyeglasses, and of eyeglass shape, on rectangle productions and preferences.

In summary, our results are consistent with much previous research in finding preference peaks around 1:1 and ϕ, but also provide some evidence for other peaks, for example at $\sqrt{2}$. However, we discovered a powerful effect of framing, the possibility of which has gone essentially unconsidered in the previous literature. Given the much higher likelihood that a subject will produce a golden rectangle in a rectangular context, this framing effect may go a long way toward explaining the inconsistency in the prior literature. Thus, these results show the importance of controlling this aspect of context (and certainly the necessity of reporting it) in future work.

Experiment 2: Pattern Generation With Tile Matrices

In this experiment, we approach the question of context from a different angle. Whereas Experiment 1 showed that the properties of a frame influence the proportions of rectangles produced, here we investigate the bottom-up effect of local structure, specifically of symmetry within pattern elements, on global patterns that participants produce. Experiment 2 involves a 6×6 matrix composed of square-patterned tile elements. When observing tile patterns in real life (see Figure 3), it is striking that (a) most tiles have some degree of internal symmetry, along one or more axes and that (b) tiles with different symmetries are used for different patterns. An informal survey of the usage of diagonal and orthogonal tiles (e.g., Pepin Press tile-pattern compendia, Hernández Navarro, 2006) shows that orthogonal axis tiles are used mainly on borders in a repetitive translational fashion (i.e., the motive is repeated along a horizontal or vertical axis without rotation or reflection). Diagonal axis tiles are almost never used in a translational fashion, but are instead usually arranged in groups of 2×2 tiles, with each tile rotated, leading to a larger diamond or circle figure.

Based on these informal observations, we hypothesized that humans are sensitive to the symmetry of local pattern elements, and adjust both their pattern-making strategies and their preferences for certain tile/pattern combinations accordingly, without explicit instructions to do so. Thus, local tile properties, that is, the presence or absence of symmetry, as well as the orientation of any symmetry, will influence the preferences for patterns, but will also bias the production of patterns in favor of certain constellations.

More specifically, we predicted that tiles with orthogonal symmetry would lead to more translational patterns, mirroring real-life usage. Tiles with diagonal symmetry will lead to patterns in which the tiles are arranged in groups of 2×2 rotated tiles. Concerning choice, we expect congruent combinations (i.e., grouped rotation in combination with a diagonal tile, translational with a horizontal tile) to be preferred over incongruent combinations (grouped rotation with a horizontal tile, translational pattern with a diagonal tile).

Method

Participants. Nine participants (five women, mean age: 27.7 years, range: 23–37 years) took part in the experiment. All had normal color vision and normal or adjusted-to-normal visual acuity. Participants gave their written informed consent prior to participating and were paid for taking part.

Stimuli. For both the production and preference tasks, we used digital images of tiles from *Barcelona Tile Designs* and *Havana Tile Designs* (Hernández Navarro, 2006; Hernández Navarro, 2007). We chose images that were available in two variants within a pattern: diagonal symmetry (mirror symmetry along one diagonal axis), and orthogonal symmetry (i.e., mirror symmetry along either the vertical or horizontal axis). The orthogonal symmetry is typically used in tile borders, and tiles with diagonal symmetry are typically arranged in the main tile pattern. We specifically chose tiles that were available in both variants to ensure that the basic color scheme, complexity, and style, were very similar. We created a third, nonsymmetrical tile type from the two tile variants by dividing both tiles along the diagonals and using two of the four resulting triangles from both images to create a tile that had 50% of its pixels from the diagonal and orthogonal tile respectively, but crucially did not have perfect symmetry along either the horizontal or diagonal symmetry axis. The tile manipulation was done in Adobe Illustrator (14.0.0). We considered these three variants together to be a "tile family."

Procedure. The experiment consisted of two tasks: a pattern production task and a two-alternative forced choice (2AFC) task. In the production part, participants were presented with a 6×6 grid of identical tiles (100×100 pixels). The tiles could have one of four possible orientations (0, 90, 180 or 270°), which were initially random. To change the orientation, the participant clicked on an individual tile, upon which the tile rotated incrementally by 90° clockwise. The initial orientation of the tiles in the array was randomized in each trial and differently for each participant. There was no time limit for the production trials, and the participants received no specific task instructions, other than to change as little

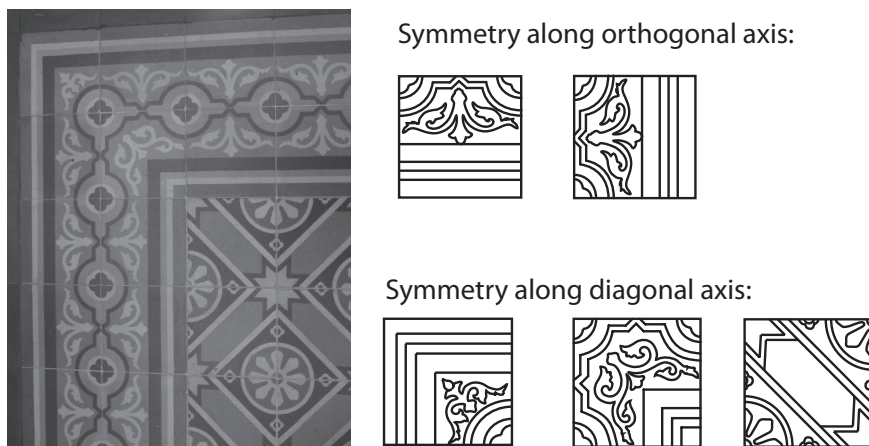*Figure 3.* Photograph of a floor tiling in a 12th-century building in Florence, Italy, 2011 by Gesche Westphal-Fitch. The tiles are shown as line drawings on the right to illustrate the internal symmetry types, orthogonal (top) and diagonal (bottom). Tiles with orthogonal symmetry are used on the border, whereas tiles with a diagonal symmetry are mainly arranged to create 2×2 diamond figures.

or as much as they liked in the initial random pattern, and click on a "Finish" button under the tile array when they were ready to move on to the next trial (Westphal-Fitch et al., 2012). In total, there were 18 production trials, which were divided into blocks of six.

After each block of production trials, a 2AFC preference session was interspersed. Here, two patterns were presented side by side and participants had to indicate their preference for one of the two images by clicking on the preferred one. We compared three patterns: translational symmetry, grouped symmetry (for examples see Figure 5) and random orientations. We did a complete pairwise comparison between the three patterns and three tile types for six tile families, yielding 216 comparisons per participant (see description of tile families below and Figure 4). We also included a distractor task of comparing the same pattern made of the same tile type from different tile families; however these preferences are not part of the present analysis. In total, there were 351 comparison trials, broken down into three blocks with 117 trials. Participants had 3 sec to make their choices, and were encouraged in the instructions to make their choices as quickly as possible. If a trial timed out, no preference was recorded, and the trial was not repeated. Participants had an opportunity to take a short break between each block. For the production task, we recorded the initial and final orientation of each tile, as well as the clicks with time information for each tile.

Data was analyzed with SPSS (Versions 17 and 19), as well as custom R scripts (Version 2.15.1) using the package prefmod (Hatzinger & Dittrich, 2012). In the preference task, the image pair and the chosen image were recorded. We used Circos (http://circus.ca, Krzywinski et al., 2009) for the circular graph.

Images were presented on a 17-in. touch screen (ELO Intellitouch, Menlo Park, CA) using custom Python software running on an Apple MiniMac. The participants indicated choices and changed the patterns by touching the screen with their fingertip. The experimenter was present in the room but was visually separated from the participant by an opaque barrier. Instructions were given in writing and did not contain words alluding to patterns, beauty, or symmetry.

Results

Analysis of production results. We analyzed how frequently grouped or translational patterns were produced, and for which tile type these patterns were most common. In addition to the basic

grouped pattern, patterns were categorized as grouped if the 2×2 figure was inverted or offset. A translational pattern could be horizontal or vertical, and the stripes could be inverted by 180°. We allowed maximally one error to occur in a pattern (but this happened in only one instance).

Of the 162 production trials, 10 patterns were excluded because no element in the original pattern array had been changed. Of the remaining patterns, 58 were grouped or translational patterns (26 grouped, 32 translational), constituting 38% of all patterns. The other patterns produced were also often highly ordered and symmetrical in more complex ways, but their analysis is beyond the scope of this paper (see Westphal-Fitch et al., 2012). We found a clear effect of tile type on the patterns produced (see Figure 6 below): Of the 26 grouped patterns, 21 were made with diagonal tiles (80.8%) and only five (19.2%) were made from nonsymmetrical tiles. None were made with orthogonal tiles. In the case of the translational patterns, only three (9.38%) were made of diagonal tiles; 16 (50%) were made with orthogonal tiles and 13 with nonsymmetrical tiles (40.6%).

The distribution of these two patterns by tile type differed significantly from values expected if there had been no association, Pearson $\chi^2(2, N = 58) = 32.77$, $p < .001$. The 58 arrays of interest were produced over all three production blocks (first block: 36.2%, second block: 29.3%, third block: 34.48%). Grouped patterns were produced with on average 81 clicks in 69.4 seconds, while the translational patterns were produced with on average 89.6 clicks in 105.3 seconds. Based on number of clicks, the two patterns seem to be roughly equivalent in effort, although the translational patterns did take longer to produce. All but one participant produced both translational and grouped patterns.

Analysis of paired comparisons. Of the 3,159 (9×351) choice trials run, 25 timed out (0.79%), leaving 3,134 valid choices, 1,207 in the distractor task and 1,927 in the real task. For all but two participants, the diagonal grouped pattern was clearly the most preferred pattern. One participant had a strong preference for grouped patterns with nonsymmetrical tiles and another had a weak preference for translational patterns with nonsymmetrical tiles (see Figure 7).

Choices were not distributed evenly across pattern and tile types: Random patterns were only chosen 22.8% of the time (regardless of tile type); patterns with a grouped pattern were chosen 42.7% of the time. The grouped rotations were most popular with diagonal (360 choices, 18.7% of all trials) and non-

Figure 4. Example of the three variants of a tile, i.e. a tile family: (a) Symmetry along one diagonal axis, (b) symmetry along the orthogonal, (here, vertical) axis, and (c) fusion between (a) and (b). Image taken from Hernández Navarro's *Barcelona Tile Designs*, published by the Pepin Press (www.pepinpress.com).
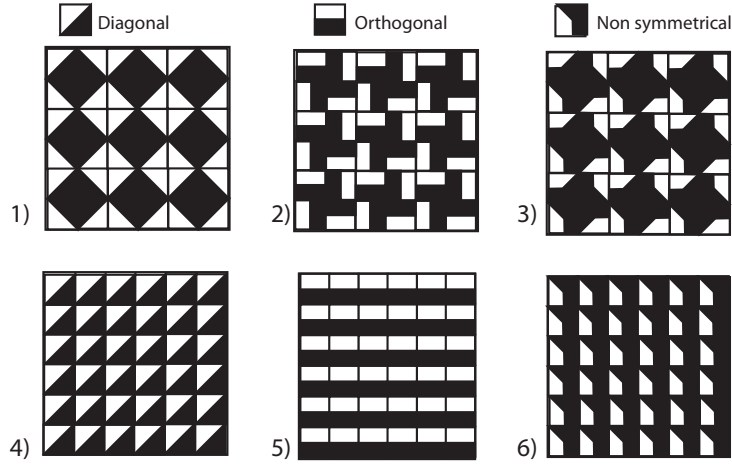
Figure 5. Examples of the grouped and translational patterns with simplified tiles for clarity (tiles used in the experiment were colored and structurally more complex). 1–3: grouped pattern with diagonal, orthogonal and nonsymmetrical tiles. 4–6: translational pattern with diagonal, orthogonal and nonsymmetrical tiles. We also created random patterns with the tiles, which are not shown here.

symmetrical tiles (276 choices, 14.3%), and less so with horizontal tiles (187 choices, 9.7%). A full overview of choice distributions is given in Table 4.

A chi-squared test confirmed that the differences in number of choices between the tile types and pattern types were highly significant, Pearson $\chi^2(4, N = 1927) = 22.29$, $p < .001$. A comparison with the production data is particularly interesting: The preference for grouped patterns (rather than translational patterns) with diagonal tiles is similar in both production and preference tasks (see Figure 6). However, for orthogonal tiles, the preference for the translational pattern over the grouped pattern is markedly weaker in the preference task than in the production task. Graphing all possible choices and the number of choices favoring the diagonal grouped pattern confirms an overwhelming preference of this tile/pattern combination. Figure 7 represents the choices visually: Each band connects an image pair. The width of the band ends represent how often that image was chosen over the

other—that is, the wider the band is, the more frequently that image was chosen over its partner. Moving around the circle from the top in a clockwise fashion, the image categories are ordered by descending popularity: Diagonal grouped patterns were chosen more often than any other image type, and nonsymmetrical grouped patterns were chosen more often than all other remaining categories. The choices are also summarized in Table 4. Of the regular patterns, the patterns exhibiting local incongruity between tiles (i.e., horizontal grouped and diagonal translational) are least popular.

We ranked the nine pattern comparisons based on the participants' decisions and fitted a log-linear Bradley Terry model (a form of generalized linear model) to the data, assuming an underlying Poisson distribution. We found that the model that fitted best on both the group and individual levels, as measured by Akaike's information criterion (AIC), included all 9 stimulus categories (*df* = 28, residual deviance: 26.82, AIC: 475.45). We determined
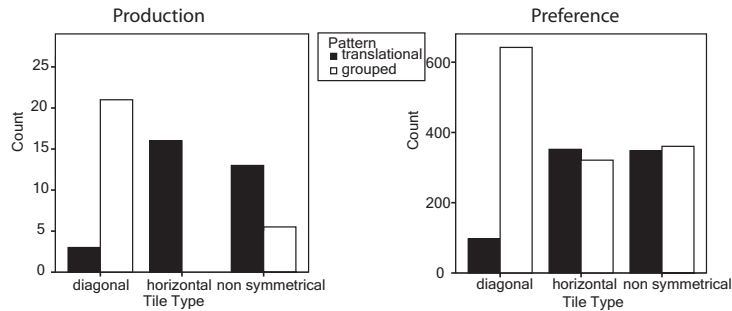

Figure 6. Perception/production differences. Left: The number of translational (black bars) and grouped-rotation (white bars) patterns made with each of the three tile types: diagonal, horizontal, and nonsymmetrical. Right: The number of patterns chosen in the preference task for each of the tile types (choices of random patterns are not shown here).
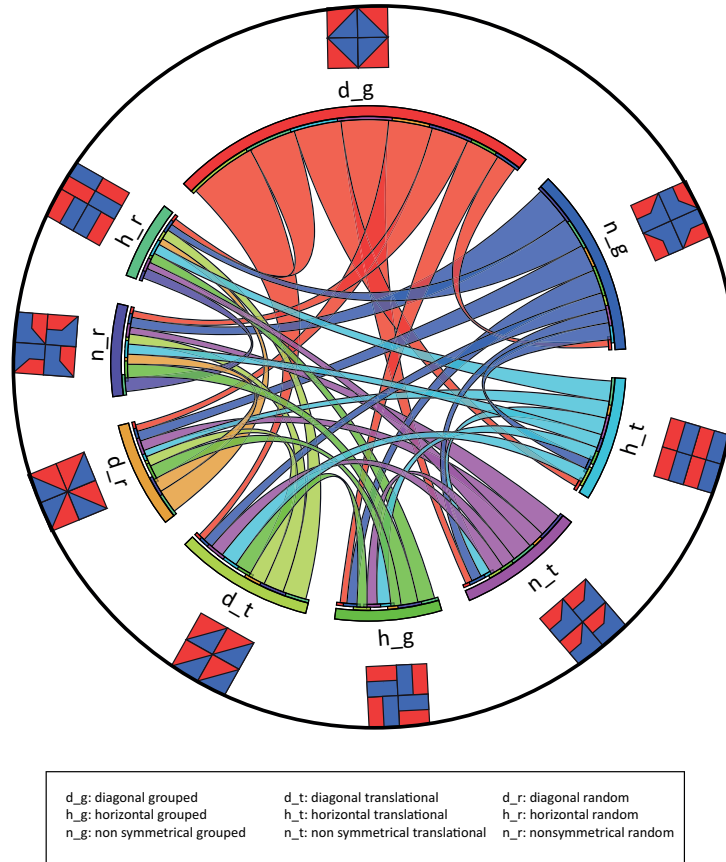
d_g: diagonal grouped	d_t: diagonal translational	d_r: diagonal random
h_g: horizontal grouped	h_t: horizontal translational	h_r: horizontal random
n_g: non symmetrical grouped	n_t: non symmetrical translational	n_r: nonsymmetrical random

Figure 7. Overview of preferences in the paired-comparisons task: All possible pairs are presented here, connected by a band that varies in width, representing the number of choices. The first letter of the category corresponds to the tile type, the second to the pattern. The pattern examples are exemplified using simplified tiles.

the fit to the data by conducting a chi squared test of the residual deviance and degrees of freedom and subtracting that value from 1. A nonsignificant value is taken to be an indicator of a good fit of the model to the data. This was the case here, suggesting that the fit is good ($1 - p = .53$, residual deviance: 26.82, $df = 28$). A further reduction in stimulus categories, resulting in a simpler decision model, led to far higher residual deviances and rises in AIC values of over 100 (all $1\text{-}p < .001$), suggesting that such a reduction in stimulus categories is not advisable (Burnham & Anderson, 1998).

