A Quantitative Analysis of Symmetry, Fluency, and Pattern Preference

by

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Abstract

People prefer symmetric over asymmetric patterns (Reber, Schwarz, & Winkielman, 2004). According to the fluency attribution perspective, this preference reflects differences in processing speed where increased processing efficiency leads to increased pattern preference. To test the account, in Experiment 1, participants' speed of response to a pattern predicted the relationship between pattern symmetry and pattern preference. Experiment 2 expanded this account and found that a second measure of processing efficiency, recognition accuracy for patterns, predicted the relationship between pattern symmetry and pattern preference. Experiment 3 tested the attribution account of the fluency attribution hypothesis. Participants made a judgment of pattern mood rather than pattern preference. Despite a change of judgment task to an unintuitive judgment of pattern mood, participants attributed increased processing efficiency for patterns to increased pattern happiness. The three experiments provide an integration of the information processing and fluency attribution perspectives to account for symmetry preference judgments.

Keywords: symmetry, fluency, preference, mediation analysis

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Next, a thank you goes to my brothers and sisters, and my parents Werner and Dianne. My mom taught me what 'burning the midnight oil' was back in grade 5 when she stayed up with me until midnight to finish a diorama on Canadian history. It was a concept I became quite familiar with throughout my university education. I would also like to thank all my friends who supported me along the way, and my wonderful partner Anneliese for her love and support.

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A Quantitative Analysis of Symmetry, Fluency, and Pattern Preference

In the following thesis, I asked what makes people like a visual pattern? I examined this through a study of how basic cognitive processes interact with symmetric and asymmetric patterns. Symmetry is a stimulus characteristic that influences preference for art (Avital, 1996), visual patterns (Chen, Wu, & Wu, 2011; Treder, 2010), and people's faces and bodies (Møller & Thornhill, 1998; Perrett et al., 1999). It has been shown to affect preference for patterns in one- (i.e. in a single row of dots), two- (i.e. in a matrix), and three-dimensions. In a task where participants were instructed to arrange dots in a manner that was 'visually pleasing,' even with careful avoidance of words such as 'symmetry' and 'pattern' in the instructions, most participants still produced patterns containing perfect or near perfect symmetry (Szilagyi & Baird, 1977). Peoples' clear preference for symmetric over asymmetric patterns makes symmetry an ideal stimulus property to examine the structure of the cognitive processes and decision mechanisms that underlie pattern preference (Clement, 1964; Garner & Clement, 1963; Hamada & Ishihara, 1988; Handel & Garner, 1966; Howe, 1980).

Visual Processing Approaches to Symmetry Preference and Symmetry Detection

Visual processing theorists argue that symmetric patterns are preferred to asymmetric patterns because symmetry is a primitive of perceptual organization grounded in the organization of the visual system and brain (Bornstein, Ferdinandsen, & Gross, 1981; Ferguson, Aminoff, & Gentner, 1996; Treder, 2010; Wagemans, 1997). Evidence for this position can be found in a number of research domains. For example, developmental psychologists have showed that infants habituate faster to symmetric than asymmetric patterns, suggesting that they can learn and remember symmetric patterns faster and more easily (Bornstein & Krinsky, 1985; Bornstein,

Ferdinandsen, & Gross, 1981; Humphrey, Humphrey, Muir, & Dodwell, 1986). In one demonstration, Bornstein et al. presented 4- and 12-month old infants with two patterns—one symmetric and the other asymmetric—and recorded how long they looked at each one. The 4-month olds looked at the two kinds of patterns for the same amount of time. The 12-month olds, however, looked at the symmetric longer than the asymmetric pattern indicating a preference for the symmetric pattern. The difference as a function of age suggests that a preference for pattern symmetry is not innate, but develops early within the first year of life (Humphrey & Humphrey, 1989).

Whereas the preference for symmetry is not present at birth, once established, the preference is entrenched with the detection of visual symmetry occurring pre-attentively and at tachistoscopic time scales (Barlow & Reeves, 1979; Wagemans, Van Gool, & D'Ydewalle, 1991; see Wagemans, 1995 for a review). One demonstration of this is found in Wagemans et al. (1991). First, participants observed symmetric and asymmetric dot patterns and were told that the symmetric patterns were regular and the random ones were not. Next, participants were shown symmetric and random dot patterns tachistoscopically (i.e., for 100 ms) and were asked to identify patterns as regular or not with a *yes/no* response. Participants were best at detecting and identifying patterns with four axes of symmetry (symmetry about the horizontal, vertical, and both diagonal midpoints), followed by patterns with two axes of symmetry, and then by patterns with only one axis of symmetry. A finer analysis revealed that participants detected symmetry about the vertical axis (i.e., left-right) better than symmetry about the horizontal axis (i.e., top-bottom), and that they detected those two kinds of symmetry faster than symmetry about the diagonal axis. Wagemans et al. argued that the speed at which people could detect symmetry points to a pre-attentive and reflexive perceptual process.

In addition, symmetry detection appears to be species general. Discrimination learning in pigeons, barn swallows, honey bees, and rhesus macaques is influenced by stimulus symmetry (Delius & Nowak, 1982; Giurfa, Eichmann, & Menzel, 1996; Lehrer, Horridge, Zhang, & Gadagkar, 1995; Møller, 1993; Sasaki, Vanduffel, Knutsen, Tyler, & Tootell, 2005). For example, barn swallows' with asymmetric tail feathers took longer to find mates than barn swallows with symmetric tail feathers. After controlling for other factors relevant to mate selection (e.g., tail length, air maneuverability), female barn swallows still preferred males with tail feather symmetry (Møller, 1993).

Finally, data from the fields of brain anatomy and physiology reinforce the behavioural data with the brains of human and nonhuman primates both showing stronger responses to symmetric over asymmetric patterns in the lateral occipital regions of the visual cortex as well as areas V3A, V4d/v, V7[1] of the visual cortex (Sasaki et al., 2005). The result suggests a quick registering of symmetry, even though symmetry is not a sensorial property recognized at the level of the retina.

Information Based Approaches to Symmetry Detection and Symmetry Preference

Mathematical and computational psychology provides a second perspective from which to examine and understand the primacy of symmetry detection and symmetry preference. For example, Enquist and Arak (1994) used an artificial neural network (ANN) model of visual cognition to demonstrate that exposing an artificial retina to natural scenes causes it to grow (they argue to evolve) a sensitivity to symmetry, where symmetry detection is learned and represented in the associative structure of the network. They proposed that the process observed in their

[1] These areas are tuned in-part to orientation (Larsson, Heeger, & Landy, 2010)

ANN provides a demonstration of how the same process might develop in the visual cortex in response to exposure to orientation-variant objects in a natural visual scene. More broadly, Enquist and Arak proposed that symmetry preference might have evolved in response to the problem of finding an orientation-invariant representation of an orientation-variant external scene. Enquist and Arak's solution to symmetry preference and detection speaks to a larger view about the purpose of symmetry detection, over and above its empirical truth. Namely, Atick (1992) suggested that an animals' survival depends on efficient pattern recognition so that it can navigate and cope with the environment in which it lives. The ANN approach to pattern recognition underscores the value of symmetry as an important feature that facilitates rotation- and orientation-invariant recognition (Fukumi, Omatu, Takeda, & Kosaka, 2001; Pintsov, 1989; see Wood, 1996 for a review). Extended to the usual problems of food foraging and predator detection, symmetry might be a factor or nature that has been important for the selection and extinction of species.

One of the key aspects of orientation-invariant pattern recognition is the concept of redundancy. In short, a pattern that contains repetition (i.e., a pattern that contains redundancy) has less information than one that does not. For example, the letter string RGBYRGBY is more redundant (50% redundant to be exact) and contains less information than a letter string RGBYTQPD (0% redundant; see Jamieson & Mewhort, 2005). The string RGBYRGBY is 50% redundant because its sequential structure can be reduced by one-half by a more efficient encoding: "RGBY twice". Shannon's (1948) invention of the information calculus was critical in developing this idea because it allowed a quantification of sequential structure, translating what was once a fuzzy introspective concept (i.e., repetition) into a measurable stimulus property (i.e., redundancy) (see also Attneave, 1959; Garner, 1962).

Prior to the information calculus, the fuzzy Gestalt concepts of *figural goodness*, *good form*, *pragnanz,* and related concepts dominated the field (Pomerantz & Kubovy, 1986). To give rigour to the ideas, Attneave (1955) re-defined the old Gestalt notions in the language of the new information calculus. To demonstrate the idea, he created a family of two-dimensional dot patterns that varied in their informational content. In his terms, a pattern with more uncertainty (i.e., information) is an unpredictable and thus poor pattern whereas a pattern with less uncertainty (i.e., information) is a more predictable and thus good pattern. To verify the concept, he asked participants to study and reproduce patterns from the stimulus set and reported that participants reproduced symmetric patterns more easily than asymmetric ones.

Next, Garner (1962) further developed Attneave's (1955) ideas using the information calculus and proposed a quantification of redundancy in the patterns. He then examined the idea experimentally to show that peoples' ratings of figural goodness (the old Gestalt term) were well predicted by the measure with redundant patterns (i.e., patterns with lower information content). People rated redundant patterns as better than non-redundant or random patterns (i.e., patterns with higher information content; Garner & Clement, 1963). Additional experiments corroborated the result by showing that redundant patterns can be recognized and named faster than non-redundant patterns (Checkosky & Whitlock, 1973; Clement, 1964). Unfortunately, whereas the information theory approach to symmetry offers a clear and formal quantification of structure, it is moot regarding the affective and subjective experience of symmetry—a factor that might be difficult to define but that is nevertheless critically important to a psychological examination of pattern preference.

The Fluency Attribution Perspective on Symmetry Preference and Symmetry Detection

The fluency attribution perspective in psychology proposes that preference and detection

of any stimulus property reflects a qualitative, introspective, and conscious decision process in which an internal state generated by the nervous system is interpreted in the context in which it arises. For example, the brain responds to the re-presentation of a pattern that gives rise to a sensation that is then interpreted as preference, recognition, or some other source, depending on the context in which the individual finds himself. In relation to the current problem, the ease of processing a symmetric pattern—also known as fluency—is attributed post-perceptually to preference (Briñol, Petty, & Tormala, 2006; Reber et al., 2004; Willems, van der Linden, & Bastin, 2007). Critically, where the visual and information processing perspectives focus on how the signal emerges from perception and memory, the fluency attribution hypothesis is more concerned with the conscious decision processes that follow from that signal.