From the coefficients of the models we calculated the worth values for both the group as a whole and individual participants for each stimulus category. The worth value corresponds to probability of being the chosen pattern in a particular pair. That is, when a pair of images is given, the one with the higher worth will be chosen, according to the following equation:

Table 4
Overview of the Number of Choices for the Different Tile Types and Pattern Types in Experiment 2

Pattern	Diagonal tile (%)	Horizontal tile (%)	Nonsymmetrical tile (%)	Total (%)
Translation	230 (11.9)	219 (11.4)	215 (11.2)	664 (34.5)
Grouped	360 (18.7)	187 (9.7)	276 (14.3)	823 (42.7)
Random	173 (9)	117 (6)	150 (7.8)	440 (22.8)
Total	763 (39.6)	523 (27.1)	641 (33.3)	1927 (100)

$$\Pi_{(jk)j} = \pi_j / \pi_j + \pi_k$$

As worth is expressed as a probability, the sum of all categories adds up to 1. As Figure 8 shows, seven out of nine participants had the highest values for diagonal–grouped. Participant 2 had a strong preference for nonsymmetrical–grouped, and Participant 1 did not show very consistent preferences, with a slight bias toward nonsymmetrical–translational.

Discussion

We found compelling evidence for a strong relationship between local tile symmetry and global pattern in both the production and preference tasks. Despite the overwhelmingly large number of possible tile constellation (there are 4^{36} (= 5×10^{21}) possible tile constellations in a 6×6 grid), over a third of all patterns produced fell into two simple pattern categories: translational and grouped. However, the occurrence of the patterns was not distributed evenly between the tile types. Rather, the grouped pattern occurred most often with diagonal tiles, and the translational pattern mainly occurred with horizontal tiles. That is, to a significant extent, creative output can be predicted based on formally describable symmetries within local elements in this constrained production environment.

Concerning the preference task, we found a strong preference for grouped patterns with diagonal tiles, matching the production result. However, the preference for translational patterns with horizontal tiles was far weaker in the perceptual choice task than in the production task (see Figure 6). This may be because the participants were fatigued by the large number of choices to be made. We cannot rule out that this may have been a contributing factor. However, if that were the only underlying factor, then we would expect preferences to be weaker overall; yet the preference for grouped over translational patterns for diagonal tiles remains

strong throughout. We suggest that the production task biases participants to rely on local cues. It is well known that global properties of compound visual stimuli typically take precedence over local features in normal humans (Navon, 1977). Given the short available time that our participants had to make their perceptual decisions, it is highly likely that global features played a larger role than local features in the perceptual choice task. In the case of the production trials however, participants had no time limit, but were constrained to modify local elements by rotating single tiles in a piecemeal fashion. Thus, it is not surprising that the local compatibility of neighboring tiles has a stronger effect during production, resulting in more translational patterns with horizontal tiles and grouped patterns with diagonal tiles. The fact that nonsymmetrical grouped patterns were the second most popular category supports this idea: The local features of the tile were ambiguous (hybrids between diagonal and orthogonal tiles), and might have been perceived as a quasi-diagonal tile, which might have enabled a fast parsing of the pattern as a good grouped pattern. By using both the method of production in combination with more traditional preference methods, we were able to detect this contrast, which would have gone unnoticed if only preference methods were used.

General Discussion

With these results, we hope to have illustrated the effectiveness of the method of production as a powerful technique for exploring aesthetic preferences for a top-down effect of framing, but also for a bottom-up effect of tile-internal symmetries on the patterns produced with them. The disparity between the production and preference tasks just mentioned suggests that the context of active production versus passive perception can have strong effects on preferences. These findings support Fechner's original argument for using a combination of generative and perceptual tasks. If
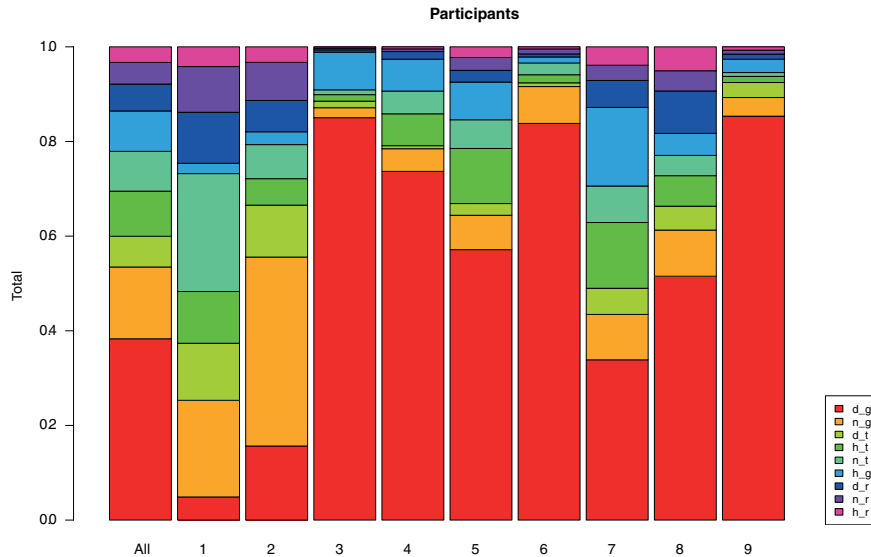

Figure 8. Values as predicted by a fitted generalized linear model (no subject or object covariates). The first letter of the category corresponds to the tile type, the second to the pattern.

it is indeed the case that pattern production lays a stronger emphasis on local relations and rapid preference tasks rely more heavily on global, easily scannable relations, then it would be particularly interesting to test human groups in which the usual "global first" perceptual principle is not as pronounced. For example, individuals with autism have been shown to have a *local* bias in perception, which in some cases leads to enhanced performance in visual tasks, due to fewer distractions from global information (Brosnan, Scott, Fox, & Pye, 2004; Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; O'Riordan & Plaisted, 2001; Mottron, Belleville, & Menard, 1999). In our pattern-preference task, we would predict that individuals with autism would maintain the preference for orthogonal tiles arranged in the translational pattern rather than the grouped pattern, as shown by our participants in the production task. Further, we would predict that the dispreference for nonsymmetrical tiles in a grouped pattern, relative to diagonal tiles, would be stronger in autists than normals.

We end by briefly considering the cognitive implications, and possible origins, of the most pervasive patterns occurring in our tile-manipulation experiment: translational and grouped. For clarity and concision we will explicitly notate each pattern using a widely accepted crystallographic symbolic notation (cf. Washburn & Crowe, 1988). This system uses a series of four alphanumeric symbols to indicate all possible symmetries that can be generated by rigid motions in the plane (translation, rotation, reflection, and glide). Translational symmetry, in which all tiles are oriented identically, is simply denoted "p1", where the 1 indicates no rotational symmetry. The 4-tile grouped rotation is denoted "p4" and our participants generated this with roughly equal frequency to p1. These notations only indicate the overall symmetry, for those cases in which the tiles have no internal symmetry. However, if the tiles themselves have symmetry, the overall pattern that results from these operations can have additional mirror symmetries along the vertical and horizontal axes (p4mm = "p4m"). The rotational plus mirror symmetry pattern p4m is of particular interest because in addition to being the typical pattern for laying tiles in the European context, it is the most common underlying pattern in Islamic art (Wichmann, 2008): 48% of 644 Islamic patterns Wich-

mann examined exhibit this pattern of combining mirror and rotational symmetry.

It is not difficult to understand why our participants often chose to orient all tiles identically, yielding translational symmetry, since this is in some sense the simplest operation to provide any order whatsoever. Thus, if as predicted by Gombrich's hypothesis of a human sense of order (Gombrich, 1984), participants felt an urge to create some order, this is the least that they could do. The frequent generation of p4m is more interesting, especially given the pervasiveness of this symmetry pattern in several cultures. This pattern occurred by far most frequently (80% of cases) when the tile possessed a diagonal mirror symmetry (45° axis), and when this tile type is arranged into the p4 rotational groups, it yields an overall pattern with both rotational and mirror symmetries (p4m). These multiple symmetries lead to an ambiguity of interpretation: Such patterns could be generated by either a series of mirror reflections (pmm) or a series of rotations (p4). Either way, if the tiles are diagonally symmetrical, the same pattern will result. Our current implementation of the FlexTiles interface allows only rotation, so participants in this study were forced to implement the p4m pattern via rotations. But perhaps the appeal of this arrangement is that it also satisfies a preference for reflectional symmetry (particularly along a vertical axis). Indeed, it is possible that the deeper appeal of these p4m patterns results mainly, or solely, from the resulting reflectional symmetry, and that the rotations are simply a means to this end, of little or no aesthetic significance themselves. Alternatively, it may be the summation of both rotational and reflectional symmetries that gives the p4m pattern its special appeal.

Recognizing this underlying generative ambiguity allows us to restate the general question in more specific, testable terms—why do people like this particular pattern so much? That is, of the various classes of symmetry, which are most perceptually accessible, and which are aesthetically preferable? There are several ways to evaluate these possibilities empirically. The first is by extending our current FlexTiles interface to allow both rotations *and* reflections (e.g., using right vs. left mouse clicks). If the underlying perceptual bias driving participants to produce p4m is for reflectional symmetry, as seems plausible, we would expect

Four possible symmetry classes

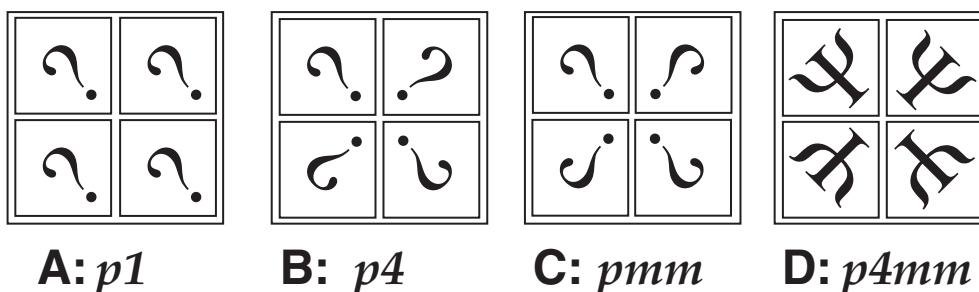**A:** *p1*   **B:** *p4*   **C:** *pmm*   **D:** *p4mm*

Figure 9. Four symmetry classes in crystallographic notation. A corresponds to translational patterns. Concerning our grouped patterns, horizontal grouped and nonsymmetrical grouped corresponds to B, and diagonal grouped could formally be B, C or D. P4mm is often abbreviated to p4m.

reflectional mouse clicks to dominate. However, if a rotational bias also exists and is important, we would not expect users generating this pattern to be strongly biased toward reflectional operations, and they might instead use a mix of rotations and reflections. Finally, if production tasks lead to a greater reliance on local cues, it may be that rotation is in some sense more predictable than reflection, making success easier to evaluate. This would then predict rotation as the preferred operation.

Further tests would involve subtly manipulating the symmetries of the tiles themselves, so that the two sets of operations yield different outcomes (see examples in Figure 9). Using the method of production, and allowing both reflection and rotation, a strong rotational preference should clearly yield figures like those in 9B, whereas reflectional preference should yield 9C. Purely perceptual preferences can also be tested through the method of choice by pitting patterns like those in examples 9A–9D against one another. Combining all these approaches could yield new insights into the more abstract principles that underlie human pattern preferences, as well as the specific conditions that might bias preferences one way or another.

An interesting issue left open by our current results concerns the degree to which the proclivities documented here are biologically based, and if so, how deep these biological roots might be. This question is best approached empirically through comparisons across species, as well as across different human cultures. Regarding nonhuman animals, we suspect that getting meaningful results from the method of production would be difficult (but it would be interesting to see what patterns would be produced by chimpanzees or other apes working on touch screens). Regarding perception, our previous work (Westphal-Fitch et al., 2012) suggests that even very simple relational patterns on grids are quite difficult for pigeons to perceive, suggesting that the biological roots of our abilities to perceive and create patterns on a matrix are not shared among all vertebrates. With respect to different cultures, we think the method of production offers a powerful and straightforward way to explore the roles of experience and culture in shaping preferences. More cross-cultural studies, like the Korean/European comparison reported here, are clearly necessary to determine whether aesthetic proclivities have pan-human roots. Although the current data on rectangle production suggest that aesthetic preferences may be widespread or even universal in our species, many more studies are required to test this hypothesis. For example, it would be very interesting to deploy our FlexTiles software in cultures in which tiles in general, and the p4/pmm pattern in particular, are rare (e.g., many East Asian countries, and all traditional hunter–gatherer cultures). Is this type of symmetry strongly preferred only by those exposed to it from an early age, or is it based on such powerful biological predispositions that little or no previous exposure is necessary? Today, such questions are relatively easy to pose via cross-cultural computer-based comparisons, but their answers can be expected to have deep implications for our understanding of aesthetics and the human sense of order.

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5 | Spatial pattern analysis

Spatial analysis of "crazy quilts", a class of potentially random aesthetic artefacts.

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Abstract

Human artefacts in general are highly structured and often display ordering principles such as translational, reflectional or rotational symmetry. In contrast, human artefacts that are intended to appear random and non symmetrical are very rare. Furthermore, many studies show that humans find it extremely difficult to recognize or reproduce truly random patterns or sequences. Here, we attempt to model two-dimensional decorative spatial patterns produced by humans that show no obvious order. "Crazy quilts" represent a historically important style of quilt making that became popular in the 1870s, and lasted about 50 years. Crazy quilts are unusual because unlike most human artefacts, they are specifically intended to appear haphazard and unstructured. We evaluate the degree to which this intention was achieved by using statistical techniques of spatial point pattern analysis to compare crazy quilts with regular quilts from the same region and era and to evaluate the fit of various random distributions to these two quilt classes. We found that the two quilt categories exhibit fundamentally different spatial characteristics: The patch areas of crazy quilts derive from a continuous random distribution, while area distributions of regular quilts consist of Gaussian mixtures. These Gaussian mixtures derive from regular pattern motifs that are repeated and we suggest that such a mixture is a distinctive signature of human-made visual patterns. In contrast, the distribution found in crazy quilts is shared with many other naturally occurring spatial patterns. Centroids of patches in the two quilt classes are spaced differently and in general, crazy quilts but not regular quilts are well-fitted by a random Strauss process. These results indicate that, within the constraints of the quilt format, Victorian quilters indeed achieved their goal of generating random structures.

Introduction

Human ornaments and decorative art represent a class of biologically generated patterns typified by a high degree of structure and order. Conventional decorative patterns can typically be described by their underlying symmetry [1]. Human visual artefacts very rarely intentionally violate ordering principles such as symmetry and repetition. Although randomness serves as the typical null hypothesis in the physical sciences, it has long been known that humans have great difficulty in producing random output. Seemingly random behaviours are not uncommon in the biological world (e.g. prey escape behaviours), yet analyses of such behaviours remain for the most part qualitative [2]. It has been shown experimentally that, given the task of creating random numerical arrays, humans generate output that deviates strongly from a truly random array, especially when a participant's response time is limited [3, 4]. Somewhat surprisingly, when participants are presented with both random numerical sequences and pseudo-random sequences produced by humans that deviate from true randomness, the latter are more likely to be classed as "random" than the truly random sequences [5]. Apparently, humans are well equipped to detect and create ordered structures, but not random structures. At least in humans, this inability seems to stem from a strong "sense of order", a term coined by E. H. Gombrich to express how our drive to "regularise" artefacts is a fundamental aspect of human cognition, almost as basic as our sense of smell or touch [6].

Given our species' apparent obsession with order, we might wonder if *any* human artefacts produced with a maker's controlled actions (rather than by an uncontrollable physical process such as cracks or

decay, or by minimal, uncontrolled variation) can be adequately described with a random process.

One candidate class are crazy quilts: a once popular class of textile craftwork often intended for display. A crazy quilt is a blanket consisting of two fabric layers. The top layer is made of "irregular bits and pieces [of fabric] strewn in a seemingly disorganized fashion" [7]. This quilt type is unusual because it is made, unlike most other quilts, specifically to create an irregular aesthetic impression. It is often claimed that the arrangement of the patches is random, e.g.: "The patchwork was constructed by stitching random patches to a fabric base" [8]. In this paper, we aim to evaluate this claim by describing the properties of spatial patterns in quilts and to quantify the differences in orderedness between regular and crazy quilts (see Fig. 1 for typical examples of both quilt categories).

Figure 1. : Examples of the quilts analysed in this study. Left: a crazy quilt (C2, International Quilt Study Center, University of Nebraska-Lincoln, 1997.007.0552). Right: a regular quilt (R8, International Quilt Study Center, University of Nebraska-Lincoln, 2003.003.0212). In all images, the margins that did not contain patchwork were cropped out prior to analysis.

Our analysis of real-life visual patterns follows an approach in empirical aesthetics first outlined by Gustav Fechner in the late 19th century [9,10]. Fechner advocated the use of three methods to investigate aesthetic proclivities in humans: studying how people produce artefacts, how artefacts are perceived and the description of properties of artefacts encountered in real life. Research on the human production and perception processes of visual patterns in the lab [11,12] has shown that abstract geometrical patterns have a near universal aesthetic appeal and that the ordering principles underlying them are readily understood by a wide range of humans. Formal descriptions of real-life patterns, in particular Islamic tilings, exist that are based on classification systems derived from crystallography [1,13–15], but very little work has been done to formally describe disorderly artefacts and patterns that do not adhere strictly

to conventional symmetry classes.

Previous research applying spatial analysis tools to human artwork has focussed mainly on paintings [16–21], photography [22, 23] or on traditional patterns used in pottery and other ornamental objects [1, 24]. Much less quantitative research has been devoted to patchwork, though see [25, 26].

A brief history of crazy quilts

Patchwork is the stitching together of small pieces of cloth (*patches*), into a larger unit, typically used for blankets, pillowcases or clothing. Though patchwork is best known from English-speaking cultures, in particular North America and England, it is has traditionally been produced in many countries (e.g. China, Pakistan, India, Thailand, Iran, Sudan, and Korea) [8].

Crazy quilts are a form of patchwork that enjoyed a brief period of popularity in the late 19th and early 20th century. The oldest examples are from the 1870s. These quilts were widely produced until the 1920s, after which their popularity waned, although they are still occasionally produced today by patchworkers around the world.

Crazy quilts typically contain many different fabric types and fabric patterns. Additionally, the edges of patches are decorated with a wide variety of embroidery stitches and centres are often embroidered with vignettes of animals and plants, although the embroidery seems to have become less elaborate as the fad progressed [25]. In combination, crazy quilts evoke an impression of lavishness and wild abundance that stands in stark contrast to the strict rules of traditional quilts and Victorian society more generally.

The roots of Western crazy quilts may lie in Japanese patchwork. In Japan, the technique of *yosegire* (reusing precious fabrics in coats and kimonos) was popular in the 19th century. Examples of *yosegire* patchwork appear quite unstructured, lacking the rigid repetitions of Western patterns. Japan began trading with the West in 1854 with the convention of Kanagawa, ending 200 years of isolation policy. In 1876, a range of textiles were displayed at the Japanese stand of the Centennial Exposition in Philadelphia, which had close to ten million visitors (the population of the United States at the time was about 38 million) [27]. Several historians claim this exhibition and ensuing popularity of Japanese craft was the inspiration behind American crazy patchwork [8, 28]. Brick [7] also argues for a Japanese influence, but credits the Gilbert and Sullivan opera "The Mikado" which debuted in 1885, after which Japanese designs and textiles, including *yosegire* style patchwork, became wildly popular.

The oldest attested usage of the adjective "crazy", meaning "full of cracks", dates from the 1580s, and it is still in use today, e.g. "crazed glazing". The contemporary meaning of "mad, insane" is attested since 1617, however evidence for describing objects or actions as mad only goes back to 1855. The oldest usage of "crazy patchwork" is found in 1885, and the appellation "crazy quilt" goes back to 1886. We therefore assume that the term "crazy quilt" at the time would primarily have meant "haphazardly cracked", though the connotation of madness may have been present as well [29].

Crazy quilts seem to have been a rare outlet for women to escape the confines of household routines and explore individual creative expression, in some cases to the annoyance of their husbands, as the anonymous poem "The Crazy-Quilt" from 1890 suggests [30]:

> [...] And where is the wife who so vauntingly swore
> That nothing on earth her affections could smother?
> She crept from your side at the chiming of four
> And is down in the parlor at work on another.
> Your breakfasts are spoiled,
> And your dinners half-boiled,
> And your efforts to get a square supper are foiled
> By the crazy-quilt mania that fiendishly raves,
> And to which all the women are absolute slaves [...]

Spatial analysis of patterns

In the current study we analyse crazy quilts using spatial statistics, comparing them to 'normal' regular quilts. Quilts in general are subject to a number of constraints that would be difficult to capture in standard random models (e.g. in a Poisson process). Two key constraints are that patches must exceed some minimum size (*minimal area constraint*) and that, although rare exceptions exist, the overall quilt shape must be approximately rectangular (*edge constraint*).

In general, patch edges are straight (for the practical reason that straight seams are easier to sew than curves if the patches are to lie flat). Unfortunately, the direct analysis of patch edges as line segments (number, angle, etc) is difficult, because the seams are not necessarily perfectly straight and thus vertices and corners cannot always be unambiguously classified. In this study, we focussed instead on the properties of the patch areas and centroids, which can both be precisely calculated and serve as adequate measures of spatial organisation for our purposes.

With these constraints in mind, we adopted a Strauss process over patch centroids as our random comparison model. A Strauss process, introduced by David Strauss in 1975 [31], is a superset of a Poisson process which models interactions between points in the plane (i.e. it is a pairwise interaction process). Strauss processes were further developed by Kelly and Ripley [32] and have been applied to a wide variety of biological spatial patterns, for example to model herd animal dispersion [33], spatial distribution of tree species [34] or neuron locations in the brain [35].

Because of imprecision in manual motor control, imperfection is inherent in any handmade object. To estimate the magnitude of this intrinsic motor error, and to provide a rigorous basis for comparison, we also analysed standard or 'regular' quilts. In this type of quilt, multiple copies of the same pattern unit ('blocks') are arranged in a translational fashion on a square grid. While each block is a nearly exact copy of the pattern, blocks will nonetheless show some unintentional random variation. Minimally, we predict that crazy quilts will be significantly more random than such regular quilts. A finding that qualitatively different spatial models fit these two classes would be germane to our overall question of the hypothesised randomness of crazy quilts.

Hypotheses

Our overall goal in this study is to evaluate the degree to which crazy quilts are compatible with a random generative process, and the degree to which this differentiates them from regular quilts. This broad question leads directly to testable hypotheses concerning patch area and patch centroid location (labelled HR and HC for hypotheses about regular and crazy quilts, respectively):

HC1: Crazy quilts are intended to create a haphazard and irregular impression. If this intention is realized, the location of patch centroids should be adequately modelled by a random spatial process.

HC2: Because crazy quilts lack repeating motifs or patch types, the patch areas should come from a single overall distribution. Furthermore, as patch ensembles are constrained to fit within rectangles, we expect small patches to be more numerous than large ones. We thus predict a positive-skewed but otherwise continuous distribution of patch sizes.

HR1: Because patterns in regular quilts are intended to be periodic and symmetrical, the locations of patch centroids should not be adequately modelled by a random spatial process.

HR2: Regular quilts are made up of repeating motifs consisting of a small number of patch types. Because each element of a given type is intended to be identical in size and shape, but will include some small degree of error, we expect the overall patch size distribution of a regular quilt to be a composite of the individual distributions for each patch type as a mixture of Gaussian distributions (rather than the single overall distribution predicted for crazy quilts, in HC2).

Materials and Methods

We performed a detailed spatial analysis of hand-tracings of 8 crazy quilts and 8 regular quilts from North America. Their overall properties are summarised in table 1. To ensure that the quilts had a comparable level of structural complexity and similar internal constraints, all quilts had at least one level of regular subdivision, i.e. were organised either in regular blocks or strips. Because many quilts were made anonymously, it was not possible to date the quilts exactly, but based on the published sources, we ensured that the quilts stemmed from roughly the same geographic area (USA) and time (ca. 1870-1930). Additionally, we only selected images that showed the entire quilt in sufficient detail to allow an exact delineation of patches within the quilts. The analysed quilts were selected from commercially available quilt books [7, 36, 37]. In general, these quilts were blanket size, but one of the crazy quilts (C5), was considerably smaller than the others, roughly pillowcase size.

Table 1. Overview of the Quilts Analysed

Quilt	Year	Number of Patches	Height (in cm)	Width (in cm)	Overall area (in cm^2)	Patched area (in cm^2)
R1	≈1930	784	208.28	208.28	43,381	15,661
R2	≈1930	440	203.2	175.26	35,612	17,934
R3	1898	421	218.44	165,1	36,064	18,520
R4	≈1930	327	215.9	209.55	45,241	31,877
R5	1891	972	187.96	173.99	32,703	32,020
R6	1890-1910	692	191.77	187.96	36,045	19,980
R7	1890-1910	736	201.93	200.66	40,519	25,460
R8	1900-1920	192	182.88	173.99	31,819	25,948
C1	≈1930	239	198.12	160.02	31,703	21,895
C2	1871	512	193.04	160.02	30,890	21,327
C3	1884	317	207.01	180.34	37,332	35,757
C4	1885	834	195.58	162.56	31,793	31,793
C5	≈1875	108	35.56	35.56	1,265	1,203
C6	≈1890	322	139.7	200.02	27,943	26,636
C7	1880-1900	106	134.6	132.08	17,778	17,505
C8	≈1889	133	210.82	170.18	35,877	34,550

Size and numbers of patches of the quilts analysed and the exact or approximate year of production. We excluded border stripes from the size measurements in our analysis, including only the region that contained patchwork ("patched area").

Digital images of the quilts were scanned from printed photographs at 300 dots per inch (CanoScan LiDe 200, Canon). Despite intensive efforts, we were unable to use segmentation algorithms to derive accurate patch borders automatically, due to considerable internal complexity and heterogeneity of the quilt patches. Thus, the outlines of individual patches were traced manually on a Wacom LCD tablet (DTZ-1200W/G) and saved as regions of interest (ROIs) using FIJI [38]. The tracings are shown in Fig. 2. We converted the ROIs from pixels to cm^2 by scaling the scanned image based on the measurements of the photographs of the quilts and the dimension given in the source books. This scale was estimated twice, based on length and width measurements, and then averaged. Unless indicated otherwise, "area" refers to true area, in cm^2, hereafter. We excluded non-patched borders (long continuous strips of fabric) from the analysis, isolating the area containing patches by using the smallest possible bounding box around the patched area. For each individual patch, we computed the centroid (by averaging the x and

y values of the pixels within the patch) and the area in FIJI. Measurement accuracy was evaluated by remeasuring one randomly selected patch from each quilt ten times and analysing the absolute range of measurements for each quilt category.

We analysed the patch area distributions in two ways: first, by fitting multimodal distributions (Gaussian mixture models) and second, by fitting various standard random unimodal distributions. For unimodal distributions, we chose three plausible candidates that take only positive values: the gamma, Weibull and lognormal distribution, with no *a priori* reason to favour any one of these particular distributions.

The gamma distribution can take a wide variety of forms, which has led it to be widely used for modelling spatial and temporal characteristics of rainfall [39], mutation rates in human mitochondrial DNA [40] and rate of material deterioration [41].

The Weibull distribution [42] is often used to model product failure, but also human aging and mortality (for a review of recent applications see [43]). Furthermore, the distribution of two- and three-dimensional particle sizes, e.g. airborne dust particles, can also be well-modelled with the Weibull distribution [44, 45].

The lognormal distribution applies to variables whose logarithms have a normal distribution [46]. While widely used in biological modelling [47, 48], it has been suggested by Brown and Wohletz [49] that although the Weibull and lognormal cover data similarly, the Weibull is more empirically grounded in the case of fragmentation of particles into smaller particles and that "the empirical use of the lognormal distribution for particle size studies over the last century may have been simply fortuitous" ([49], p.15).

Finally, we also included the standard normal distribution, since we predicted this would fit regular quilts best (in the form of Gaussian mixture models).

We used maximum likelihood estimation to fit the distributions with the R (version 2.12.2, http://cran.r-project.org/) package "fitdistrplus" (version 0.3-4). We scaled the area values down (area × 0.01) as required to bring values into the supported distribution range [50] for all quilts except C5, where we used area × 0.1 because the quilt was smaller than the others and required less reduction. We used the Akaike Information Criterion (AIC) [51], a measure derived from the log likelihood function, to assess which of these distributions fit the data best. We considered all top-ranking candidates (with a difference in AIC values (△AIC) less than 2) to be likely candidate distributions [52]. To additionally evaluate the likelihood of one model over the other, we follow Burnham and Anderson [52] in converting AIC values into normalised Akaike weights which indicate the likelihood of a model given the data. This adjustment is particularly useful when comparing two models with similar AIC values. Unlike conventional statistical tests, AIC does not allow *absolute* inferences about how well a model fits the data; instead it provides a *relative* assessment of which of the available models fits the data best, compared to the other candidates.

We constructed Gaussian mixture models for both quilt categories. For regular quilts, we classified the patches into categories (i.e. the different squares, triangles etc that occurred in the pattern block) manually. We used the area means, standard deviations and relative frequencies of each patch category to seed the mixture models which we then used to randomly generate the same number of elements as in the quilts. Initially, we constructed mixture models with patch categories estimated by the Bayesian Information Critierion and no external seeding of category information, which led to higher rates of misclassified patches, since pattern elements may have different shapes, but similar areas. We thus opted for seeded models that offered comparably good fits and reflected the number of motifs in regular quilts accurately.

Using seeded models, we plotted the actual patch area distribution and the distribution of the estimates of simulated patch category areas using the R package "mixtools" [53]. For crazy quilts, we used the identical procedure, but we used the overall mean and standard deviation of the whole dataset of each quilt as seeds, since there were no obvious patch categories. We used bandwidth values (which are equal to the standard deviation of the kernel estimates) as a proxy to test for the difference in the amount of smoothing required to fit the distributions in the two quilt categories.

To test the goodness of fit of these Gaussian models explicitly, we generated 39 simulations with the model parameters derived from the data using the R package "mixtools" and custom Python software (version 2.65, http://www.python.org). The area values of the simulations and the actual data were sorted by size, and the minimum, maximum and actual areas were then plotted. If the actual areas were above the maxima or below the minima generated by the simulations, we interpreted this as a significant deviation ($\alpha = 2/40 = .05$) from the model.