Although fluency is an ill-defined term, it can and has been defined operationally to fit a context in which it was applied. For example, researchers have discussed a distinction between perceptual and memorial fluency in relation to the speed with which a stimulus is processed (Oppenheimer, 2008; Schooler & Hertwig, 2005) and in relation to the accuracy or completeness with which a stimulus is remembered (Reber, Meier, Ruch-Monachon, & Tiberini, 2006). Those two concepts have obvious similarities to Tversky and Kahnemans's (1974) concepts of the availability and vividness heuristics in which a person rates the probability of an event based on how many similar examples come to mind (i.e., availability) or how completely a representation can be retrieved from memory (i.e., vividness).

In an authoritative review, Reber et al. (2004) proposed and supported four principles of the fluency attribution theory. First, fluency varies as a function of objective stimulus properties. Second, highly fluent stimuli are (a) rated positively and (b) elicit a positive affective response. Third, preference for a stimulus is affected by processing fluency because people draw on their

conscious experience to make attributions about how much they prefer the stimulus. Fourth, the source of the increased fluency and how surprising it is, affects preference judgments.

Assumptions of the fluency attribution theory have been demonstrated in a number of experimental paradigms. In perceptual fluency tasks, the readability of city names influenced peoples' estimates of their distance to those cities. In another experiment, people valued stocks relative to how easy it was to pronounce company names (Alter & Oppenheimer, 2006, 2008). In recognition tasks, perceived fluency affected feelings of familiarity and how famous a name was (Jacoby & Dallas, 1981; Jacoby, Kelly, Brown, & Jascheko, 1989; Leboe & Whittlesea, 2002; Whittlesea & Leboe, 2000, 2003). In illusion of truth studies, people rate familiar statements as truer than unfamiliar statements (Ozubko & Fugelsang, 2011). Finally, in priming studies, people prefer images that have been presented earlier in the experiment (Kunst-Wilson & Zajonc, 1980; Olds & Westerman, 2012; Reber, Winkielman, & Schwarz, 1998; Seamon, Brody, & Kauff, 1983; Zajonc, 1968). In a typical image priming study, Seamon et al. repeatedly showed participants pairs of irregular eight-sided polygons. Participants were asked at different stages to indicate either their recognition for the polygon, or which one they liked more. People liked the familiar polygons more than the novel ones. The positive affect for fluent stimuli has also been shown physiologically. Primed images show an increased smile response in studies that monitor face muscles by a technique called facial electromyography (Harmon-Jones & Allen, 2001; Winkielman & Cacioppo, 2001).

In summary, the fluency attribution perspective on symmetry preference offers a psychological decision mechanism to supplement the quantitative analysis of symmetry and symmetry detection described in the information processing and visual processing perspectives. In my view, an integration of these perspectives is necessary to form a whole and coherent

psychological theory of the problem and that was the goal of this thesis.

In this thesis, I argue that symmetric patterns are preferred over asymmetric patterns because people attribute increased fluency to increased preference. To quantify fluency directly from the stimulus, I leveraged the tools from Garner's (1962, 1974) information theoretic analysis of stimulus structure and perception. To explain peoples' decisions following from distinctions in the information processing loads imposed by different visual patterns, I leveraged the fluency attribution account of preference and decision.

Quantifying Stimulus Structure

A visual stimulus has symmetry if it can be manipulated by geometric transformations to reproduce a part or the whole of itself. An example of this definition is provided in Figure 1. A rotation is implemented by turning a stimulus by 90 degrees about its midpoint. A reflection is implemented by flipping the pattern (as if turning the page of a book) about one of its outer edges. The patterns in Figure 1 show a pattern rotated by 90 degrees four times in a top row and then reflected on the lower edge to form the second row. Although I have produced each set in this particular way, any combination of rotation and reflection will produce exactly the full eight pattern sets shown. Throughout this thesis, I call a full eight-pattern rotation/reflection set a pattern's rotation-reflection subset or its RRS for short[2].

[2] Garner and Clement (1963) and others (e.g. Bear, 1973; Lachmann & Van Leeuwen, 2005a) have referred to these subsets as equivalence set size (ESS)

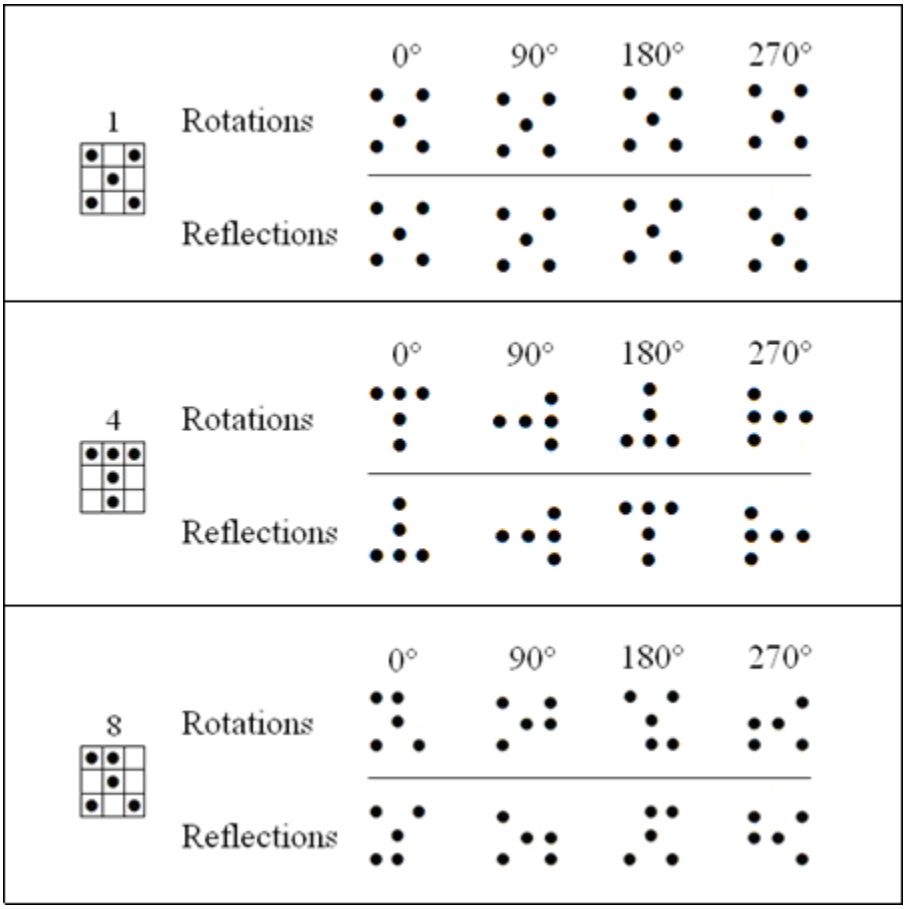

Figure 1. Unique dot pattern subsets created by performing 90-degree rotations and horizontal reflections

According to Garner (1974), a patterns' information content is quantified by counting the number of unique patterns in its RRS. To illustrate, the pattern in the top panel of Figure 1 includes only one unique configuration in its RRS (i.e. all eight patterns are the same) and so it has an RRS equal to 1. The RRS for the pattern in the middle panel includes four unique configurations and so it is quantified as an RRS 4 pattern. The RRS for the pattern in the bottom panel includes eight unique configurations and so it is quantified as an RRS 8 pattern. With some but few exceptions, a pattern that reproduces itself perfectly over geometric manipulations of rotation and reflection is more symmetric than a pattern that does not.

As recognized by Garner and Clement (1963), the RRS quantification of stimulus structure is not identical to symmetry. To illustrate, the backwards Z pattern in Figure 2 has no axis of bilateral symmetry but is quantified as an RRS 4 pattern using the RRS metric. However, this disconnection is more the exception than the rule.

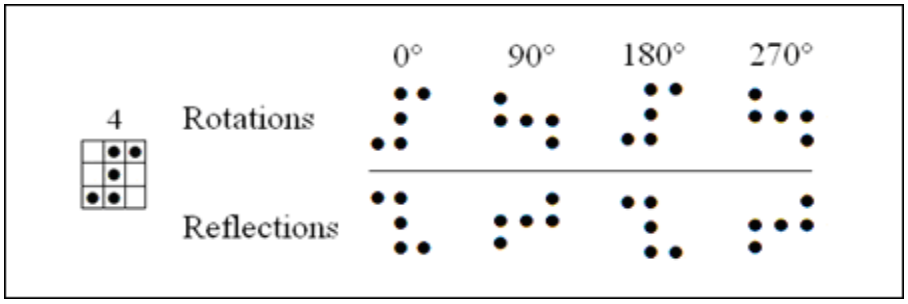

Figure 2. An RRS 4 pattern that contains no axes of bilateral symmetry.

To account for the imperfect relationship between RRS and symmetry (see Figure 2), I quantified a pattern by its RRS as well as by its number of symmetric axes and type of symmetry (Royer, 1981). A pattern that has 1 unique configuration in its RRS is symmetric about its vertical, horizontal, and diagonal axes. Except in unique cases as seen in Figure 2, a pattern that has 4 unique configurations in its RRS is symmetric about only one axis: its vertical, horizontal, or diagonal axis. Finally, a pattern that has 8 unique configurations in its RRS is asymmetric about all three of its major axes.

Whereas RRS served as my main calculation for pattern symmetry, it is a proxy. It is more correct to discuss RRS as a calculation for the amount of information in a pattern with smaller RRS patterns having less information and more symmetry than larger RRS patterns. Although I recognize that RRS and symmetry are not identical, they are isomorphic and for the

sake of consistency I used the term symmetry throughout the thesis.

In the work that follows I examined the inter-relationships of pattern symmetry, pattern processing, and pattern preference. My aim was to show that I can explain the known relationship between pattern symmetry and pattern preference by their mutual relationship with processing fluency. To begin, I asked participants to rate their preference for dot patterns using a Likert scale (i.e., 1 = *least liked* and 7 = *most liked*). Next, I measured the speed at which they recognize those patterns in a speeded matching task. I predicted that people will prefer symmetric over asymmetric patterns and, critically, that they will also process symmetric patterns faster than asymmetric ones. Finally, I applied the logic of mediation analysis, a statistical technique grounded in linear regression and developed for the most part in the subfield of social psychology, to evaluate the strength of evidence that people prefer symmetric patterns because they process them more fluently and attribute that differential fluency to liking. In Experiments 2 and 3, I extended the analysis to test various aspects of the result. In all three experiments, the sequence of experimental tasks began with a ratings task to eliminate a contaminating influence of priming on preference ratings.

Experiment 1: Symmetry and Perceptual Fluency

Experiment 1 was conducted to examine the interrelationships between pattern symmetry, processing fluency, and pattern preference and to evaluate the hypothesis that the known positive correlation between pattern symmetry and pattern preference is mediated by processing fluency. In the first part of the experiment, participants rated their preference for dot patterns. In the second part of the experiment, participants performed a speeded recognition task for those same patterns. The speed at which they recognized a pattern served as a measurement of processing fluency. Once the data were collected, I performed a mediation analysis to evaluate the

hypothesis that the positive correlation between pattern symmetry and pattern preference reflects differences in processing speed and a cognitive attribution of processing speed to preference.