We analysed the skewness of the area distributions with the R package "moments" [54]. Again, for crazy quilts, we used the overall distribution, but for the regular quilts, we analysed skewness for each of the patch categories separately.

Moving from patch area analysis to the spatial distribution of patch centroids, we fitted Strauss models to the patch centroids of both crazy and regular quilts in R using the package "spatstat" [55]. Strauss processes model the random spatial distribution of points that do not overlap or coincide. The parameter r of the Strauss process denotes an interaction distance between points. This parameter must be larger than zero, to satisfy the "no overlap " constraint. The parameter γ controls the strength of the interaction between points. If $\gamma = 1$, then the process is a Poisson process with intensity β (average number of points within a certain area), whereas if $\gamma = 0$, then the process is "hard core", that is, the points can never lie closer together than distance r [56]. Thus, γ describes the interaction between the points, and r describes the distance in which this interaction can occur. The goodness of fit of the Strauss process can be assessed by the L-function, which is based on Ripley's K-function [57]. The K-function counts the number of occurrence of points within varying distances (r) around each point [58]. For complete spatial randomness, $K(t) = \pi r^2$. The L value is a transformation of the K value: $L = (K/\pi)^{1/2}$.

L is preferable to K for our analysis because it is constant in a Poisson pattern ($L = r$), unlike K. That is, transforming K to L removes the contribution of the random Poisson process from the distribution, showing only the effects of r. Because we had no *a priori* reason to believe that a Strauss process was specific to either quilt category, we applied this process to both regular and crazy quilts. To estimate the value of r, we applied the method of maximising pseudolikelihood [56]. This approach was originally proposed by Besag to estimate the unknown parameters of a sample that do not follow a multivariate normal distribution [59, 60]. We tested all values between the minimum and maximum interpoint distances (r) in 0.01 steps. The value with the maximum pseudolikelihood was chosen as the optimal interaction radius r for the model of the Strauss process fitted to our patterns. The highest and lowest of the simulated values form simulation envelopes that determine the critical points (i.e. $\alpha = .05$) of the Monte Carlo test for upper and lower K values [57, 61].

To estimate the effect of the border on the patterns (for example, the centroids might be more sparse near the quilt edges), we ran the process twice, with and without an isotropic border correction, and compared the resulting r values. For each quilt, the goodness of fit of the parameter was then tested by 39 simulations of N random points (with $N=$ number of centroids present in the original quilt), placed randomly in a space of the same dimensions as the quilt, constrained only by the parameter r. For those cases where there was no effect of the isotropic correction, we also ran the simulations of the model fit without any corrections, using the estimated r value. With two exceptions (C2 and C4), the values for r estimated with and without isotropic border correction were identical. This implies that the effect of the border on centroid distribution is weak. For the two exceptions, we ran the simulations both with and without the isotopic correction and compared the fit. For C2, the fit of the simulation was the same with either r value, while it improved for C4 with the correction.

In addition to the R packages already mentioned, basic statistical analyses were performed in SPSS version 17 (http://www-01.ibm.com/software/analytics/spss) and using custom Python scripts.

Results

Basic quilt statistics

In total, the quilts contained 7,135 patches (regular: 4,564, crazy: 2,571), see Fig. 2. Crazy quilts had on average 321 patches (range: 106 - 834), while regular quilts had on average 571 patches (range: 192 - 972) but this apparent trend for more patches in regular quilts did not attain statistical significance (Mann-Whitney U test: p = 0.06, U = 14,000). There was no obvious relationship between number of patches and quilt size for either quilt type (Linear, logarithmic, inverse, quadratic and cubic regressions were attempted, all p >.396). The total patched area in cm^2 for crazy quilts averaged 23,102 (SD: 10,871) versus 23,425 (SD: 6,349) for regular quilts, which was not statistically significant (Mann-Whitney U test: p = 0.64, U = 27.5). Thus, the quilt categories were comparable with regard to size, number of patches, and no relationship was found between number of patches and overall quilt size for either category. The difference in manual measuring error for the two quilt types (Crazy quilts: 3.25% measuring error, SD: 2.38. Regular quilts: 3.35% measuring error, SD: 1.86) was not statistically significant (Mann-Whitney U test, p=.8, U=29).

The distribution of patch areas

Hypotheses HC2 and HR2 predict significant differences between the two quilt types in their distributions of patch sizes. We found that the patch areas for regular quilts were indeed characterized by a multimodal distribution, while the distributions for patch areas of crazy quilts were unimodal. As predicted, the overall area distributions of the crazy quilts had a strong positive skew (mean skewness: 2.3, SD: 1.4). In the case of regular quilts, the patch area distributions of each patch category were only weakly skewed and were split between positive and negative skew: 20 categories had a negative skew (mean skewness: -0.74, SD: 0.83) and 24 had a positive skew (mean skewness: 1.46, SD: 2.11), suggesting that variation in patch areas due to variation in motor control is not *a priori* skewed either way. In summary, we found that the patch area distributions of crazy quilts were unimodal, while the patch area distributions for regular quilts were multimodal, confirming HC2 and HR2.

Crazy quilts: unimodal distribution types

The unimodal distributions underlying different crazy quilt patches did not consistently fit with a single distribution type. As expected, due to the constraints of quilt-making, the normal distribution was a very unlikely candidate for all cases. In three cases, lognormal clearly was the best candidate, with no other distributions being very likely (all △AIC >9.42). The AIC values for gamma and Weibull distributions in general were much closer: in three cases, △AIC was <2, so either of these two distributions provide a possible best candidate (see table 2). The gamma distribution was the strongest candidate in two further cases (C2 and C3), where no other candidate distribution was likely. However, in all those cases where the Weibull distribution was a likely candidate, the gamma distribution was also likely, and the Akaike weights for the Weibull distribution were not very strong, not exceeding a probability of 70%. Overall, we observed a split between the crazy quilts where lognormal was the best candidate (N=3) and those cases in which gamma and Weibull fit best (N=5). Figure 3 shows an overlay of histograms and the best fitting distributions as well as QQ plots of the theoretical distributions and the actual data. Deviations of the data from the theoretical distributions are most visible in the high quantiles, which is unsurprising, because there are fewer large patches than small patches in the quilts, and thus the data is sparser in the high quantiles. In summary, crazy quilt patch area distributions were well-modelled by various distribution classes but no single type fit all exemplars.
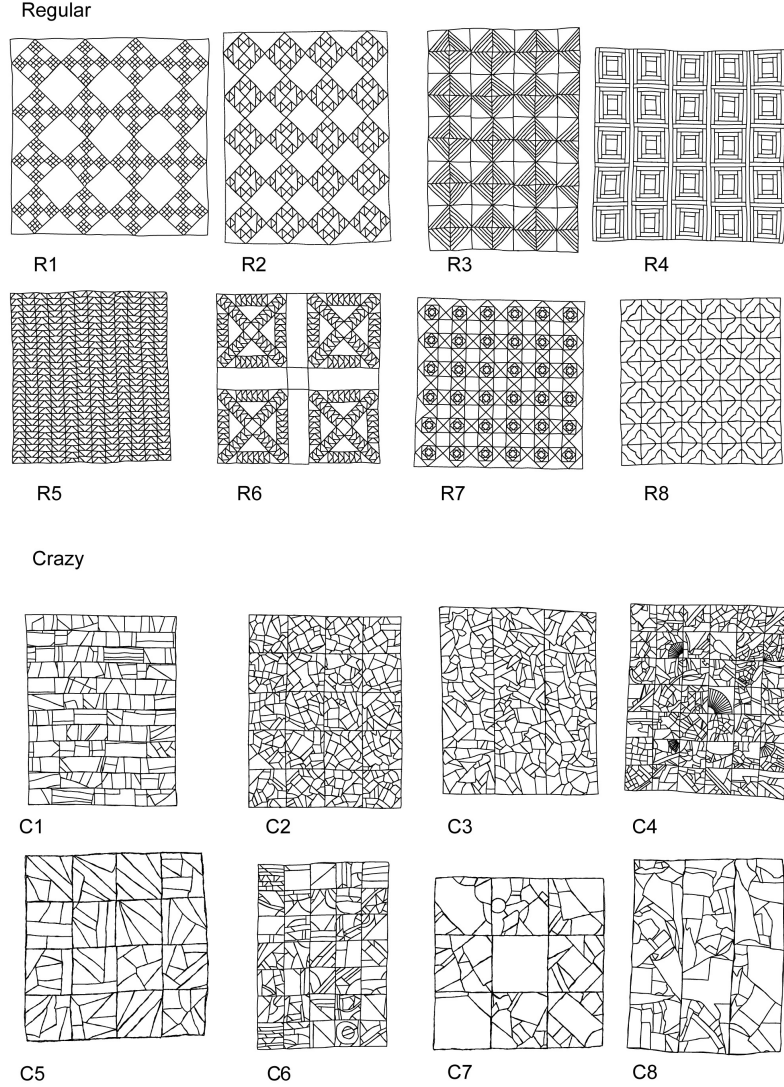
Regular

R1 R2 R3 R4

R5 R6 R7 R8

Crazy

C1 C2 C3 C4

C5 C6 C7 C8

Figure 2. Patch outlines of the sixteen quilts that were analysed (borders were not analysed and are not shown). R1-R8: "Regular" quilts with traditional repeating geometric patterns. C1-C8: "Crazy" quilts with no obvious repeating pattern.

Regular quilts: Gaussian mixture models

In contrast, kernel density estimates of Gaussian mixture models proved very good fits to the multimodal patch area distributions in the regular quilts (see Fig. 4), while the estimates of Gaussian models for the crazy quilts (see Fig. 5) show little overlap with the estimates of the real distributions. In particular, the Gaussian models for crazy quilts extend into negative values, violating our minimal size constraint. Standard Gaussian distributions thus provide poor models for crazy quilts.

The difference in bandwidths (standard deviation of the kernel density) for the two quilt types was

Table 2. Unimodal distributions fitted to crazy quilts

Quilt	C1	C2	C3	C4	C5	C6	C7	C8
Gamma	**1.72** **(30)**	**0** **(.99)**	**0** **(.90)**	81.89 (<.01)	**1.86** **(.25)**	**0** **(.51)**	29.44 (<.01)	9.56 (<.01)
Weibull	**0** **(.70)**	8.53 (<.01)	15.97 (<.01)	140.86 (<.01)	**0** **(.64)**	**0.18** **(.49)**	28.89 (<.01)	9.42 (<.01)
Lognormal	53.41 (<.01)	48.49 (<.01)	4.39 (.10)	**0 (1)**	17.95 (<.01)	25.58 (<.01)	**0 (1)**	**0** **(.98)**
Normal	125.34 (<.01)	165.61 (<.01)	107.18 (<.01)	872.04 (<.01)	3.45 (.11)	324.41 (<.01)	204.52 (<.01)	172.08 (<.01)

AIC values for the different distributions fitted to the quilts. The best fitting distributions are marked in bold, with the Akaike weights given in brackets. If $\triangle$AIC<2 for two models, we considered both models to be a possible fit (this was the case for quilts C1, C5 and C6).
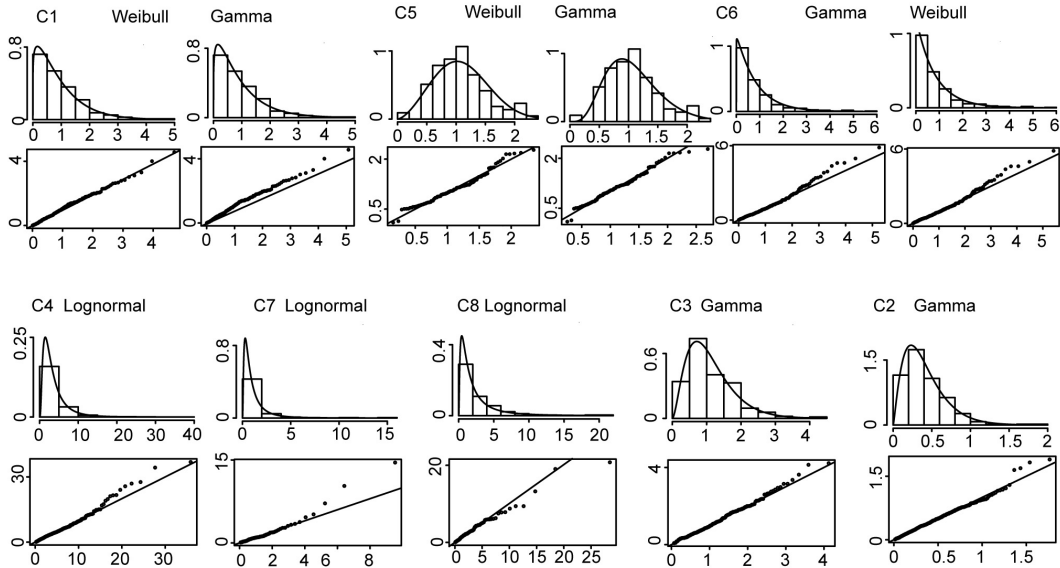

Figure 3. Random distributions fitted to the crazy quilt patch areas. In those cases where $\triangle$AIC<2, both distributions are shown. For each quilt, the best fit distributions and the histograms of the area distributions are superimposed in the top graph. Below, the QQ plots of the quilt sample quantiles (X-axis) and the theoretical quantiles as predicted by the fitted distributions (Y-axis) are shown.

statistically significant (Mann-Whitney U test: p=.03, U=12, Cohen's $d = 1.075$) and much higher for crazy quilts (mean bandwidth for regular quilts: 5.14, for crazy quilts: 19.49), indicating that a significantly higher degree of smoothing was required for a Gaussian distribution to be even approximately fitted to crazy quilts.

We calculated the number of occurrences when the actual patch area values were above the maximal value or below the minimal value of the simulations (see Table 3). The differences in the percentage
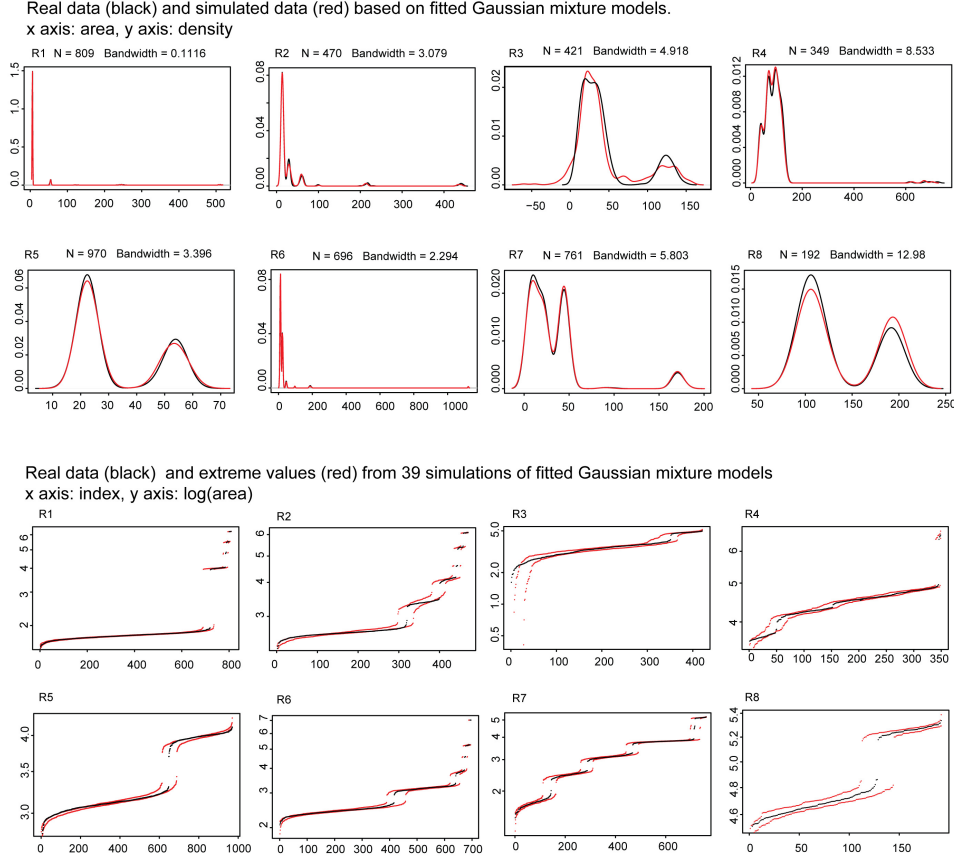
Figure 4. Top panel: The kernel density estimates of Gaussian mixtures of patch areas of regular quilts. The black line shows the actual data and the red line shows the the Gaussian mixtures simulated based on patch categories. Bottom panel: Fit of the data (black) and 39 simulations (highest and lowest values of the simulations indicated with red dots (log scale).

of deviations between the two quilt types was statistically significant (Mann-Whitney U test: p<.001, U=64, Cohen's $d = 3.36$). Thus overall, Gaussian mixture models proved a significantly better fit for the regular quilts (Fig. 4) than the crazy quilts (Fig. 5), based both on bandwidth differences and the fit of the simulation envelopes.

Spatial distribution of patches: fitted Strauss processes

The previous results show that there are fundamental differences between crazy and regular quilts in terms of the distributions that best describe patch areas. We also evaluated the degree to which a well-defined random process – a Strauss process – can be used to model patch centroid locations for the two quilt types.

We first estimated the point interaction parameter r from the data from both quilt classes using maximum pseudolikelihood. We then simulated a Strauss process with points randomly placed in space, under the constraint of this r estimate, and compared them with the actual distributions. The results

Real data (black) and simulated data (red) based on fitted Gaussian models.
x axis: area, y axis: density

Real data (black) and extreme values (red) from 39 simulations of fitted Gaussian mixture models
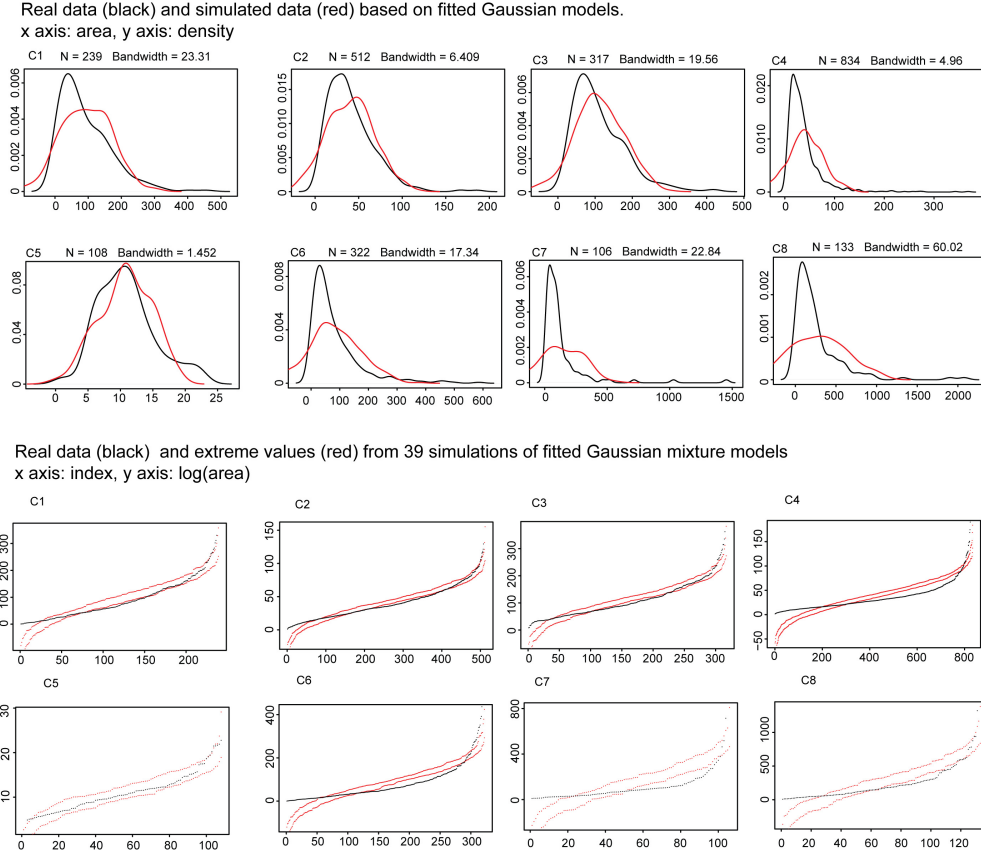x axis: index, y axis: log(area)

Figure 5. Kernel density estimates of single Gaussian distributions of the patch areas of crazy quilts. The black line shows the actual data and the red line shows the Gaussian mixtures simulated based on patch categories. Bottom panel: Fit of the data (black) and 39 simulations (highest and lowest values of the simulations indicated with red dots).

of the simulations are shown in figure 6: density values are plotted on the X axis, and the L values for various distances (r) are plotted on the Y axis (roughly, L gives number of other points lying within the distances of a focal point, see Methods). The simulation envelopes based on the highest and lowest ranking values from 39 simulations are shown as grey bands, while the dashed red line shows the predicted L values of a fully random Strauss process. For quilts accurately modelled by such a process, the data (black line) should be within the grey envelope. A deviation of the 'observed' line above the envelope means that there are more points within the Strauss interaction radius r than predicted by the model, and a deviation below the envelope that there are fewer points than predicted, i.e. that there is repellence between the points.

Table 3. Deviations from Gaussian mixture models for crazy and regular quilts

Regular Quilts	# of deviations (%)	Crazy Quilts	# of deviations (%)
R1	0 (0)	C1	119 (49.79)
R2	156 (33.19)	C2	329 (64.26)
R3	21 (4.99)	C3	179 (56.47)
R4	7 (2.00)	C4	719 (86.21)
R5	173 (17.84)	C5	5 (4.63)
R6	9 (1.29)	C6	249 (77.33)
R7	0 (0)	C7	77 (72.64)
R8	0 (0)	C8	84 (63.16)

Deviations above or below 95% limits of Monte Carlo simulations based on Gaussian mixture models for regular and crazy quilts. Both the number of deviant patches, and their corresponding percentage of the total number of patches in that quilt, are given.

When fitting the Strauss process with the estimated r values, the model fitting function returned γ values > 1 for three of the eight regular quilts (R1, R3 and R4). As the Strauss process is only defined for γ values ≤ 1, this is strong evidence that it is not an appropriate model for these centroid sets. Therefore, we did not fit Strauss processes to these quilts, but do show the density of centroids for various r values for these quilts in figure 6. In the graphs, a fully random pattern with no interpoint interaction (i.e. Poisson) would be a straight line. Clearly, the distributions of patch centroids deviate strongly from a Poisson process. However, for crazy quilts, in contrast to regular quilts, the Strauss process typically provides an excellent fit. While C6 and C7 show some clustering at medium radius values, this is within the simulation envelopes. Only C4 was consistently and significantly under-dispersed across the whole range of r values. One possible reason for this is that C4 had a very large number of patches for its size, so that centroids were consistently closer together than predicted by a random model. Furthermore, C4 is unusual in that it contains two isolated regular 'fan' shapes.

Figure 6 clearly illustrates that the regular quilts cannot be accurately modelled with a Strauss process. Unlike crazy quilts, regular quilts show large oscillations in the L value as r increases. reflecting the regular clustering of patches. In sum, the distributions of centroids in crazy quilts, but not regular quilts, are generally consistent with a simple Strauss random process. These data are clearly consistent with our hypotheses HC1 and HR1.

Discussion

Using statistical spatial analysis tools, we found clear differences between regular and crazy quilts. We showed that the distributions of patch areas differ for the two quilt categories: the patch areas of regular quilts follow a multimodal distribution, the peaks of which correspond to the patch categories of the pattern, consistent with hypothesis HR2. In contrast, patches of crazy quilts have unimodal distributions (consistent with HC2), but no single random function consistently fits the distributions best. In all crazy quilts, the area distributions had a positive skew, i.e. small patches are more frequent than large patches. These findings were consistent with hypothesis HC1 concerning the areas of patches in crazy quilts.

For the crazy quilt patch sizes, we found that the Weibull distribution and the gamma distribution were an equally likely fit in three cases and the lognormal was the best fit for three others, but there was no overlap between gamma and Weibull on the one hand and lognormal on the other. Thus different random distributions approximate the patch size distributions of regular quilts.
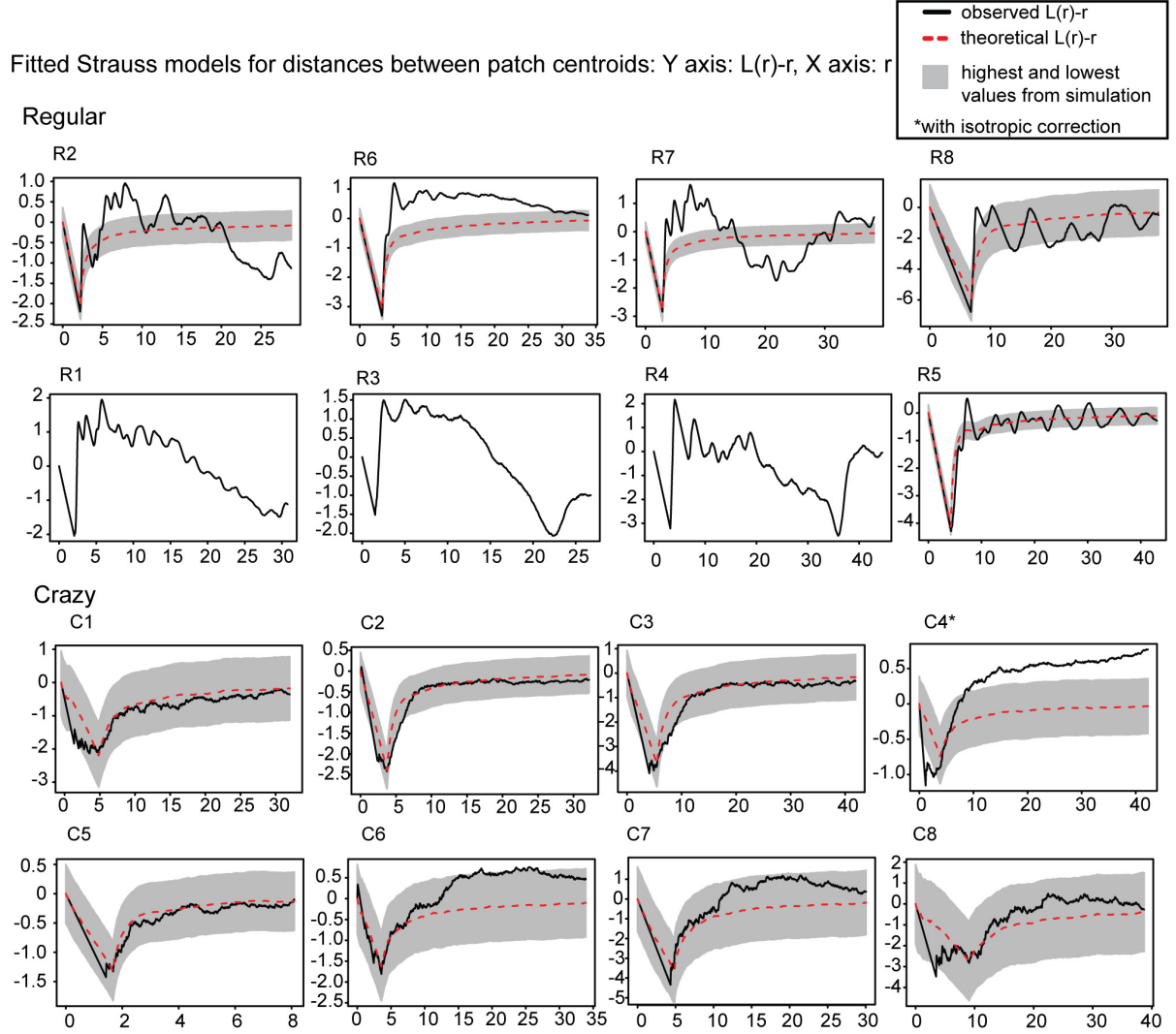
Figure 6. Simulation envelopes of fitted Strauss models for regular quilts (top panel) and crazy quilts (bottom panel) based on centroid locations. For three regular quilts the simulation algorithm did not converge and thus no simulation envelope is shown. The solid black line depicts the actual data, and the data predicted by the model is shown with a dashed red line. The grey envelopes show the highest and lowest values of 39 simulations. The Y-axis shows the L-function, derived from Ripley's K-function, and the X-axis shows the varying r values. A deviation of the black line beyond the grey envelope can be interpreted as a significant deviation of the data from the fitted Strauss model.

Concerning centroid locations, we found that patch centroids of crazy quilts could be accurately modelled by a random Strauss process with one parameter (r) derived from the data, consistent with our hypothesis HC1 about the essentially random placement of patch centroids in crazy quilts. Furthermore,

this analysis indirectly supports our hypothesis concerning the non-random placement of centroids in regular quilts (HR1).

The results of this investigation show clearly that, despite humans' well-documented difficulty with recognizing or generating random sequences, Victorian quiltmakers were able to intentionally produce spatial patterns compatible with random processes. The clear distinction we found between regular quilts and crazy quilts shows that the randomness observed in crazy quilts does not result from low-level motor inaccuracy, which is equally present in both quilt types. We demonstrated a close fit between quilt centroids and random Strauss processes in which the only fitted parameter was a minimal distance between patch centroids. This shows that within the constraints of the patchwork method itself (which demands a certain minimal amount of cloth simply to stitch the patches together), crazy quilt properties match those expected from a random spatial process. We thus conclude that Victorian-era quilt makers achieved a level of intentional spatial randomness that, to our knowledge, has never been documented in any other human artefact. Our results however do not allow inferences to be drawn concerning the actual production process, which obviously would not have been entirely random, and would have required some planning (e.g. adjusting size of the quilt to the available amount of fabric or planning even colour distributions). However, a description of the end product, as we have undertaken here, has the advantage that it could be applied to other artefact types. For example, we think it would be fascinating to compare these findings with other random seeming human made patterns, e.g. crackle glazing, patchwork made in Japanese and Korean traditions, stained glass, mosaics, pavings etc, using the techniques developed here.

The results presented here do not, of course, suggest that all aspects of crazy quilts are random. Obviously, the weave of the fabric patches, or the stitches used to combine patches, are highly regular. Furthermore, individual patches were traditionally often decorated with detailed, and often representational, needlework which is anything but random. Finally, the colour selection of patches appears, at least in most cases, to be non-random (although we did not analyse colour in the current study, and accurate determination of a single "colour" for the complex fabric patches typical of our quilts is far from trivial, see [26]).

The multimodal distributions underlying the regular quilts derive from the repeated production of the same pattern motifs. The repeated production of multiple units to create symmetrical patterns may thus be the visible manifestation of humans' unusual cognitive proclivity for order and symmetry [62–66]

Naturally, it would be intriguing to record and model the actual production process of crazy and regular quilts to gain insight into the levels of planning involved in producing crazy versus regular quilts. In particular, it is interesting that many crazy quilts have an intermediate level of organisation in to blocks or stripes. The organisation of a production process into discrete chunks offers advantages in terms of efficiency [67]. Examining how hierarchical organisation benefits the quiltmaking process, which is guided not only by efficiency, but also by aesthetic considerations, may offer further insights into the organisation underlying human self-guided productive processes more generally.

The details of the process by which historical crazy quilts were produced are unavailable today, although it would be possible to document the generation process in present-day quilt makers. More practically, it should be possible to mimic key features of quilt making (e.g. patch selection, trimming and combination processes) with computer interfaces to investigate aspects of the quilt-making process in the laboratory. We see no reason to doubt that any human provided with such an interface could produce random patterns like those documented in our quilts, given that, in their heyday, crazy quilts were produced by a substantial proportion of quilters. Such a research project based on Fechner's "method of production" would be a logical, and we think valuable, extension of the analyses reported here.