Method

Participants

Eighty-seven participants with normal or corrected-to-normal vision were recruited from the University of Manitoba undergraduate participant pool. There were no restrictions on participation and participants received course credit in exchange for their time.

Stimuli

Each pattern was constructed in Microsoft Excel (2007) by placing a black dot with a 0.2 cm diameter at the horizontal and vertical center of nine squares in a 5 x 5 matrix. The actual size of each presented pattern was 2.5 cm x 2.5 cm[3].

[3] Due to the small actual size of the pattern relative to the size of the monitors display area (47.6cm x 26.8cm), pattern figures throughout this thesis were not drawn to scale.

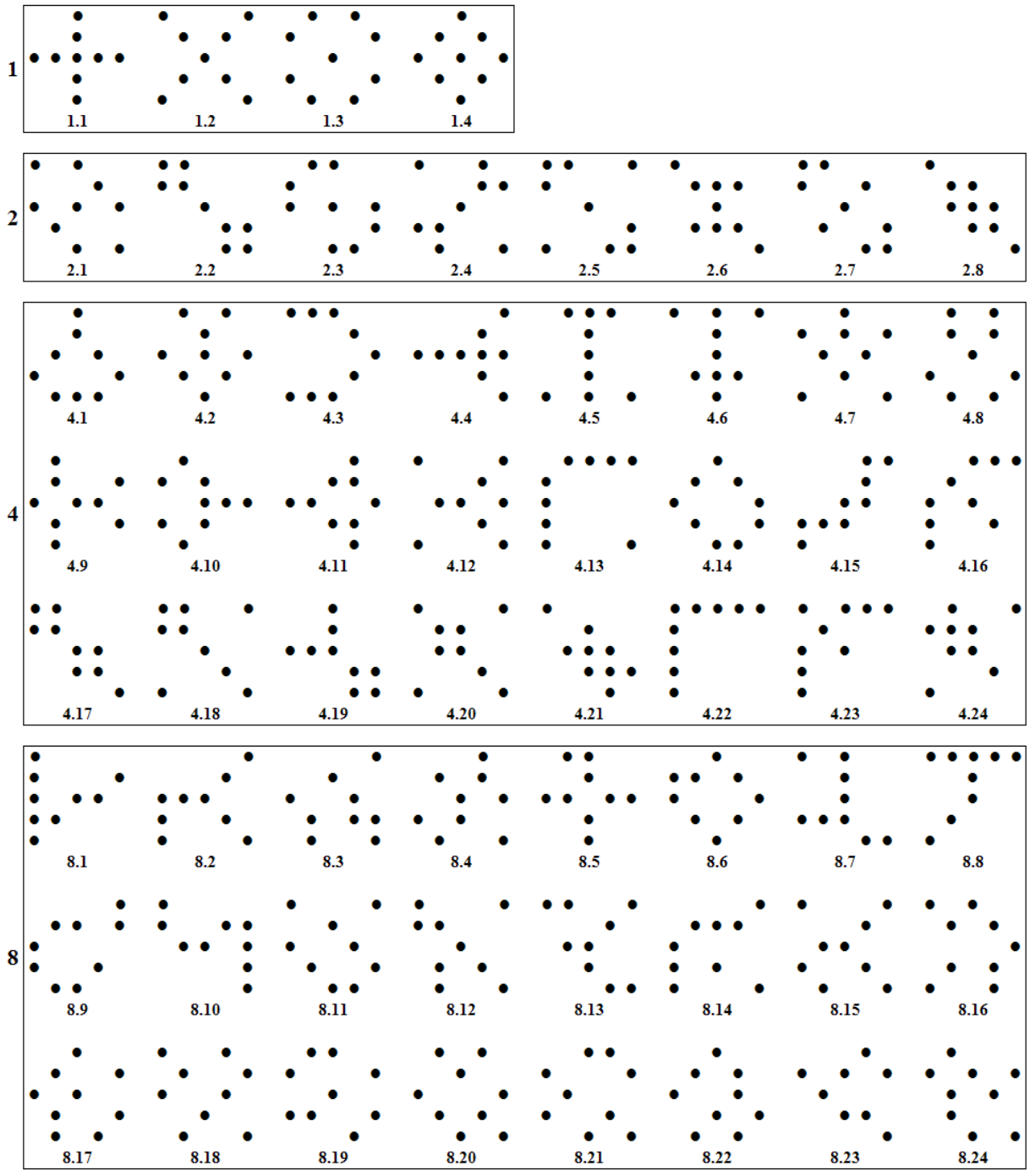

Figure 3. The full set of 60 dot pattern stimuli from RRS sizes 1, 2, 4, and 8.

Figure 3 shows a set of 60 patterns. The '#.#' identifier below each pattern indicates its RRS size as well as an arbitrary number designation to identify the pattern uniquely within its

RRS set. For example, pattern 4.3 is pattern 3 in the RRS 4 set.

Each pattern in Figure 3 is composed of 9 dots placed in different cells of an invisible 5 x 5 matrix. Consistent with Garner (1962; Garner & Clement, 1963), at least one dot appears in each row and each column of the undrawn 5 x 5 matrix. This constraint ensures that each pattern has the same implied visual angle and thus solves for confounds of pattern size.

Whereas the patterns in Figure 3 do not show the possible eight-pattern RRS of the presented patterns, they were constructed in the same way as Garner's (1962) famous set formed using a 3 x 3 matrix size (see Figures 1 and 2). However, the patterns in Figure 3 are fit to a 5 x 5 matrix size. This allowed me to construct a larger stimulus set spanning over four rather than three different RRS sizes (i.e., RRS 1, RRS 2, RRS 4, and RRS 8). The RRS 2 patterns, which cannot be constructed using the 3 x 3 matrix size, can display left-right and right-left diagonal bilateral symmetry but not vertical or horizontal symmetry, both of which can be present in RRS 1 and RRS 4 patterns.

Apparatus

The experiment was presented on Dell Optiplex PC's equipped with a standard keyboard and 21.5-inch LCD monitors. All responses were recorded electronically by key presses on a computer keyboard. The experimental software was programmed using and delivered by E-Prime 1.2 behavioural software suite (Psychology Software Tools, Pittsburgh, PA). Critically important for this experiment, E-prime gives accurate millisecond timing; the variable that I used to measure processing fluency.

Procedure

Participants were brought into a computer lab in groups of one to six and seated at individual computers. The experimenter instructed participants that the experiment would take

approximately 30 minutes and urged participants to be as fast and accurate as possible when responding to individual trials. Participants were then told that the experiment was self-paced with on-screen instructions, and to raise their hands if they had any questions.

Instructions for the experiment were re-presented on the computer screens, typed in black font on a white background.

Instructions for the liking task:

> *Welcome to the experiment and thanks for participating. On each of 60 trials, a simple visual pattern will be presented on your computer screen. We want you to indicate how much you like each pattern. Please give your ratings on a scale from 1 to 7, where 1 = least liked and 7 = most liked. Press the spacebar to begin.*

When the participant pressed the spacebar, the screen was cleared. One second later, a pattern was presented at the center of the screen, and a rating scale numbered 1 through 7 on a continuum from *Least Liked* to *Most Liked* was presented at the bottom of the screen (see Figure 4).

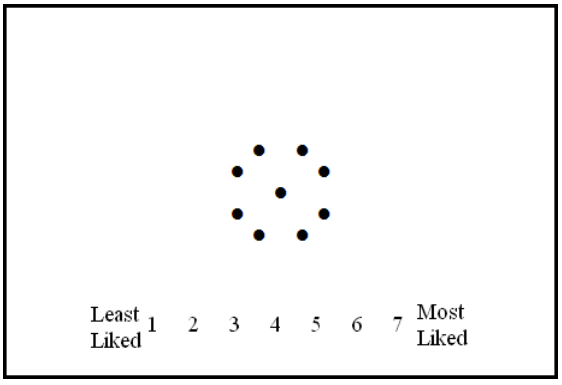

Figure 4. An example of a rating task trial from Experiment 1.

The participant responded by pressing one of seven response keys: *1*, *2*, *3*, *4*, *5*, *6*, or *7*. If

they pressed a different key, nothing happened. Upon pressing a response key, the key press was recorded and the computer screen was cleared; 1 s later the next pattern was presented. Whereas participants rated the same 60 patterns, the patterns were presented in a random order. This cycle continued until all 60 patterns were presented and the participant had provided a rating for each one. After participants completed the rating task, the screen was cleared for 1 s before the practice trial instructions for the same-different task were presented.

Instructions for the same-different task - Practice trials:

> *You will now perform a speeded identification task. On each trial, you will see two dot patterns - one presented after the other. Your task is to indicate QUICKLY and ACCURATELY if the two patterns were the same or different. To respond "same", press the "Z" key on your computer keyboard. To respond "different", press the "M" key on your computer keyboard. Please keep your fingers resting on the keyboard* [response keys] *at all times. The task will involve 500 trials in total. The first 20 trials are practice trials where accuracy feedback will be provided. You can take a break at any time by not pressing the spacebar to begin the next trial. Press the spacebar to begin.*

After a spacebar press to begin the trial, the screen was cleared for 500 ms followed by the sequential presentation of two patterns. The first pattern—the target pattern—was presented just left of center for 500 ms, the screen was cleared for 500 ms, and the second pattern—the probe pattern—was presented just right of center. The location at which the target and probe patterns were presented partially overlapped. The probe pattern remained on the screen until the participant pressed either the 'Z' or "M' key with a finger on their left or right hand to indicate 'same' or 'different' respectively.

Following a 'Z' or 'M' key-press, feedback was presented for 500 ms at the center of the screen indicating both the response accuracy for the individual trial as well as the cumulative

accuracy presented as a percent correct over all of the practice trials up to that point. All participants responded to the same 20 practice trials, which were split evenly into 10 same trials where the probe matched the target pattern and 10 different trials where the probe mismatched the target pattern. After all 20 practice trials were completed, the screen was cleared and instructions for the experimental trials were presented.

Instructions for the same-different task – Experimental trials:

The experimental trials will now begin. Remember to respond as QUICKLY and as ACCURATELY as possible. A reminder: To respond "same", press the 'Z' key on your computer keyboard. To respond "different", press the 'M' key on your computer keyboard. Please keep your fingers resting on the keyboard [response keys] *at all times. You can take a break at any time by not pressing the spacebar to begin the next trial. Press the spacebar to begin.*

Figure 5 depicts one complete trial sequence for the same-different task.