Quilting remains an extremely popular tradition. Crazy quilts are well known, but rarely made today. The highly ordered and hierarchically-structured regular quilts represent a much older, and much more persistent, patchwork tradition. It is unlikely that this dominance results from a practical or economic constraint, since it would be much easier to turn a bag of cloth scraps into a crazy quilt than a regular

quilt, and the measurements and straight lines required to make a regular quilt are both more difficult, and more wasteful of cloth, than those needed to create a crazy quilt. Instead, we suggest that the rarity of crazy quilts and their short lived popularity provides a clear historical indicator of the deep, and as yet unexplained, drive in our species to surround and adorn ourselves with structured and symmetrical, rather than random patterns : an evocative reflection of what Gombrich [6] termed the human "sense of order".

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6 | Discussion

The focus of this dissertation has been on the cognitive processes underlying the perception and production of abstract geometrical patterns in humans and animals and on the analysis of the spatial properties of aesthetic artefacts. While the empirical findings of each experiment are discussed in detail in the individual chapters, I would like to take the opportunity here to assess the results more generally and to further elaborate on the methods employed and their possible future applications.

6.1 Method of production

Fechner's method of production was successfully applied in experiments with adult humans with no artistic background (chapters 3 and 4). Participants readily and spontaneously produced ordered visual patterns, and in general reported that they enjoyed the process. The patterns that they generated were consistent enough to allow statistical analysis. One drawback to this approach proved to be the open-ended nature of the task, with participants often taking a long time to complete patterns. However, this also underlines the validity of the method, since participants seemed to be truly engaging with the process and attempting to produce structured, varied and pleasing patterns rather than merely completing the experiment as quickly as possible. The patterns that participants produced exhibited predominantly translational, bilateral or rotational symmetry (see Fig. 6.1).

I reported in chapter 3 that a grouped rotation pattern was often produced in the first instance of a trial. The grouped rotation pattern consists of groups of four tiles that together form a larger composite shape (see Fig. 6.2, top row). It seems plausible that this pattern represents the "best" or "most natural" arrangement for certain tile types. However, the similarity of responses in the first trials in the pattern production task overall might also have been due to the similar cultural backgrounds of the participants, who were predominantly Western European. I thus tried to determine whether different cultural backgrounds would lead to different strategies during production. I compared the output of Westerners and Koreans using a very simple production task which entailed changing the width/height ratio of rectangles which were located in frames of various dimensions. There were no significant differences between cultural groups; that is, participants in both groups produced highly similar distribution of rectangles, and were affected in a similar way by contextual cues. For both groups, the properties of a visual
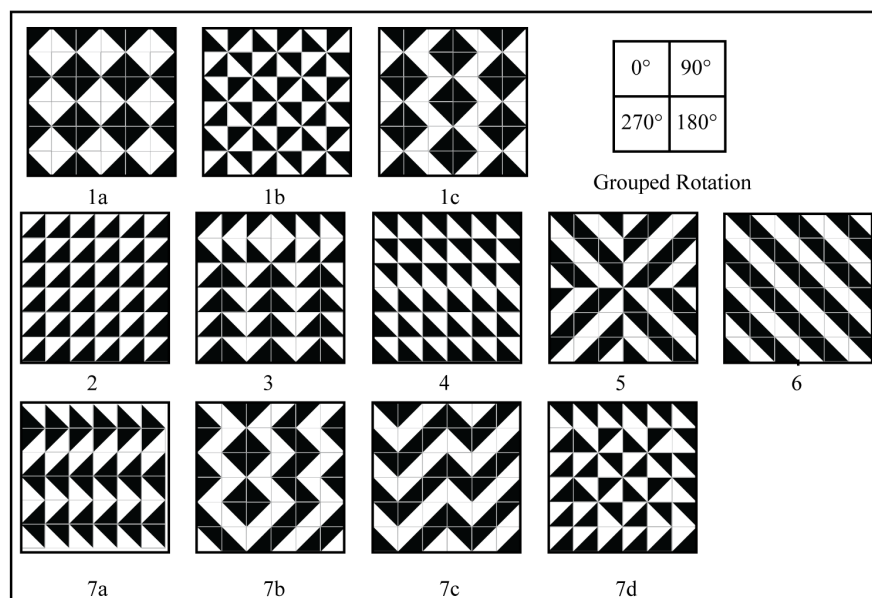
Figure 6.1: Examples of patterns created by participants using the method of production. Originally published in Westphal-Fitch et al. [2012, p. 2010, Fig. 2].

frame influenced the properties of the shapes produced. The influence of visual framing has generally not been taken into account in experiments that study simple shape preferences, which typically displayed figures on computer screens or sheets of paper, effectively creating a frame around the shapes. A next step in this research programme would be to conduct cross-cultural pattern production and preference experiments to determine whether patterns are subject to a stronger cultural influence than the simple geometrical shape used in the framing experiment.

Given the contemporary ubiquity of graphics-ready computing devices there is, I think, great potential for using the method of production further, particularly in ontogenetic studies. It would be fascinating to analyse the structural complexity of patterns produced by children of varying ages, and attempt to relate those patterns to stages of syntactic development in language acquisition to analyse whether patterns of production of visual complexity and syntactic complexity emerge at the same time. Another intriguing line of research would be to quantify the pleasurable experience of production (informally expressed by many participants after the experiments), for example using physiological parameters such as facial electromyography, pupillometry or changes in heart rate or changes in hormone (e.g. cortisol or oxytocin) levels.

Neither the idea of using the method of production, nor the idea of focussing on "direct" factors, are new. However, the implementation of the method of production in the FlexTiles interface using two-dimensional patters and user-determined changes in the orientation of pattern elements is, to my knowledge, novel and seems to capture at

least parts of the productive aesthetic processes underlying ornament and decoration. Fechner's method of production has been relatively neglected (but see McManus et al. [2011]), but I suspect that computer-based interfaces will drive a resurgence of this important approach to empirical aesthetics.

6.2   Method of choice

I also combined pattern production with Fechner's method of choice in experiments designed to assess how preferences for various patterns on a perceptual level might correlate with the frequencies of pattern variants produced. I found that despite the relative simplicity of these plane patterns, they elicited clear preferences: participants readily engaged in both the two-choice task (chapter 4) and the Likert scale rating task (chapter 3). Due to the binary choice it requires, the two-choice paradigm proved to be useful because results are easily comparable between participants. Based on a single response, it is of course impossible to tell whether the choice is actually a choice *against* the less preferred image, or a choice *for* the preferred image. Only by using multiple comparisons of different pattern variants, as I did here, can a ranking of preferences be established. In a rating task with a Likert scale, the "style" of a participant, for example avoiding or using only the extremes of the scale, makes it more difficult to compare responses between participants, in contrast to the two choice task. Nonetheless, the Likert scale method has the distinct advantage that a pattern could be rated by itself, rather than in comparison to a second pattern. However, even here there may be an implicit comparison with recently viewed images.

I compared production and choice data in chapter 4. Given a choice between a random pattern, and either translational or rotational patterns in a two-choice task, random patterns were least likely to be chosen. This dispreference is congruent with the results from pattern production, where the final patterns produced typically contained high degrees of order which were clearly non-random. It seems that humans strongly prefer structure in visual arrays relative to random arrays, and do not spontaneously produce random patterns. Thus the experimental data here provide support for Gombrich's postulated "sense of order", an idea he had based primarily on art historical evidence.

Examining preferences for translational and rotational patterns, there was a strong relationship between local pattern element properties and global pattern arrangements for diagonal tiles. During production, the grouped rotation pattern was produced most often with diagonal tiles. The same pattern was also strongly preferred in the two-choice task when constructed from tiles that had diagonal symmetry and rejected more often when constructed from tiles with horizontal symmetry, suggesting a strong relation between local tile properties and global tiling properties. In contrast, translational patterns were often produced with tiles containing horizontal symmetry and only rarely with tiles containing diagonal symmetry, but there was no strong preference for the translational pattern constructed from horizontal tiles in the two-choice task (see chapter 4, Fig. 6). Determining the reasons why the preference and production data overlap

in the case of diagonal tiles, but not horizontal tiles, would require further empirical work, with different stimuli allowing a more fine-grained comparison between symmetry classes.

Regarding the interplay between local pattern element properties and global patterns that are constructed from them, it is interesting to note that in real life artists and artisans often engage in behaviours such as blurring the eyes or stepping back from the canvas, presumably to gain a more global view of the object they are working on. Quiltmakers often view their work (which can easily reach 2 × 2 m) through special "reducing glasses" or a set of binoculars held backwards to help detect flaws in their designs. Presumably, the transition between local view required during production and global view necessary for overall perception, entails a switching of cognitive modes that is somewhat effortful, which can be aided by these or similar tricks.

The interplay between global pattern properties and local properties of pattern elements would be a rich area for further research in aesthetics, for example testing such sensitivities in populations of humans that are often claimed to have a local visual bias, such as individuals diagnosed with autism. Although I presented results for ASD individuals in chapter 3 indicating no significant difference from age and IQ-matched normal controls in a flaw detection task, finer or more challenging stimuli might still elicit some differences. Another route of inquiry would be to test to what extent the strength of the global visual bias in normal adults can be altered through prior local priming. The relation between global and local levels in visual arrays has previously been addressed in animal cognition experiments [Fagot and Deruelle, 1997; Deruelle and Fagot, 1998; Tanaka and Fujita, 2000; Cavoto and Cook, 2001; Aust and Huber, 2003; Goto et al., 2004], thus also making this topic an obvious contender for further comparative work.

The production process in the experiments presented here was local by design, that is, only one element could be changed at a time. This is not unrealistic, since such a local, stepwise procedure is typical of beading, embroidery or patchwork, for example. Other crafts, however, produce multiple changes per production step. In weaving, for example, the weft thread is drawn across many warp threads in a single motion, leading to many simultaneous small local changes in the pattern. It would be interesting to investigate the interplay between production and choice in such a context. Furthermore, most real-life patterns consist of more than one pattern element, and although the complexity of analysis would rise considerably, it would be intriguing to analyse production data for more complex arrays containing multiple different repeating elements.

6.3 Method of use

In the spirit of Fechner's method of use, in which actual artefacts are analysed, I conducted a spatial analysis comparing "normal" orderd quilts with crazy quilts, a class of real life patterns that are not obviously ordered (chapter 5). I found that a random Strauss model (a model based on a random Poisson process that has the additional constraint that points cannot fall within a certain radius of one another) can be fitted adequately to crazy quilt patch centroids, but not to traditional quilt patch centroids.

Furthermore, patch size distributions of crazy quilts differ strongly from traditional quilt patterns. These findings indicate not only that regular and crazy quilts differ from each other in their spatial organisation, but also that the arrangement of crazy quilt patches in the two-dimensional plane approaches a random distribution, running counter to the usual order and symmetry that typically underlies visual aesthetic artefacts.

The relative scarcity of unordered aesthetic artefacts like crazy quilts is consistent with findings presented here that participants consistently chose ordered over random patterns and spontaneously produced highly ordered patterns rather than random patterns. Why crazy quilts became so popular in the nineteenth century is not clear: one possible answer might lie in the highly ornate and detailed embellishment of patches with embroidery and the deliberate and selective use of valuable and unusual fabrics for patches. This local intricacy and detail contrasts with the absence of order on the global level; were the global pattern symmetrical and ordered as is the case in most quilts, then the viewer's eye might be drawn away from the local detail into which the maker had invested so much time and effort. If this is true, then crazy quilts represent an unusual real-life method to counteract viewers' global perceptual bias, drawing their attention to a level of local processing not normally applied to objects of such large dimensions. The perceptual side of crazy quilts would thus be interesting to investigate further. One research question might be whether viewers in a quilt exhibition assume a position with a shorter viewing distance when viewing crazy quilts, compared to traditional quilts. A shorter viewing distance would be indicative of a local viewing strategy, while a global viewing strategy would require a larger viewing distance. It may also be the case that preference ratings for crazy quilts change depending on whether perceivers have a local or global view of the quilts. Thus, precisely because they are unusual in their global disorder, crazy quilts provide an interesting tool to investigate important empirical questions in aesthetics.

6.4 Parsing and deviant detection

In the pattern parsing experiments (chapter 3), I investigated pattern perception by examining whether humans and pigeons could detect the presence of a structural error in a pattern, that is, whether the production rule underlying the pattern had been violated. The results indicate that different human groups perform very well on tasks requiring the detection of such violations. Adults and children seemed to have an intuitive grasp of pattern production rules and were able to detect the order underlying patterns without explicit instructions. I found a maturational effect, that is, adults perform better than children, and children's performance is positively correlated with age. Hence it seems that the proficiency for pattern parsing improves with age. The youngest children in this study (aged seven) already displayed some proficiency in detecting deviations. It has long been known that newborn human infants look longer at panels containing black and white structures than at plain colour panels, and that novel structures are looked at longer than familiar structures, suggesting a robust bias in infant perception towards visual complexity and novelty [Fantz, 1963, 1964]. It would be interesting to study the

perceptual processes in young children with such a preferential looking paradigm, to test at what developmental stage sensitivity to deviations in visual geometrical patterns sets in.

Although individuals with ASD have been shown to process visual stimuli differently than normal individuals in other visual perception studies [O'Riordan and Plaisted, 2001; O'Riordan et al., 2001; O'Riordan, 2004; Behrmann et al., 2006; Perreault et al., 2011], I did not find any differences in performance between normal and ASD individuals when discriminating flawed and unflawed patterns, perhaps due to a ceiling effect. The ASD participants in this study reported that they enjoyed the patterns and the task of finding flaws in them. One ASD participant even suggested that the task should be further developed and marketed as "in-flight entertainment".

An interesting finding concerned the serial rotation pattern, which consists of stepwise serial rotation of the tiles in a linear order with no intermediate level of organisation, unlike in grouped rotation, see Fig. 6.2. This serial pattern was never produced spontaneously by participants despite the fact that parsing experiments showed that humans are able to detect deviations in a serial rotation pattern at levels significantly above chance. Thus in the case of the serial rotation pattern, but not of translational and rotational patterns, parsing and production data diverge, suggesting that parsability by itself does not predict whether certain pattern types will actually be produced. It seems therefore that not all structure types that can be perceived are necessarily produced spontaneously.

The parsing approach provides a useful bridge between traditional artificial grammar learning (AGL) paradigms and research on the production processes and preferences related to two-dimensional patterns. While AGL is typically used to address questions of statistical learning in relation to language acquisition or sometimes music [Fitch and Friederici, 2012], the results presented here indicate that statistical learning may also be active in the visual domain in connection with patterns (compare with [Stobbe et al., 2012] who examined parsing of visual patterns in one dimension by humans and birds). I also attempted to test two-dimensional pattern parsing in animals. Pigeons were tested on patterns generated by two of the generation rules already tested on humans. Unlike humans, pigeons did not seem to detect violations of orientation rules in geometrical patterns, while a colour violation was detected relatively easily by the birds. My attempt to study visual perception of structural order in pigeons thus did not lead to positive results. Pigeons are known for their excellent vision and have been shown to solve highly complex visual tasks, [Huber et al., 2005; Aust and Huber, 2006, 2010], including differentiating regular visual structures from randomness [Cook et al., 2005], and texture discrimination [Blough and Franklin, 1985; Cook et al., 1995], which however did not require the birds to pay close attention to relations between elements within the ordered arrays as was the case here.