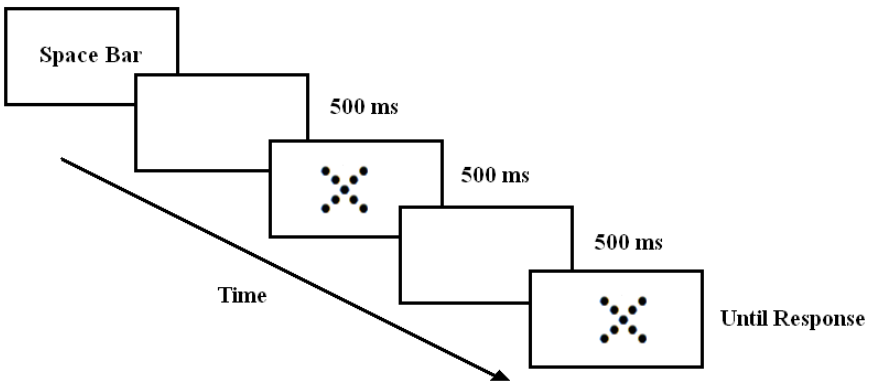

Figure 5. The trial sequence for the same-different task in Experiment 1.

The 480 experimental trials were identical in structure to the practice trials. The 480 experimental trials were split evenly between same and different trials. In same trials, each

pattern was presented as both the target and probe four times. In different trials, each target pattern was presented with a randomly selected probe pattern, subject to the constraint that both patterns belonged to the same RRS size. Since RRS size 1 included only four patterns (see Figure 3), a randomly selected RRS 1 pattern was presented as a different probe twice over the experimental trials. There were a sufficient number of patterns in the RRS 2, 4, and 8 sets that it was not necessary to re-present a pattern as the probe more than once on separate different trials.

After completion of the same-different task, participants were thanked for their participation and dismissed.

Results and Discussion

Twelve participants failed to achieve 90% accuracy in the same-different task. Their data were excluded from the analyses that follow to avoid contamination of reaction time scores due to a speed-accuracy tradeoff. Thus, subsequent analyses were conducted on 75 of the original 87 participants.

I inspected data from individual trials of individual subjects and deleted data from trials where the RT was less than 150 ms or was greater than 1500 ms. My reasoning was that responses less than 150 ms were too fast to reflect a decision based on the presented stimulus and that responses longer than 1500 ms were slow enough to suggest a lapse in attention (for precedence see Hermans, De Houwer, & Eelen, 2001; Mondor & Leboe, 2008). In total, data from 538 trials were excluded due to extreme RTs amounting to only 1.58% of the complete data set. As an assurance against effects due to filtering of participants and RT responses, a complimentary analysis was conducted using the median RT rather than the mean RT (See Appendix B)

Table 1 presents the mean liking ratings, mean RT, and mean accuracy for the presented

patterns, each as a function of RRS (1, 2, 4, and 8). As shown, participants' preferred patterns with smaller RRS sizes and were faster to identify patterns with smaller RRS sizes as the same. Below I present an analysis of each measure and then conduct a combined analysis of them in a mediation analysis.

	Liking Rating		Same-Different Task							
			Same				Different			
			RT (ms)		Error (%)		RT (ms)		Error (%)	
RRS	*M*	*SE*	*M*	*SE*	*E*	*SE*	*M*	*SE*	*E*	*SE*
1	5.42	0.15	551	10.2	4.37	0.73	636	10.8	4.17	0.70
2	4.88	0.11	574	9.53	4.23	0.48	650	10.7	7.05	0.66
4	4.50	0.09	574	8.62	5.21	0.35	638	10.4	3.79	0.30
8	3.13	0.09	595	8.84	5.55	0.35	649	9.46	5.29	0.43

Table 1. Mean ratings of liking and standard errors are presented for the rating task. Mean RTs, mean accuracy, and standard errors are also presented for same and different trials in the same-different task.

Analysis of Preference Ratings

Results of the liking data were analyzed using a single factor within-subjects analysis of variance (ANOVA). Mean liking rating differed significantly as a function of RRS size, $F(3,222) = 102.67$, $p < .001$. As shown in Table 1, RRS 1 patterns were liked the most, RRS 8 patterns were liked the least, and liking for RRS 2 and RRS 4 patterns was intermediate. A Bonferroni correction to protect against Type 1 error inflation confirmed that all pairwise comparisons were significant, $\alpha = .05$.

These data support the conclusion that people preferred symmetric over asymmetric patterns and are consistent with the results from related studies conducted in other labs (Garner & Clement, 1963; Tinio & Leder, 2009).

Analysis of Accuracy in the Speeded Recognition Task

A 4 x 2 within-subjects ANOVA was conducted on the error data from the speeded same-different task using RRS (1, 2, 4, and 8) as one factor and trial type (same, different) as the other.

There was a statistically significant interaction between RRS and trial type (i.e., same versus different trials), $F(3,22) = 8.37$, $p < .001$. To understand the interaction, I decomposed the omnibus test into simple effects. There was no statistical evidence for differences in the mean error rates in performance on same trials, $F(3, 222) = 2.12$, $p > .05$. However, error rates in performance on different trials did differ as a function of RRS size, $F(3, 222) = 9.73$, $p < .001$. Namely, participants had more trouble rejecting RRS 2 and RRS 8 patterns as different, relative to RRS 1 and RRS 4 patterns, $F(1, 74) = 21.38$, $p < .001$. I conclude that the form of the interaction of RRS and trial type, while statistically significant, offers little clarity regarding performance in the speeded recognition task.

Despite the uneven error rates over RRS categories on different trials, the even error rates over RRS sizes on same trials suggests that I can use those RTs as a proxy for processing fluency, without the complications associated with a speed-accuracy trade-off.

Analysis of RT in the Speeded Recognition Task

A 4 x 2 within-subjects ANOVA was conducted on RT scores as a function of both RRS (1, 2, 4, and 8) and trial type (same, different). There was a statistically significant interaction of RRS and trial type, $F(3, 222) = 6.55$, $p < .001$. A decomposition of the data by simple effects confirmed that RT as a function of RRS on same trials differed, $F(3, 222) = 24.007$, $p < .001$, with the responses to RRS 1 patterns occurring faster than responses to RRS 8 patterns, and with responses to RRS 2 and RRS 4 patterns falling between those two extremes. Analysis of all pairwise differences using a Bonferroni correction on mean RTs confirmed that all mean RTs differed, except for the difference in mean RT for RRS 2 and RRS 4 patterns, $\alpha = .05$.

Consistent with the results of the error analysis, different trials were also significantly different when analyzing mean different RT as a function of RRS, $F(3, 222) = 3.28$, $p = .036$. Participants were slowest at detecting differences in RRS 2 and RRS 8 patterns and fastest with detecting differences in RRS 1 and RRS 4 patterns, $F(1, 74) = 10.61$, $p < .005$. The fact that error rates were highest in the slowest RRS categories suggests no evidence for a conventional speed-accuracy tradeoff where accuracy suffers in order to accomplish speed. Rather, it appears that RRS 2 and RRS 8 patterns were simply harder to recognize than RRS 1 and RRS 4 patterns. Finally, the results of the RT analysis also confirmed the main effect of trial type, independent of the interaction. Participants were faster to correctly indicate that a test probe matched the target ($M = 573$ ms) than they were to indicate that a test probe mismatched the target ($M = 643$ ms), $F(1,74) = 129.14$, $p < .001$. The main effect of trial type is consistent with trends in prior work (i.e., the fast same effect; see Farell, 1985).

In summary, participants preferred RRS 1 patterns most, RRS 8 patterns least, and RRS 2 and RRS 4 patterns in between the two extremes. Critically, this pattern was mirrored in the RT data for same trials where participants were fastest to correctly identify RRS 1 patterns, slowest to correctly identify RRS 8 patterns, and intermediate to correctly identify RRS 2 and RRS 8 patterns. Taken together, the results signal a systematic effect where the size of the RRS affects both the preference and processing speed for the patterns.

In the next analysis, I examined whether the relationship between RRS and liking can be explained by how fluently (i.e., how quickly) the patterns are processed.

Mediation Analysis: Evaluating the Fluency Hypothesis

As shown in Table 1, there are clear interrelationships between ratings of pattern preference and performance in the same-different task. First, as RRS increases, so does mean

same RT, r = .914. Next, as mean same RT increases, liking rating decreases, r = -.948. Finally, as RRS increases, liking rating decreases, r = -.993. As I outlined in the introduction to this experiment, I hypothesized that the relationship between pattern symmetry and pattern preference is mediated by the psychological property of fluency, a factor that I measured as the speed at which participants could correctly identify a presented pattern in the speeded recognition task. To evaluate the strength of evidence for that claim, I conducted a mediation analysis.

I first calculated the mean same RT and mean liking rating for each of the 60 stimulus patterns. These scores were computed collapsing over data from all 75 participants. I then conducted a test for full mediation with three single-predictor and one two-predictor regression models (Baron & Kenny, 1986).

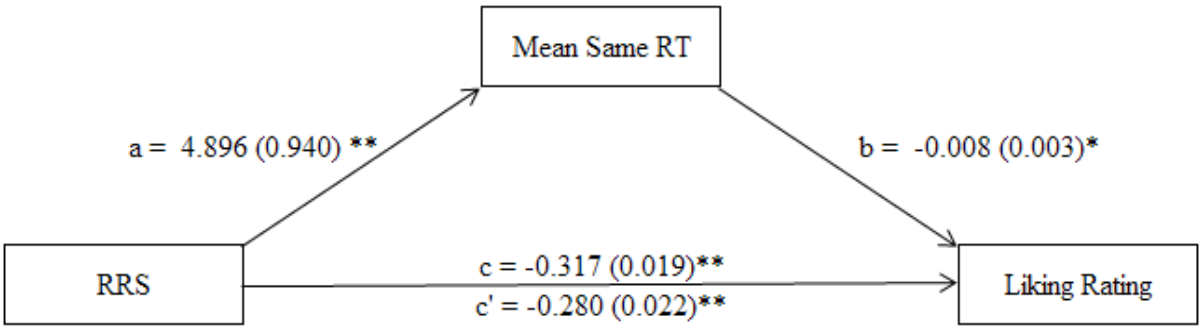

Figure 6. A mediation model depicting the proposed interrelationship between the variables RRS, mean same RT, and liking rating. The coefficients to the right of the path identifiers represent unstandardized regression coefficients, standard errors are in parentheses. *p < .05; **p < .001.

Figure 6 summarizes the outcome of the mediation analysis. The boxed words are the variables of interest. Arrows indicate the proposed relationships between the variables of

interest. Values printed beside the arrows are unstandardized regression coefficients (i.e., slopes) associated with relevant regression models (e.g., the coefficient a is the slope for the regression model $MeanSameRT = b_0 + b_1(RRS)$). Thus, each regression coefficient describes the strength of the relationship between the two connected variables. Statistically significant paths are marked by one or two asterisks, where a single asterisk indicates statistical significance at $p < .05$ and two asterisks indicate statistical significance at $p < .01$. As shown, all coefficients are statistically significant.