Further questions and experiments would need to be addressed in order to say with certainty that a task entailing a single target detection based on orientation differences is impossible for pigeons to solve. Possible parameters to vary would include the stimulus size and the birds' viewing distance. Despite the negative results I reported here,
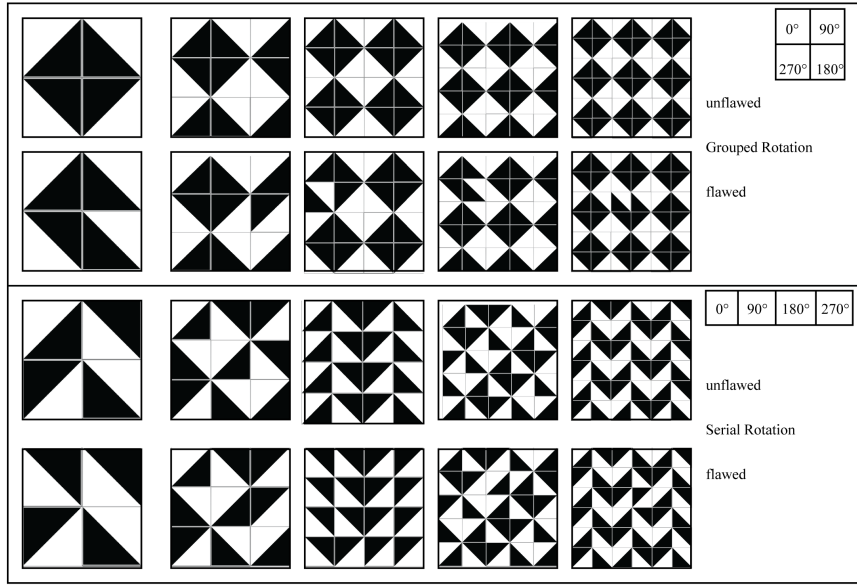
Figure 6.2: Examples of patterns used in the parsing experiments. Top: Grouped rotation for 2×2 to 6×6 matrices, with and without deviants. Bottom: Serial rotation for 2×2 to 6×6 matrices, with and without deviants. Originally published in Westphal-Fitch et al. [2012, p. 2017 , Fig. 10].

I maintain that this approach nonetheless has considerable potential for comparing basic pattern processing abilities between humans and other animals. Potentially more promising birds to test in this context might be species that exhibit nest or bower choice by females, as is the case in weaverbirds and bowerbirds. In these species, females inspect the nest or bower constructions of the male (see chapter 2), and thus in principle may be sensitive to visual structural regularities. Whether such a sensitivity to visual structure would be operational outside of a mate choice context, or indeed is present in both males and females, remain open questions [Borgia, 1986; Endler et al., 2005, 2010]. Another potentially interesting group to study are birds (e.g. blue jays) who prey on moths, which often have symmetrical markings, suggesting a perceptual sensitivity to bilateral symmetry, at least in a predatory context (Bond and Kamil [1998, 2002]).

6.5 Concluding remarks

In sum, the empirical data presented here support the notion that a rigorous empirical, lab-based approach to aesthetics, using relatively simple patterns as stimuli, is possible and renders useful and interesting results. In particular, comparison between production and preference data has the potential to reveal properties of the different cognitive processes that are active in these respective domains, and how differences between production and preference might be accounted for. This will allow empirical investigations of "normal" creativity, a central aspect of aesthetics that has remained relatively neglected to date. Nonetheless, there are many factors that will need to be addressed in greater depth to complete the picture. Further pairings of methods, including cross-cultural studies and ontogenetic aspects, will be necessary to obtain a richer understanding of pattern aesthetics, beyond the first steps taken here.

In my opinion, Fechner's distinction between direct and associative factors provides a useful conceptual framework for empirical work. Concentrating exclusively on direct factors remains, of course, an idealisation – in reality, some minimal associative processes are always likely to be activated in perceivers and producers alike. The interaction between associative factors and direct factors is intriguing, but statistical analysis of associative factors is extremely daunting due to the fact that they are not easily quantifiable or controllable in the properties of the stimuli used in experiments, and participants bring their own individual associations with them.

Furthermore, while the main argument of this thesis has been that aesthetics is a capacity broadly shared amongst humans, it is important to ascertain to what extent formal art education has an effect on aesthetic behaviours, in particular whether it affects outcomes on the relative influence of direct or associative factors (or both), and if so, whether production and preferences are affected equally. If aesthetics is indeed a commonly shared capacity, I would expect that experiments focussing on direct factors would reveal few differences, but that stronger differences may be found in the domain of associative knowledge.

The easiest way to include associative factors in stimuli would be to use real artworks or depictions of artworks as stimuli in experiments. While perhaps guaranteeing an

authentic aesthetic experience, artworks are of course also very difficult to match for complexity, similarity etcetera. Art experts would be crucial in this type of experiment, both in selecting relevant stimuli, but also as participants with high levels of formal expertise (see for example [Washburn, 2000; Engelbrecht et al., 2009]), thus allowing a direct investigation of the effect of art activities and formal art history education.

I will close with some philosophical remarks. I suggest that far from being characterised by disinterestedness in the Kantian sense, the *defining characteristic* of aesthetic artefacts is that they have a strong sensory appeal and evoke a keen and inescapable interest in humans. Even simple patterns can excite the faculty that Gombrich dubbed the 'sense of order'. Both viewing and producing aesthetic objects seem to be fundamentally pleasing and self-rewarding enterprises. In general, human artefacts can be distinguished quite readily from naturally occurring scenes and objects. While we currently live in environments that are saturated with products of the human aesthetic drive, in prehistorical times when human populations were small, encountering new or unfamiliar human-generated objects would have been rare, meaningful and exciting. Consistent with this notion, a recent fMRI study has shown that reward-related brain regions (ventral striatum) are activated only when viewing art images, but not non-art images matched for content [Lacey et al., 2011]. Participants were not asked to rate or otherwise judge the images in that study. I think it likely that such an effect can be found not only when viewing paintings that are easily identifiable as art, but also more generally for hand-crafted objects and abstract patterns.

Comparative work with non-human species remains particularly challenging in the context of aesthetics (but see [Watanabe, 2010, 2011, 2013; Endler et al., 2010; Endler, 2012]), but also crucial if we are to understand the biological basis of our own sense of order and to attempt to understand how aesthetics evolved in our species. Bridging between the positive results that have been reported on low-level feature processing tasks and higher order questions concerning preferences and aesthetics is being attempted by scientists conducting interspecies comparisons between humans and other animals on the perception of the same stimuli (e.g. Ghirlando et al. [2002]). If successful, comparative work between species in this area could reveal the evolutionary pathways this capacity might have taken and which ecological constraints and pressures played a role in forming it. A remarkable feature of human cognition is the ability to de- and encode structures that rely on the iterative application of generative rules, not only in the auditory domain (speech and music) but also, as I have argued here, in the visual domain. More specifically, I think that the extent to which other species can parse and produce structural regularities in the visual and auditory domain may have important implications for our understanding of how the complex structural transformations underlying music, language and music evolved in humans. Such future research will be needed if we are to fully understand the biological underpinnings of the rich and pleasurable aesthetic experiences available to every human being.

7 | Bibliography

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8 | Appendix

8.1 Overview of publications contributing to the thesis

Chapter 2 : Westphal-Fitch, Gesche and Fitch, W. Tecumseh: Towards a comparative approach to empirical aesthetics. *Submitted for review as a chapter for the upcoming book "Art, Aesthetics, and the Brain" to Oxford University Press on 21.03.2013.*

GW-F was the main author of the manuscript, conducted the literature review and drew the illustrations.

Chapter 3 : Westphal-Fitch, Gesche; Huber Ludwig; Gómez, Juan Carlos, and Fitch, W. Tecumseh (2012): Production and perception rules underlying visual patterns: Effects of symmetry and hierarchy. *Philosophical Transaction of the Royal Society B*, 367: 2007-2022.

GW-F designed and conducted the experiments, analysed the data and was the main author of the manuscript.

Chapter 4 : Westphal-Fitch, Gesche, Oh, Jinook and Fitch, W.Tecumseh (2013): Studying aesthetics with the method of production: effects of context and local symmetry. *Psychology of Aesthetics, Creativity, and the Arts* 7: 13-26.

GW-F designed the Flextiles experiments, conducted the experiments, analysed the data and was the main author of the manuscript.

Chapter 5 : Westphal-Fitch, Gesche and Fitch, W. Tecumseh: Spatial analysis of "crazy quilts", a class of potentially random aesthetic artefacts. *Submitted for review to PLoS One on 11.04.2013.*

GW-F conceived the study, gathered and analysed the data and was the main author of the manuscript.

8.2 Additional publications

In this short commentary on the journal article "The artful mind meets art history: Toward a psycho-historical framework for the science of art appreciation" by Bullot and Reber [2013], W. Tecumseh Fitch and I argue in favour of an aesthetic framework that

does not require historical or associative knowledge on behalf of the viewer in order to appreciate art [Fitch and Westphal-Fitch, 2013].

effective metallic abrasive that is still used to accomplish the same effect by contemporary ivory carvers (White 2005). It seems reasonable to suppose that this lustrous effect was intended by the artists, because mammoth ivory is a material that is difficult to work as a result of its growth rings.

To conclude, the artistic design stance is a complex conglomerate of cognitive processes that involve both mediate and immediate observation. Paying closer attention to its noninferential features can increase artistic understanding, especially for objects for which no art historical context is available.

Fechner revisited: Towards an inclusive approach to aesthetics

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Abstract: Accepting Bullot & Reber's (B&R's) criteria for art appreciation would confine the study of aesthetics to those works for which historical information is available, mainly post–eighteenth-century Western "high art." We reject their contention that "correct" artistic understanding is limited to experts with detailed knowledge or education in art, which implies a narrowly elitist conception of aesthetics. Scientific aesthetics must be broadly inclusive.

Bullot & Reber (B&R) are certainly correct that knowledge of cultural context changes our perception of art, because such knowledge changes our understanding of virtually anything. But we reject their contention that such knowledge is indispensable, because detailed information about artist, patron, meaning, or context is limited or unavailable for most of the world's art. Although art historical knowledge may enhance an aesthetic experience, it is not a necessary condition. Indeed for the vast majority of perceivers, such knowledge is not, and has never been, an essential part of the aesthetic experience. To deny them "true" artistic understanding, or classify their aesthetic experience as "deficient," is unacceptable for at least two reasons.

First, it is often impossible to reconstruct the agent behind an artwork, or the context in which it was produced. From the cave paintings of Lascaux to the cathedral of Notre Dame, the actual artisans, and the varied rationales behind their actions, remain unknown. The same is also true of traditional folk art and applied art, such as patchwork, pottery, mosaics, and so forth. The makers of these "low" arts often remain anonymous and their context of creation vague or unknown. Nonetheless, these "unregarded arts" are fully fledged manifestations of the human drive to create art and often elicit rich aesthetic experiences (Gombrich 1979). The modern distinction between art and craft, and the Romantic conception of artistic expression as individual inspiration and creative novelty, is recent even in Western thought (Kristeller 1952; Shiner 2001) and wholly inapplicable to many other cultures and times. Western representational artwork is unusual in its richly documented written history, but even in the Western canon, attention to authorship and interest in the author's intentions is a recent phenomenon. Hence, B&R's "psycho-historical framework" is inapplicable, even to much of the traditional Western canon, from Egypt to Greece, Rome, and medieval Europe. For the rest of the world's art, knowledge of and interest in such issues is very recent or nonexistent – or even antithetical to accepted artistic or religious principles (e.g., in Islam). From the Alhambra to Machu Picchu, "causal/historical information" is scant, but

nonetheless such masterworks certainly deserve consideration in any future science of art appreciation.

Secondly, if the human aesthetic sense is deeply rooted in our species' biology – as we believe it is – then we must understand aesthetic appreciation in its native form, independent of education or secondary knowledge. A full command of one's native language does not require schooling or literacy, and both rich understanding and skillful production of music are possible without explicit knowledge of musical theory or music-reading ability. Thus, both modern linguistics and musicology have rejected elitist and prescriptivist views of language and music, and both fields today focus on the everyday speaker/listener (Honing 2009; Yule 2006). Equivalently, aesthetic science should take seriously the hypothesis that the aesthetic capacity is a fundamental human cognitive trait. Testing this hypothesis entails the firm rejection of any notion that "true" or "correct" understanding is limited to a select few, or to artworks for which rare ancillary knowledge is available. For most human artworks and traditions, both the creator(s) and the intended audiences lacked formal education or background in art history. Any framework placing such factors at center stage therefore provides an inadequate basis for a future science of aesthetics.

How to proceed? The founder of empirical aesthetics, Gustav Fechner, distinguished two perceptual components: direct and associative (Fechner 1871; Fechner 1876). Fechner restricted empirical aesthetics to the direct component, because of the experimental control it allows. Although it is interesting that "yellow" is associated with cowardice in English culture, but with wisdom and royalty in Chinese culture, we do not believe that such associations are of central importance for the scientific understanding of human perception and appreciation of color. A rich understanding of human color perception requires experimental analysis of color contrast, discrimination and memory (psychology), an understanding of color receptors, color blindness, and comparisons with other species (biology), and cross-cultural experiments like those of Berlin and Kay (1969) (anthropology). Currently, our understanding of such "direct" factors in aesthetic science remains extremely limited. In its absence, worrying about edge cases like Warhol's *Brillo Soap Pads Boxes*, Duchamp's urinal, or Cage's *4'33"* seems myopic at best (Fig. 1).

Fechner proposed three methods for studying aesthetics empirically: choice, production, and real use (Fechner 1876). Only the first has been widely adopted by psychologists, mostly in choice paradigms using simplified artificial stimuli. We concur with B&R that this practice, by itself, is inadequate. But a rich reservoir of human-generated patterns is available, produced in all human cultures to elicit an aesthetic response: nonrepresentational geometrical patterns (Fig. 2). Following Fechner, we argue that such patterns provide an ideal middle ground between representational "fine art" expressing a creative artistic vision, full of associative content, and the artificially simplified stimuli beloved of psychologists. Fechner singled out ornamental art as ideal for studying direct factors such as symmetry, complexity, structural ambiguity, and regularity, with little associative content. With modern software, such patterns provide full experimental control, but still elicit a bona fide aesthetic reaction. For example, we have recently applied Fechner's method of production to tilings using touchscreens, analyzing which structural variants humans spontaneously produce, and comparing them to the patterns participants prefer and to those found in reality (Fig. 2). Humans prefer to make, and perceive, patterns with a high level of symmetry and regularity (direct component). Creativity is also evident: participants often produced different pattern variants for the same tile array (Westphal-Fitch et al. 2012).

In conclusion, we share B&R's dislike of the "two cultures" divide in aesthetics and agree that progress in a science of aesthetics demands collaboration between psychologists, art
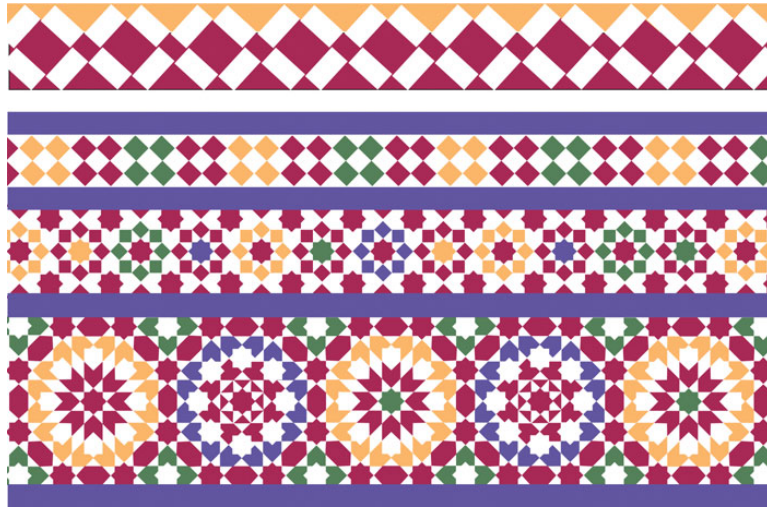
Figure 1 (Fitch & Westphal-Fitch). An example of complex, beautiful nonrepresentational art, illustrated by Nadja Kavcik, based on an Islamic tiling, maker unknown.
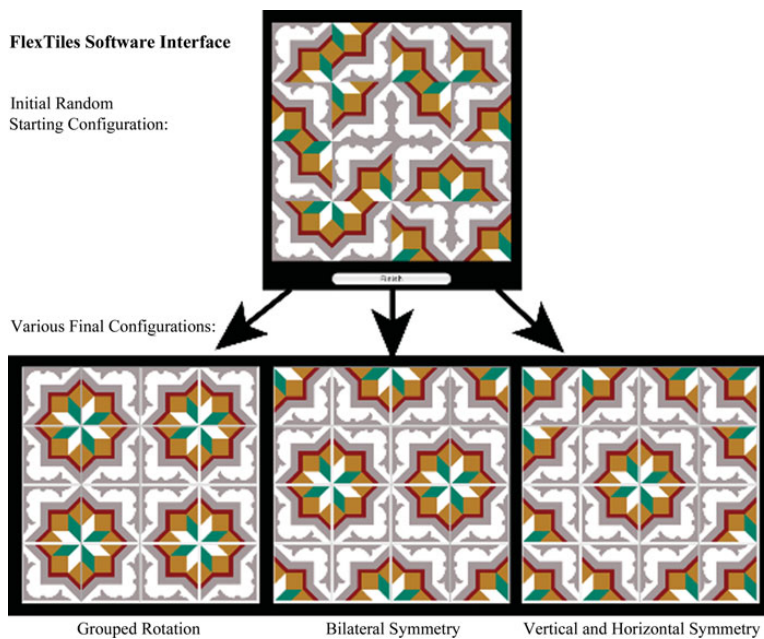

Figure 2 (Fitch & Westphal-Fitch). Schematic illustrating "FlexTiles" software. Participants are presented with a random matrix of tiles on a touch screen. Pressing the tiles rotates them, and participants are told simply to press until they are done. Participants typically create highly ordered, symmetrical patterns, despite no instructions to do so; three example outputs are shown. (from Westphal-Fitch et al. 2012).

historians, and artists. However, we believe that B&R's proposed framework risks unintentionally smuggling the covert elitism of traditional art history and philosophical aesthetics into a future science of art appreciation. Any framework placing historical and cultural information at the heart of aesthetic appreciation will be narrow and Eurocentric from the outset and incapable of addressing the truly deep questions of the human aesthetic capacity rigorously and empirically.