Ideally, the data would support a hypothesis that the relationship between RRS and liking ratings could be fully explained by their shared variance with the fluency measure (i.e., mean same RT). This would be confirmed if path c was significant but path c' was not. As shown, this is not the case and, therefore, I concluded that whereas the relationship between RRS and liking ratings might be partially explained as a reflection of fluency attribution, the relationship is not fully explained by that account.

Given the failure to find full mediation, I conducted a test for partial mediation–the hypothesis that the relationship between RRS and liking is partly albeit not entirely explained by fluency (i.e., the proposed mediator). I evaluated this possibility using a bootstrapped mediation analysis, a test that solves for known problems with the more typically used Sobel (1982) test (Preacher & Hayes, 2004; 2008). The bootstrap analysis confirmed that mean same RT does partially mediate the relationship between RRS and liking rating, $z = -2.65$, $p = .007$. The test supports the inference that fluency mediates the relationship between RRS and liking ratings, but opens the door up to other potential explanations as well.

Symmetry Type

Whereas RRS quantifies the amount of symmetry in a pattern, it does not consider the form of that symmetry. For example, a pattern in the shape of the letter T is symmetric about the vertical axis. However, if rotated 90 degrees, it is symmetric about the horizontal axis. Whereas the axis of symmetry might be relevant to peoples' perception of symmetry, it is not relevant to the RRS measure. To analyze the hypothesis that the axis of symmetry affects pattern preference, I reconsidered the collected data as a function of the form of symmetry in presented patterns.

In a single factor within-subjects ANOVA, I examined liking ratings as a function of symmetry type (vertical, horizontal, and diagonal) on the RRS 4 patterns—the group of patterns that varied in the axis of symmetry without varying in information content. To conduct the ANOVA, I first divided the 24 RRS 4 patterns into subgroups that contained only one axis of bilateral symmetry. This produced 6 vertically symmetric patterns (i.e., patterns 4.1, 4.2, 4.5, 4.6, 4.7, 4.8), 6 horizontally symmetric patterns (i.e., patterns 4.3, 4.4, 4.9, 4.10, 4.11, 4.12), and 12 diagonally symmetric patterns (i.e., patterns 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24). The analysis confirmed a statistically significant difference in liking ratings as a function of symmetry type, $F(2, 148) = 10.40$, $p < .001$, where vertically symmetric patterns ($M = 4.75$) were rated as more liked than both horizontally ($M = 4.36$) and diagonally symmetric patterns ($M = 4.45$).

Although I did not set out to analyze preference as a function of symmetry type, the results of this analysis are consistent with prior research that reported higher ratings of 'goodness' and greater salience for vertically symmetric patterns compared to horizontal and diagonally symmetric patterns (Fisher & Fracass, 1987; Goldmeier, 1972; Hamada & Ishihara, 1988; Rock & Leaman, 1963). However, the largest difference in ratings for patterns with

different types of symmetry (M = .39) was significantly smaller than the largest difference for ratings with different RRS size (M = 2.28), $F(1, 74) = 100.18$, $p < .001$. Thus, although axis of symmetry does affect liking ratings, the effect is minimal compared to the effect that RRS has on liking ratings.

Conclusions

Although Experiment 1 establishes evidence for the fluency attribution account of peoples' preference for symmetric over asymmetric patterns, it does not provide conclusive evidence. First, the speed of processing only partially mediated the relationship between pattern symmetry and pattern preference. Second, the axis of symmetry also played a numerically small, albeit statistically significant role in affective preference judgments.

Whereas Experiment 1 provides some initial evidence for the hypothesis that the relationship between pattern symmetry and pattern preference is mediated by processing fluency, the experiment relied on the premise that RT on same trials offers a valid and accurate proxy for fluency. If one rejects the premise, then the reasoning that follows from it is invalid. In Experiment 2, I re-examined the mediation hypothesis from Experiment 1. However, I used recognition accuracy rather than speed of recognition as the empirical index of fluency.

Experiment 2: Symmetry and Recognition Fluency

In Experiment 2, I re-examined the interrelationships between pattern symmetry, processing efficiency, and pattern preference. However, in contrast to Experiment 1, I measured fluency by peoples' ability to recognize the patterns they studied rather than their ability to recognize the patterns in a speeded identification procedure, the difference is meaningful. Whereas the same-different task in Experiment 1 measured the speed of memorial storage and retrieval for the stimulus patterns, the recognition task in Experiment 2 measures the quality of

memory for the stimulus patterns. In addition, if the argument from Experiment 1 is sound, then I would expect to observe converging evidence for the conclusion that symmetric patterns are easier to process and therefore preferred.

In this experiment, participants performed two tasks. First, they rated their preference for dot patterns through a liking judgment, as they did in Experiment 1. Ten minutes later, they performed a two-alternative forced choice (2AFC) recognition test for the patterns they had judged. As in Experiment 1, I hypothesized that fluency, measured as recognition accuracy instead of RT on same trials, mediates the relationship between pattern symmetry and pattern preference. In other words, patterns that are more easily remembered will be preferred.

Method

Participants

Sixty participants with normal or corrected-to-normal vision were recruited from the University of Manitoba undergraduate participant pool. There were no other restrictions on participation and participants received course credit in exchange for their time.

Stimuli

As described in Experiment 1 (see Figure 3).

Apparatus

As described in Experiment 1.

Procedure

Similar to Experiment 1, participants were brought into a computer lab in groups of one to six and seated at individual computers. Verbal instructions were given indicating that the experiment was self-paced. Subsequent to this, all instructions were presented on the computer screen typed in black font on a white background.

As in Experiment 1, the experiment began with a liking rating task. Instructions were the same, except that participants were told they would make judgments for 30 rather than 60 patterns. Correspondingly, participants rated 30 of the 60 patterns in Figure 3 selected randomly with the constraint that the set include two RRS 1 patterns, four RRS 2 patterns, twelve RRS 4 patterns, and twelve RRS 8 patterns.

Following the rating task, the screen was cleared for 1 s, followed by instructions for a wait task with arithmetic problems that lasted 10 minutes (see Appendix A).

Instructions for the wait task:

> *Please take the next 10 minutes to answer the questions on the paper(s) to the right side of your keyboard. You will find the questions under the paper with instructions, "Do Not Lift." If you have finished completing the questions before the 10 minutes is up, please sit quietly until the next set of instructions appears on the computer screen.*
>
> [10 minutes elapse…]
>
> *Please put down the paper(s) and pen. It is okay if you have not finished completing all the questions on the paper(s). Press the spacebar to continue.*

When the participant pressed the space bar, the screen was cleared. One second later, instructions for the recognition task were presented.

Instructions for the two-alternative forced choice task:

> *In this part of the experiment, you will perform a recognition task for the patterns you previously rated. On each trial, you will see two dot patterns presented side by side. Your task is to indicate as accurately as possible which pattern you rated at the start of the experiment. Respond by pressing the corresponding number (either '1' or '2') below the presented pattern. The task will involve 30 trials in total. You can take a break at any time by not pressing the spacebar to begin the next trial. Press the spacebar to begin.*

After the participant pressed the spacebar, the screen was cleared for 1 s followed by the presentation of the first recognition task trial. In a recognition trial, two-patterns were presented with numbers centered below them and the question 'Which pattern did you see?' centered above them (see Figure 7). One pattern was presented in the rating task; the other was not. The old patterns were presented equally often on the left as on the right over the test session.

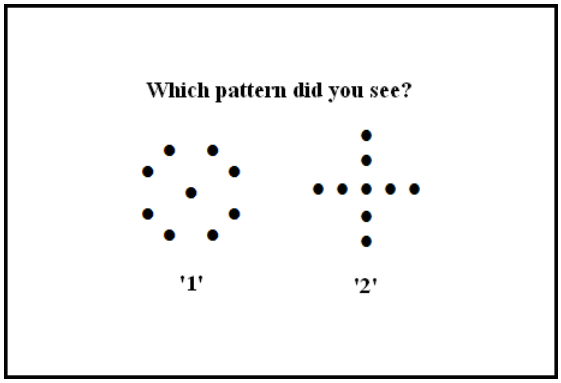

Figure 7. An example of a recognition task trial from Experiment 2.

The participant responded by pressing the *1* key or the *2* key on the computer keyboard. Upon pressing a response key, the screen was cleared for 1 s followed by a prompt to press the spacebar to initiate the next trial. This cycle continued until the participant had made a recognition decision for all 30 trials.

After completing the 2AFC task, participants were thanked for their time and dismissed.

Results and Discussion

Table 2 presents the mean liking ratings, mean recognition accuracy, and standard errors

for both measures for RRS 1, 2, 4, and 8 patterns. As shown, participants' preferred patterns with smaller RRS sizes and were generally better at recognizing previously seen patterns with a smaller RRS. More detailed analyses of the data follow.

	Liking Rating		Recognition	
RRS	*M*	*SE*	*M*	*SE*
1	5.44	0.18	90.0	2.60
2	4.85	0.13	71.2	3.07
4	4.62	0.09	77.2	1.71
8	3.43	0.11	63.7	2.08

Table 2. Mean liking ratings, mean percent correct and standard errors for the two.

Analysis of Preference Ratings

The preference ratings were analyzed in a single factor within-subjects ANOVA. The analysis confirmed statistical differences in peoples' pattern preference as a function of RRS, $F(3,177) = 47.00$, $p < .001$. Namely, people liked RRS 1 patterns most, liked RRS 8 patterns least, and liked RRS 2 and RRS 4 patterns intermediate to the two extremes. It is worth noting that the liking ratings in the experiment are nearly identical to the ratings in Experiment 1. However, Bonferroni correction on all pairwise comparisons revealed an insignificant difference between RRS 2 and RRS 4 liking ratings, $p = .241$. Despite the difference, participants showed an overall preference for symmetric over asymmetric patterns and the consistency of data over Experiments 1 and 2 strengthens that position.

Analysis of Recognition Accuracy

A single factor within-subjects ANOVA was used to analyze recognition accuracy as a function of RRS (RRS 1, 2, 4, and 8). The analysis confirmed a main effect of RRS, $F(3, 177) =$

26.30, $p < .001$. As shown in Table 2, recognition accuracy was best for RRS 1 patterns, worst for RRS 8 patterns, and intermediate for both RRS 2 and RRS 4 patterns. A Bonferroni correction to compensate for Type 1 error with all pairwise comparisons revealed that recognition accuracy performance was distinguished significantly for all comparisons except for RRS 2 and RRS 4 patterns and RRS 2 and RRS 8 patterns, $\alpha = .05$. The insignificant difference in recognition accuracy for RRS 2 and RRS 4 patterns is consistent with the speeded recognition data in Experiment 1. The insignificant difference in recognition accuracy for RRS 2 and RRS 8 patterns is consistent with results from different trials in the same-different task in Experiment 1. In different trials of the same-different task from Experiment 1, participants were asked to discriminate between two patterns as fast and as accurately as possible. Since performance was worst for discriminating between RRS 2 and RRS 8 patterns, it is not surprising that performance for those same patterns in an untimed recognition task would also suffer as accurate recognition relies on the ability to discriminate patterns previously seen from new patterns.

In summary, similar to Experiment 1, participants preferred RRS 1 patterns the most, RRS 8 patterns the least, and RRS 2 and RRS 4 patterns intermediate of the two extremes. In addition, participants were most accurate in identifying previously rated RRS 1 patterns, least accurate in identifying previously rated RRS 8 patterns, and intermediate at identifying previously rated RRS 2 and RRS 4 patterns.

Taken together, with the results of Experiment 1, these results signal a systematic effect of both preference and recognition for patterns as a function of RRS size. In the next analysis, I examined whether the relationship between RRS and liking can be explained as a function of fluency as measured by recognition accuracy.

Mediation Analysis: Evaluating the Fluency Hypothesis

As shown in Table 2, there were strong interrelationships between the variables RRS, liking rating, and recognition accuracy. An increase in RRS is strongly and negatively correlated with both recognition accuracy, r = -.795, and liking rating, r = -.984. A strong and positive correlation was also found between recognition accuracy and liking rating, r = .886.

To perform the mediation analysis, I first calculated the mean recognition accuracy and mean liking ratings for each of the 60 stimulus patterns, collapsing over all 60 participants. Next I conducted a test for full mediation with three single-predictor and one two-predictor regression models, similar to Experiment 1.

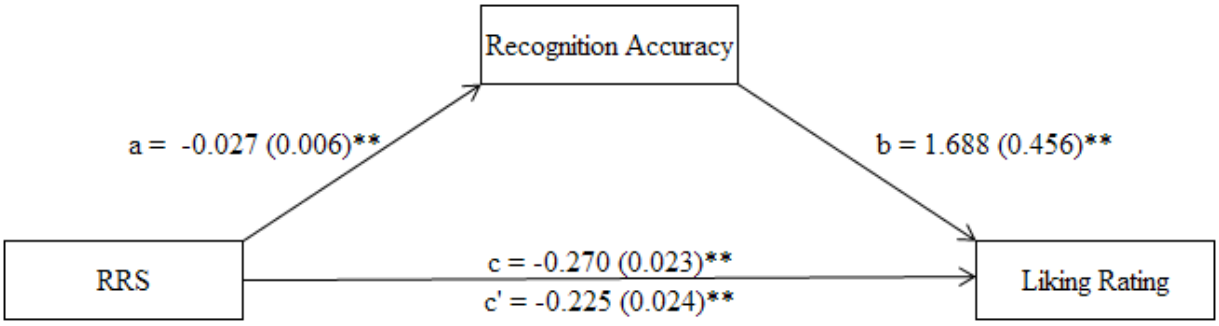

Figure 8. A mediation model depicting the proposed interrelationship between the variables RRS, recognition accuracy, and liking rating. The coefficients to the right of the path identifiers represent unstandardized regression coefficients, standard errors are in parentheses. **p < .001.

Figure 8 provides a summary of the mediation analysis. As shown in Figure 8, all paths connecting the variables are statistically reliable at p < .001. As in Experiment 1, the analysis failed to confirm complete mediation (i.e., both paths c and c' are statistically significant). Based on that null result, I conclude that the evidence is not sufficient to claim that the relationship between RRS and liking ratings is fully explained by their shared variance with the measurement of fluency (i.e., recognition accuracy).

Given the failure of the full mediation analysis, I conducted a test for partial mediation

using a bootstrapped mediation analysis. The results of this analysis confirm that recognition accuracy partially mediates the relationship between RRS and liking rating, $z = -2.88$, $p = .003$.

The results of the mediation analysis add support to the results of Experiment 1 that patterns with a greater amount of symmetry are processed more fluently, and that increased fluency is attributed to increased preference. That conclusion is consistent whether fluency is measured by recognition speed or recognition accuracy. However, the analysis suggests that more than symmetry as measured by RRS is needed to understand the relationship between RRS and liking fully.

Symmetry Type

As in Experiment 1, I divided the 24 RRS 4 patterns into symmetry subgroups (i.e., horizontal, vertical, and diagonal). Consistent with the symmetry analysis in Experiment 1, mean liking ratings for vertically symmetric patterns ($M = 4.91$) were higher than mean ratings for both horizontally ($M = 4.53$) and diagonally symmetric patterns ($M = 4.52$), $F(2,118) = 4.41$, $p = .015$. However, as in Experiment 1, axis of symmetry predicted liking much less than RRS.

Conclusions

Whereas Experiments 1 and 2 show that peoples' preference for patterns is predicted by how fluently they are processed and that how fluently they are processed depends on their symmetry, the fluency attribution account is not just a theory of pattern preference. Rather, according to a fluency attribution account, participants ought to attribute their experiences of fluency to whatever stimulus property they are invited to attribute it to. Thus, participants would be expected to judge patterns that are processed more fluently as happier, more fragrant, better, and so on (Reber et al., 2004). In Experiment 3, I tested the fluency attribution hypothesis by changing the dimension that participants judged from liking to happiness.

Experiment 3: Fluency Attribution

The results of Experiments 1 and 2 were interpreted with the assumption that fluency is being attributed to pattern preference. In Experiment 3, I tested this assumption of the fluency attribution perspective. According to this perspective, if participants are attributing fluency to preference, they should theoretically attribute fluency to almost any subjective judgment. For example, people ought to judge more fluently processed stimuli as happier than their less fluently processed counterparts.

In Experiment 3, I had participants rate how 'happy' a pattern is. I then used a same-different task identical to Experiment 1 to measure processing efficiency. I hypothesized that the same interrelationships between pattern symmetry, processing efficiency, and pattern preference would emerge despite the change in judgment from preference to mood.

In a third task, participants rated the 'organization' of the 24 RRS 8 patterns. In Experiments 1 and 2, pattern symmetry influenced both fluency and pattern preference. The organization rating task of Experiment 3 was conducted so that I could perform a post hoc examination of how other aspects of stimulus structure may be related to people's pattern judgments and recognition speed.

I hypothesized that participants would rate patterns that they thought were happier as more organized. Secondly, I hypothesized that more fluently processed stimuli would be rated as more organized.

Method

Participants

Seventy-nine participants with normal or corrected-to-normal vision were recruited from the University of Manitoba undergraduate participant pool. There were no other restrictions on

participation and all participants received credit towards their grade in exchange for their time.

Stimuli

As described in Experiment 1 (see Figure 3).

Apparatus

As described in Experiment 1.

Procedure

To ensure an accurate measurement of attribution, the rating and same-different task in Experiment 3 were identical to Experiment 1 except for the change in rating scale. Participants were instead asked to rate patterns on a scale of 1 to 7, from *Least Happy* to *Most Happy*. Following the completion of the happiness rating and same-different tasks, the screen was cleared for 1 s before the instructions for the organization task were presented.

Instructions for the organization task:

> *You are almost finished. In this final task, you will be asked to rate 24 patterns on whether you think they are organized. Press spacebar to continue.*

The spacebar press cleared the screen for 1 s. After that, an RRS 8 pattern was presented on the screen with an organization judgment question and the two response options presented below it (see Figure 9).

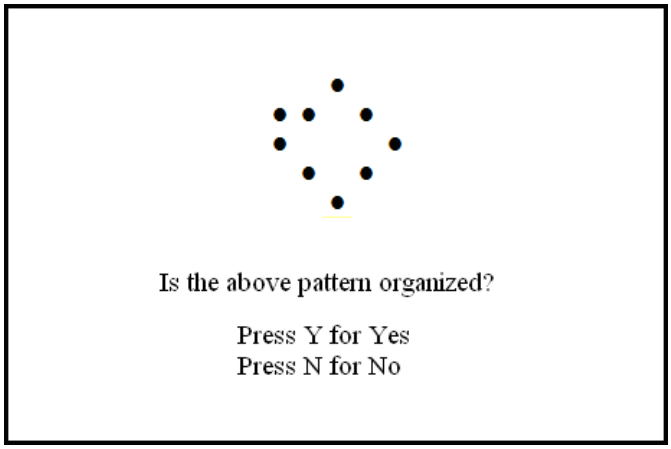

Figure 9. An example of an organization judgment task trial from Experiment 3.

After participants made a yes/no response, the screen was cleared for 1 s after which the next trial began. This cycle continued until all 24 patterns from RRS 8 were presented in random order.

Following the organization task, all participants were asked to report whether they understood the instructions in the experiment, after which they were thanked for their participation and dismissed.

Results and Discussion

Analysis of Experiment 3 data was identical to the analysis in Experiment 1 (with the exception of the organization analysis which was not present in Experiment 1). Data from 18 of 79 participants was discarded because those participants failed to achieve 90% accuracy in the same-different task. This precaution was used to eliminate complications in the analysis of results due to a speed-accuracy tradeoff. A further one participant was excluded from the following analyses because they indicated at the end of the experiment that they did not understand the experimental instructions. Thus, the analyses were conducted on 60 of the

original 79 participants.

Next, I inspected data from individual trials for individual subjects. RT responses that were less than 150 ms or greater than 1500 ms were removed from further analyses as they were likely either too fast to reflect a decision based on perception or too slow suggesting a lapse in attention. This removed only 360 total responses, or 1.31 % of all responses. Except for the initial error analysis, all analyses were conducted on accurate trials only. Similar to Experiment 1, as an assurance against effects due to filtering participants and RT responses, a complimentary analysis was conducted using the median RT rather than the mean RT (See Appendix C)

Table 3 presents the mean happiness ratings, mean RT, and mean accuracy for the presented patterns, each as a function of RRS (1, 2, 4, and 8). The data can be read in exactly the same way as the data from Experiment 1 (see Table 1).

	Happiness Rating		Same/Different Task							
			RT Same				RT Different			
RRS	*M*	*SE*	*M*	*SE*	*% E*	*SE*	*M*	*SE*	*% E*	*SE*
1	5.22	0.16	564	11.4	3.48	0.76	655	11.7	3.12	0.54
2	4.41	0.13	573	8.79	4.24	0.53	651	12.2	5.68	0.56
4	4.30	0.10	581	9.15	4.39	0.40	644	11.0	2.93	0.27
8	3.48	0.11	599	9.55	5.66	0.52	656	10.6	4.53	0.39

Table 3. Mean ratings of happiness and standard errors are presented for the rating task. Mean RTs, mean accuracy, and standard errors are also presented for same and different trials in the same-different task.