Educating the design stance: Issues of coherence and transgression

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8.3 Abstract

The core topic of this thesis is empirical aesthetics: in this case research on the visual perception and production of abstract geometrical patterns. Geometrical patterns are relevant to aesthetics because humans around the globe produce them to decorate themselves and their environment, suggesting that this creative drive is deeply rooted in human psychology. In contrast, representational images are by no means found in all cultures, and in those cultures in which they do occur, they do not replace non-representational art and geometrical patterns. Geometrical patterns not only have a strong aesthetic dimension, reflecting what art historian Ernst Gombrich termed our "sense of order", but their structure can also be described precisely at all stages of the creative process, facilitating quantitative analysis.

I begin with a historical outline of the origins of aesthetics as a discipline. I argue that the usual dichotomy between art and crafts (including ornaments, decorations and so on) is artificial: both categories are manifestations of the human aesthetic drive and as much a part of human nature as language or music. To gain a complete understanding of the human aesthetic sense, phenomena traditionally termed "craft" must also be included in research on empirical aesthetics, in addition to traditional "high art".

My second core topic is the role of production in the study of aesthetics. With few exceptions, the main focus in empirical aesthetics to date has been on perception rather than production of art. Gustav Fechner had already described three different methods for studying aesthetics in the nineteenth century: *Methode der Wahl* (Method of choice), *Methode der Herstellung* (Method of production) and *Methode der Verwendung* (Method of use). He recommended that at least two of the three methods be used in combination when studying any aesthetic phenomenon. Here, I apply all three methods to the study of various types of abstract geometrical patterns.

Experiments implementing Fechner's method of production with geometrical patterns are presented. Results show that humans with no art background spontaneously produce ordered patterns without any instructions to do so. Due to the high degree of order and symmetry in the patterns produced, and consistency of participants' creations, it is possible to analyse patterns for structural regularity and compare them across participants. Preferences for pattern variants are assessed using a paired comparison method as well as a traditional Likert scale rating method and compared with the production data. Both in production and preference tests, participants consistently opt for structured rather than random variants.

I then apply Fechner's method of use by analysing the spatial characteristics of real-life quilts: normal quilts that exhibit strongly symmetrical patterns and "crazy" quilts, a style of quilts from the 19th century that lacks obvious structural regularity and order. The spatial characteristics of crazy quilt patterns, but not of normal quilts, can be modelled with a random Strauss process.

As a further means of probing pattern perception, I present an experimental method of parsing and deviant detection that tests to what extent deviations from structural regularity can be detected in visual patterns. Humans including adults, children and

individuals diagnosed with Autism Spectrum Disorder are able to detect deviations in different pattern types varying in complexity. The same method is also implemented with pigeons. Unlike humans, pigeons do not seem to distinguish patterns that contain a structural deviation from those that do not, but are able to distinguish patterns that contain a colour deviation from those that do not.

Comparative research with other species is particularly challenging for empirical aesthetics. Nonetheless, a comparative approach is essential for reconstructing the evolutionary history of aesthetics. Traits that have evolved convergently may be of particular interest, for example in insects and birds, in order to investigate the influence of a species' ecology and social organisation on traits such as nest-building and symmetry perception that have the potential to acquire an aesthetic dimension. It is argued that aesthetics cannot be studied as a monolithic whole in animals. A modular approach, in which single components are studied separately in a systematic way, seems to have greater potential for discovering and describing the ability of animals in this complex domain.

In summary, the work in this thesis illustrates the promise of abstract geometrical patterns for furthering our understanding of important elements of the human aesthetic urge and our "sense of order". Particularly when implemented graphically on computers, visual patterns provide a means for controlled quantitative exploration of the human creative process that should play an important role in empirical aesthetics in the future.

8.4 Zusammenfassung

Diese Dissertation befasst sich mit empirischer Ästhetik, in diesem Fall der Erforschung von visueller Wahrnehmung und der Herstellung von abstrakten geometrischen Mustern. Geometrische Muster haben eine hohe Relevanz für die Ästhetikforschung, da Menschen aller Kulturen sie herstellen, um sich und ihre Umgebung zu schmücken. So scheint es naheliegend, dass dieser ästhetische Schaffensdrang tief in der menschlichen Psychologie verwurzelt ist. Hinzu kommt, dass abstrakte Muster, die zur Verzierung verwendet werden, weltweit vorzufinden sind, repräsentative Kunst hingegen längst nicht in allen Kulturen vorkommt und dort, wo sie auftritt, die geometrischen Muster nicht ersetzt. Geometrische Muster haben nicht nur eine starke ästhetische Dimension, die den menschlichen *sense of order* ('Ordnungssinn'), wie es der Kunsthistoriker Ernst Gombrich nannte, widerspiegelt, ihre Strukturen sind auch zu jedem Zeitpunkt des kreativen Prozesses exakt beschreibbar, was eine quantitative Analyse erleichtert.

Die Arbeit beginnt mit einer Übersicht der historischen Entwicklung der Ästhetik als wissenschaftliche Disziplin. Es wird argumentiert, dass die Dichotomie zwischen Kunst und Kunsthandwerk (wozu Ornamente, Dekoration, usw. gehören) eine künstliche ist – beide Kategorien sind Manifestationen eines menschlichen Ästhetiktriebes, der zum menschlichen Wesen genauso dazugehört wie Sprache oder Musik. Um den menschlichen ästhetischen Sinn vollständig zu begreifen, müssen demnach auch Phänomene wie Kunsthandwerk und Ornament zusätzlich zur Kunst im engen Sinne untersucht werden.

Das zweite Hauptthema dieser Dissertation ist die Rolle der Herstellung (Produktion) in der empirischen Ästhetikforschung. Bis auf wenige Ausnahmen lag der Fokus bisher vor allem auf der Wahrnehmung von Kunstwerken, nicht aber auf deren Herstellung. Bereits im 19. Jahrhundert stellte Gustav Fechner drei Methoden vor, um Ästhetik zu untersuchen: Methode der Wahl, Methode der Herstellung und Methode der Verwendung. Er empfahl die Kombination von mindestens zwei Methoden bei der Untersuchung eines ästhetischen Phänomens. In dieser Arbeit werden alle drei Methoden auf abstrakte geometrische Muster angewendet.

Experimente, die Fechners Methode der Produktion anwenden, werden präsentiert. Die Ergebnisse zeigen, dass Menschen ohne künstlerischen Hintergrund und ohne Anleitung spontan geordnete Muster herstellen. Aufgrund des hohen Grades an Ordnung und Symmetrie innerhalb der hergestellten Muster, und der Übereinstimmung zwischen den Kreationen von verschiedenen Teilnehmern, ist es möglich, die strukturelle Regelmäßigkeit innerhalb der Muster zu analysieren und zwischen Teilnehmern zu vergleichen. Die Präferenzen für verschiedene Muster werden durch die Methode des Paarvergleichs und einer Bewertung auf einer herkömmlichen Likertskala untersucht und in Beziehung zu den Produktionsdaten gesetzt. Sowohl in den Produktions- als auch in den Präferenztests werden strukturierte und nicht beliebige Mustervarianten bevorzugt.

Fechners Methode der Verwendung wende ich in Form einer Analyse der räumlichen Eigenschaften von zwei Kategorien von echten Quilts ('Steppdecken') an: zum einen herkömmliche Quilts, die streng symmetrische Muster haben, und zum anderen *crazy quilts* ('verrückte Quilts'), die im 19. Jahrhundert sehr beliebt waren und keine

erkennbaren Muster oder Ordnung aufweisen. Die räumlichen Eigenschaften von Crazy Quilt-Mustern, aber nicht von herkömmlichen Quilts, können mit einem *random Strauss process* modelliert werden.

Als einen weiteren Ansatz um die Wahrnehmung von Mustern zu untersuchen, präsentiere ich eine experimentelle Methode zur perzeptualen Musterverarbeitung (*parsing and deviant detection*), mit der untersucht wird, inwiefern Abweichungen von struktureller Regelmäßigkeit in visuellen Mustern erkannt werden können. Erwachsene, Kinder und Erwachsene auf dem autistischem Spektrum konnten Abweichungen in verschiedenen Mustertypen von unterschiedlicher struktureller Komplexität entdecken. Die gleiche Methode wurde auf Tauben angewendet. Im Gegensatz zu Menschen scheinen Tauben zwischen Mustern, die eine strukturelle Abweichung enthalten und denen ohne Abweichung nicht zu unterscheiden. Muster, die eine Farbabweichung enthalten werden jedoch von denen ohne Farbabweichung unterschieden.

Eine große Herausforderung für die empirische Ästhetik ist die vergleichende Forschung mit anderen Spezies. Ein vergleichender Ansatz ist unerlässlich, um die evolutionäre Geschichte des ästhetischen Empfindens zu ergründen. Hierbei sollte auch auf konvergent entwickelte Merkmale geschaut werden, beispielsweise bei Insekten und Vögeln, um den Einfluss der Ökologie und des Sozialverhaltens einer Spezies auf Verhaltensweisen wie etwa Nestbau oder Symmetriewahrnehmung, die das Potenzial haben, eine ästhetische Dimension anzunehmen, zu untersuchen.

Es wird argumentiert, dass Ästhetik kaum als Ganzes bei Tieren experimentell untersucht werden kann. Ein vielversprechender Ansatz hingegen ist die systematische Untersuchung einzelner Bestandteile, um die Fähigkeiten von Tieren in diesem vielschichtigen Bereich differenziert zu betrachten.

Diese Arbeit illustriert das Potenzial, das abstrakte geometrische Muster haben, um unser Verständnis von wichtigen Teilen des menschlichen ästhetischen Drangs oder "Ordnungssinns", zu erweitern. Visuelle Muster, insbesondere wenn sie mit computerbasierten Methoden eingesetzt werden, stellen ein Mittel der kontrollierten quantitativen Untersuchung des menschlichen kreativen Prozesses dar, die zukünftig eine wichtige Rolle in der empirischen Ästhetik einnehmen sollte.

8.5 Curriculum vitae

Gesche Westphal-Fitch

Education

from 2010	Associated student of the FWF PhD programme "Cognition and Communication", headed by Prof. Thomas Bugnyar
from 2009	PhD candidate at the Department of Cognitive Biology, University of Vienna, supervised by Prof. Ludwig Huber
2008-2009	Research fellow at the School of Psychology, University of St Andrews, UK
2001–2007	Master's degree in English Philology (focus on linguistics), Communication Studies, and North American Studies (focus on linguistics) at the Freie Universität Berlin. Thesis title: *"A comparative analysis of extraposition and adverbial syntax in Pennsylvania German. Possible influences of long-term English language contact."*
1997-2001	Apprenticeship and occupation in newspaper publishing
1997	High school graduation (Scharnebeck, Germany)

Professional Skills and Activities

2013	Member of the International Association of Empirical Aesthetics (IAEA)
	Collaboration with the University of Tokyo to conduct cross-cultural music and pattern perception experiments
2012	Collaboration with the Psychology Department of the University of Vienna to conduct facial EMG study on human pattern processing
	Typesetting in LaTeX
	Programming in *R* for statistical analysis, especially spatial point analysis
2011	Programming in *Matplotlib* for scientific graph generation
2010	Programming in *Python* for data handling, image creation and analysis
	Administration and maintenance of the department's experiment scheduling software *Sona*

Publications

2013	Westphal-Fitch G, Oh J, Fitch WT. Studying aesthetics with the method of production: effects of context and local symmetry. Psychology of Aesthetics, Creativity, and the Arts. 2013;7(1):13–26
	Fitch WT, Westphal-Fitch G. Fechner revisited: towards an inclusive approach to aesthetics. Behavioral and Brain Sciences. 2013;36(2):140–114
	Westphal-Fitch G, Fitch WT. Towards a comparative approach to empirical aesthetics. Nadal M, editor. Oxford: Oxford University Press; submitted
	Westphal-Fitch G, Fitch WT. Spatial analysis of "crazy quilts", a class of potentially random aesthetic artefacts. PLOS ONE;in press
2012	Westphal-Fitch G, Huber L, Gómez JC, Fitch WT. Production and perception rules underlying visual patterns: Effects of symmetry and hierarchy. Philosophical Transactions of the Royal Society B. 2012;367(1598):2007–2022
	Stobbe N, Westphal-Fitch G, Aust U, Fitch WT. Visual artificial grammar learning: comparative research on humans, kea (*Nestor notabilis*) and pigeons (*Columba livia*). Philosophical Transactions of the Royal Society B. 2012;367:1995–2006
	Fitch WT, Westphal-Fitch G. General Introduction. In: Fitch WT, Westphal-Fitch G, editors. Language Evolution. Abingdon: Routledge; 2012. p. 1–19
2011	Westphal-Fitch G. Changes in frequency as a measure of language change: Extraposition in Pennsylvania German. In: Putnam MJ, editor. Studies on German-Language Islands. Amsterdam: John Benjamins; 2011. p. 371–384

Presentations and Posters

2013	Poster presentation at 3rd ToK Conference of CompCog, Messerli Research Institute, Vetmeduni Vienna: *Comparative studies in visual pattern processing*
	Workshop on symmetry and patterns for children (*Die wunderbare Welt der Muster*) at the Kinderuni ("Children's University"), University of Vienna
2012	Poster presentation at the CogSci Lorenz Lecture, University of Vienna: *Fechner revisited. Production meets perception*
	Presentation during lab visit to the University of Zurich: *Comparative studies on visual pattern processing*
	Presentation and discussion panel member at the 5th Vienna Aesthetics Symposium at the Department of Psychology, University of Vienna
2011	Cognitio 2011 (Nonhuman Minds, Animal, Artificial or Other Minds. Montreal, Canada): *How do minds perceive patterns?*
2010	Poster presentation at a workshop on Artificial Grammar Learning and Formal Language Theory (Nijmegen, Netherlands): *Comparative studies in pattern processing*
2010	Hot Topics 2010 (Department of Cognitive Biology, Vienna): *The development of syntax*
2008	5th Stirling Perception Meeting (Stirling, UK): *Visual search in a grid: Significant effects of grouping and rotation*
2006	German Language and Immigration in International Perspective (University of Madison, Wisconsin, USA): *Syntactic change in Pennsylvania German.* Funded by a travel grant from the Freie Universität Berlin
	DGfS (German linguistics society) GLOW Linguistic summer school (Stuttgart, Germany). Funded by a travel grant from the DGfS