Analysis of Mood Ratings

I analyzed participants' happiness ratings using a single factor within-subjects ANOVA as a function of RRS size (1, 2, 4, and 8). Mean happiness rating differed significantly as a function of RRS size, $F(3,177) = 45.40$, $p < .001$. The pattern of results for happiness ratings matched closely to the liking ratings from Experiments 1 and 2.

RRS 1 patterns were rated the *most happy* and RRS 8 patterns were rated the *least happy*, with RRS 2 and RRS 4 patterns rated intermediate of the two extremes. All pairwise comparisons were significant except for a comparison of RRS 2 and RRS 4 patterns, α = .05 (a Bonferroni correction was used to control for Type 1 error inflation). This result was identical to that of Experiment 2, which also found no statistically significant difference in ratings between RRS 2 and RRS 4 patterns.

In summary, a change in rating task from a preference judgment to a mood judgment did not affect how participants rated the patterns. Ratings of happiness differed significantly as a function of pattern symmetry, just as ratings of liking did in Experiments 1 and 2.

Analysis of Accuracy in the Speeded Recognition Task

A 4 x 2 within-subjects ANOVA was conducted on the error data from the speeded same-different task using RRS (1, 2, 4, and 8) and trial type (same, different) as the two factors. There was a statistically significant interaction between RRS and trial type, $F(3, 177) = 5.06$, $p = .005$. I decomposed the interaction into simple effects and found that both same and different trial types differed significantly as a function of RRS, $F(3, 177) = 3.79$, $p =. 025$, and $F(3, 177) = 12.99$, $p < .001$ respectively. Pairwise comparisons using a Bonferroni correction for same trial error rates found only significant comparisons between RRS 4 and RRS 8 $p < .05$. Pairwise comparisons between RRS 1 and RRS 8 patterns and RRS 2 and RRS 8 patterns were nearly significant at $p = .054$ and $p = .050$ respectively. Opposite from a typical speed-accuracy trade-off, RRS 8 patterns had the worst accuracy and the slowest mean same RTs. The different trial error rates are consistent with the pattern of results found in Experiment 1 and with the conclusion that the results do not show a conventional speed-accuracy trade off of speed for

accuracy. Performance was worst for RRS 2 and RRS 8 within pattern pairs, and markedly improved when the task was to distinguish between two RRS 1 patterns or two RRS 4 patterns, $F(1, 59) = 32.18$, $p < .001$.

Analysis of RT in the Speeded Recognition Task

A 4 x 2 within-subjects ANOVA was conducted on RT scores as a function of both RRS (1, 2, 4, and 8) and trial type (same, different) in the same-different task. There was a statistically significant interaction for mean RT scores as a function of RRS and trial type, $F(3, 177) = 5.98$, $p = .004$. I decomposed the interaction into simple effects for trial type and found that whereas mean same RT differed significantly as a function of RRS, $F(3, 177) = 11.88$, $p < .001$, there were no statistically significant differences in mean different RT. Consistent with the pattern of results in Experiment 1 for same trials, RRS 1 patterns were responded to fastest, RRS 8 patterns were responded to slowest, and RRS 2 and RRS 4 patterns were responded to intermediate of the two extremes. Pairwise comparisons using the Bonferroni correction to control for Type 1 errors found that the mean RT for RRS 2 and RRS 4 patterns did not differ significantly, a similar result as found in Experiment 1. However, contrary to the results of Experiment 1, RT did not differ significantly between RRS 1 and RRS 2 patterns, and RRS 1 and RRS 4 patterns. A closer examination of the data revealed that outlier response times greater than 1100 ms but below the cutoff value 1500 ms had a significant impact on the mean RT responses to RRS 1 patterns. With a more stringent outlier cutoff removing responses greater than 1100 ms (a cutoff which eliminated only 4.16 percent of total RT responses), the results were identical to Experiment 1. See Appendix D for a reanalysis of RT in the speeded recognition task using the revised mean RT cutoff.

In summary, when accounting for outlier effects, these results reinforce the results of Experiment 1 and coincide with the results of Experiment 2. First, ratings of pattern mood differed significantly as a function of RRS, just as ratings of pattern preference differed significantly as a function of RRS in Experiments 1 and 2. Second, mean same RT differed significantly as a function of RRS; RRS 1 patterns were responded to fastest, RRS 8 patterns were responded to slowest, and RRS 2 and RRS 4 patterns were responded to intermediate of the two extremes. Taken together, the results further support a systematic effect where the size of the RRS affects a ratings judgment and processing speed for patterns. In the next analysis, I examined whether the relationship between RRS and happiness can be explained by how fluently a pattern is processed.

Mediation Analysis: Evaluation the Fluency Hypothesis

To examine the attribution aspect of the fluency attribution hypothesis, I conducted a mediation analysis to determine whether the relationship between pattern symmetry and pattern mood is mediated by fluency. As shown in Table 3, there are clear interrelationships between pattern happiness and performance in the same-different task. First, as RRS increases, so does mean same RT, $r = .993$. Second, as mean same RT increases, happiness ratings decrease, $r = -.973$. Finally, as RRS increases, happiness ratings decrease, $r = -.939$.

To perform the mediation analysis, I first calculated the mean same RT and mean happiness rating for each of the 60 stimulus patterns, collapsing over all 60 participants. Next I conducted a test for full mediation with three single-predictors and one two-predictor regression models, identical to the test conducted in Experiment 1.

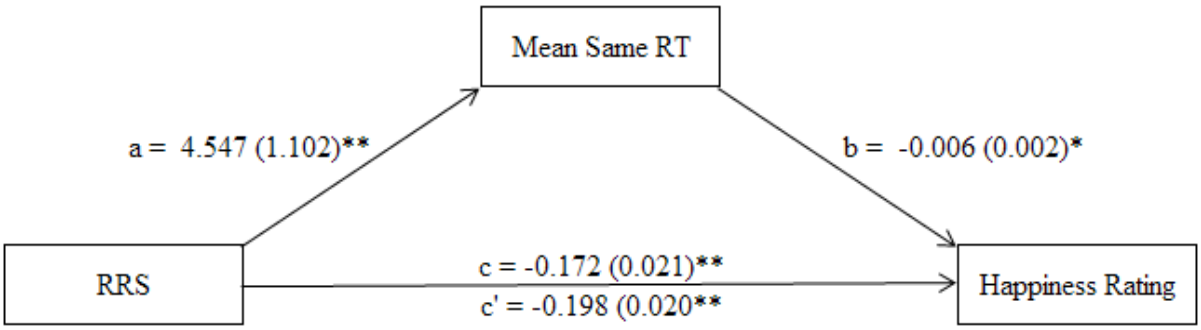

Figure 10. A mediation model depicting the proposed interrelationship between RRS, mean same RT, and mean happiness rating. The coefficients to the right of the path identifiers represent unstandardized regression coefficients, standard errors are in parentheses. *$p < .01$, **$p < .001$.

Figure 10 provides a summary of the mediation analysis. As shown in Figure 10, all connecting paths between the variables are statistically reliable. As in Experiments 1 and 2, the analysis failed to confirm full mediation. A two-predictor regression analysis with RRS and processing speed predicting happiness rating was significant, indicating that processing speed did not fully account for the relationship between RRS and happiness ratings. Given the failure to find full mediation, I conducted a test for partial mediation using a bootstrapped mediation analysis. The results of this analysis confirm that speed of processing partially mediates the relationship between RRS and happiness ratings, $z = -2.23$, $p < .05$.

The results of the mediation analysis confirm the attribution aspect of the fluency attribution hypothesis. Participants process symmetric patterns faster, and attribute the increased fluency to ratings of pattern mood. The attribution was made regardless of whether judgment is a preference judgment like in Experiment 1, or a mood judgment like the current experiment. However, as in Experiments 1 and 2, the result of partial mediation indicated that other factors are present which affect pattern processing.

Symmetry Type

To examine how symmetry type affected ratings of pattern happiness, I first divided the 24 RRS 4 patterns into their respective symmetry subgroups. In a single factor within-subject ANOVA for happiness rating as a function of symmetry type, I found a main effect, $F(2, 118) = 5.03$, $p = .012$. Once again, patterns with vertical symmetry ($M = 4.57$) were rated happier than patterns with horizontal ($M = 4.23$) and diagonal ($M = 4.20$) symmetries. This result confirms a similar result found in Experiments 1 and 2 for liking ratings that found differences in preference dependent on a pattern's axis of symmetry. However, as in those experiments, the size of the effect was small relative to the size of the effect that RRS had on happiness ratings.

Pattern Organization – Individual Differences

The addition of the organization-rating task in Experiment 3 provided a means of examining how other aspects of stimulus structure might influence fluency and rating judgments. I hypothesized that participants would rate patterns that they thought were happier as more organized. Secondly, I hypothesized that more fluently processed stimuli would be rated as more organized. To conduct the analysis, I compared the data from the happiness rating and same-different task with data from the organization task. I looked at the reaction time and happiness ratings for all the organized and disorganized patterns for each participant. It is worth noting that judgments of organization were made for each pattern by each individual, so a pattern could be rated as both organized or disorganized depending on who rated it. In Table 4, the mean happiness ratings and mean same RTs for organized and disorganized patterns are presented with their standard errors.

	Happiness Rating		RT Same	
Organization	*M*	*SE*	*M*	*SE*
Organized	3.76	0.13	584	10.2
Disorganized	3.30	0.13	604	10.4

Table 4. Mean happiness ratings and mean same RT for patterns judged as organized and disorganized by participants.

Analysis of organization and happiness rating. A within-subjects ANOVA was conducted on happiness ratings to examine whether they varied as a function of organization. The main effect of organization was significant for happiness ratings, $F(1, 59) = 20.20$, $p < .001$. Overall, participants made higher ratings of happiness for patterns they also rated as organized. Although I cannot identify what aspects of a stimulus participants used to rate a pattern as organized, the results suggest that factors other than bilateral symmetry influence peoples' rating judgments.

Analysis of organization and RT. A second within-subjects ANOVA was conducted on mean same RT to examine whether they also varied as a function of organization. The main effect of organization was significant, $F(1, 59) = 13.15$, $p = .001$. Overall, participants made faster same responses for patterns they also rated as organized. Since RRS 8 patterns contain no axes of bilateral symmetry, this result indicates that other aspects of stimulus structure in addition to symmetry affect pattern processing.

In summary, the results of the organization analyses suggest that other aspects of stimulus structure in addition to symmetry affect the rating and processing of patterns. To explore the aspects of stimulus structure affecting these measures, I next analyzed the patterns based on the percentage of organization agreement, collapsed over 60 participants.

Pattern Organization – Pattern Differences

In a second analysis of pattern organization, I first calculated the pattern organization percentage as the agreement amongst participants regarding whether a pattern was organized. Next, I computed both the mean same RT and mean happiness ratings for the 24 RRS 8 patterns over the 60 participants.

Analysis of organization and happiness rating

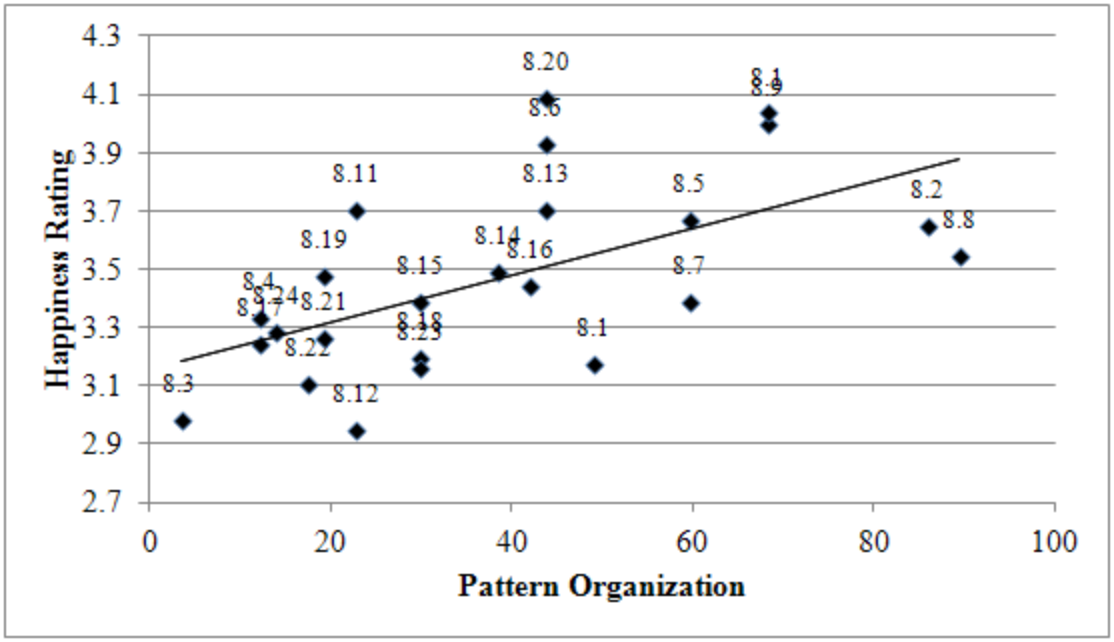

Figure 11. Mean happiness ratings are presented as a function of mean pattern organization. The pattern identifier is indicated above the data point. See Figure 13 for the full set of RRS 8 patterns organized by pattern organization.

In Figure 11, the pattern organization percentage was shown to be positively correlated with mean happiness ratings, $r(22) = .587$, $p = .003$. Patterns that participant agreed were more organized, were also rated as happier.

Analysis of organization and RT

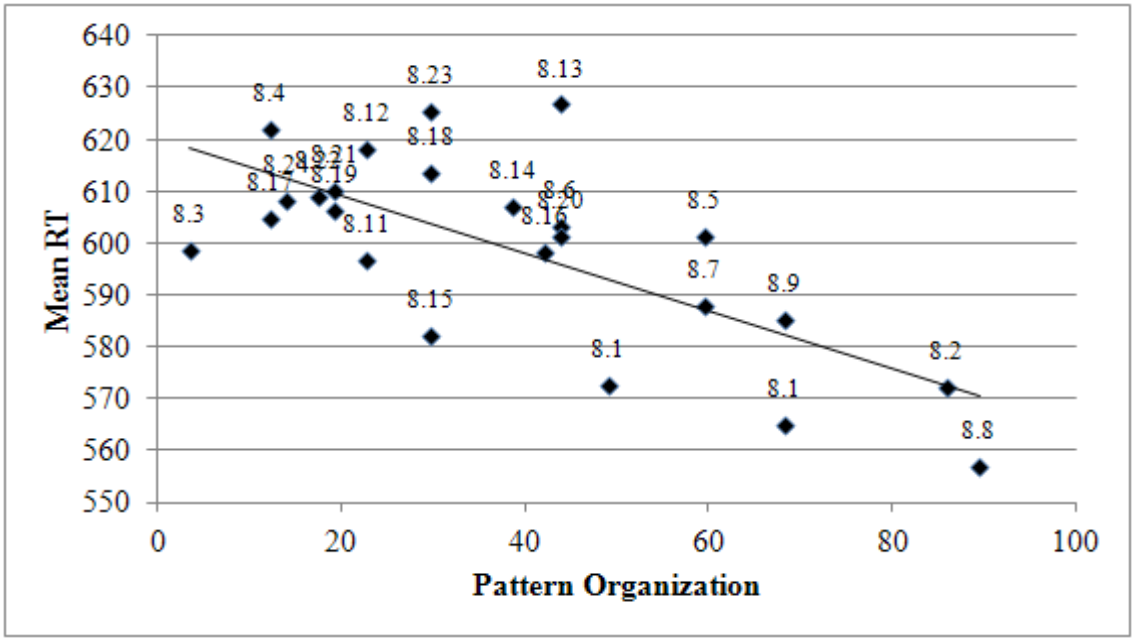

Figure 12. Mean same RTs in the same-different task are presented as a function of pattern organization. The individual pattern identifier is indicated above the data point. See Figure 13 for the full set of RRS 8 patterns organized by pattern organization.

As shown in Figure 12, the pattern organization percentage was negatively correlated with mean same RT, $r(22) = -.702$, $p < .001$. The greater the pattern organization percentage, the faster the mean same RT.

Pattern organization differences. In Figure 13, the 24 RRS 8 patterns are shown in descending order in accordance with the pattern organization percentage collapsed over all participants.

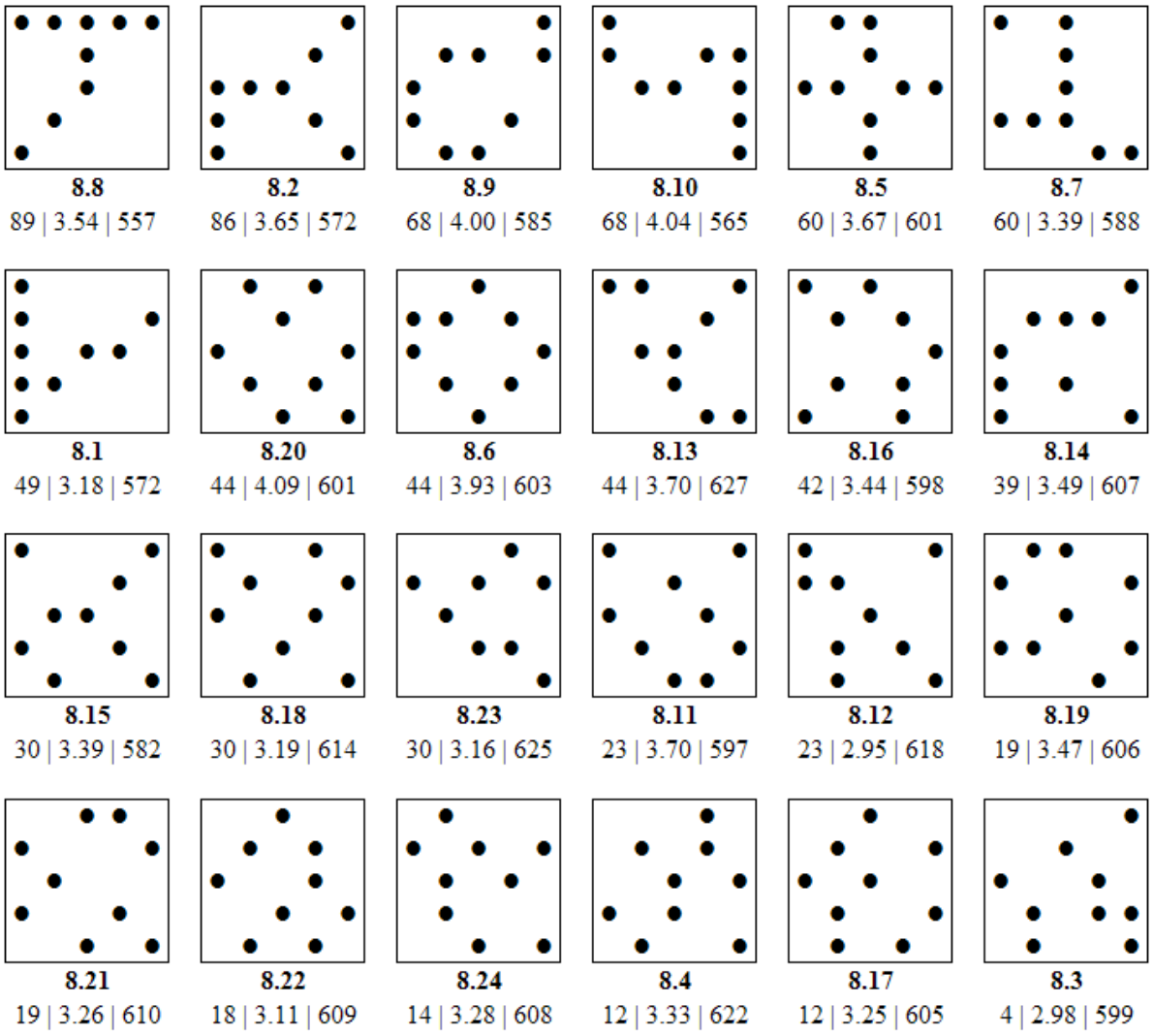

Figure 13. The pattern identifier for the 24 RRS 8 patterns is indicated immediately below the pattern. Below the pattern identifier from left to right is the pattern organization percentage, mean happiness rating, and mean same RT for each pattern. Note: Mean same RT is in ms

The topmost patterns in Figure 13 had more agreement about their level of organization than the bottommost patterns. In the two middle rows, and especially the second row from the top, participants were fairly evenly split as to whether the patterns were organized. It is clear that patterns that do not contain any axis of bilateral symmetry may still exhibit other properties that

differentiate them. Some examples of potential differentiating properties are the old Gestalt concepts of cohesion, continuation, proximity, local symmetries, and near global symmetries (Nucci & Wagemans, 2007; Palmer & Hemenway, 1978; Sarkar & Boyer, 1993). As shown in Figures 14, 15, and 16, properties of 'good' figures beyond symmetry exist within the patterns that had higher ratings of organization.

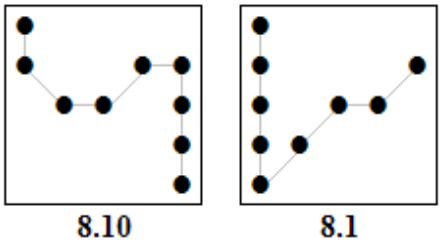

Figure 14. The property of continuation within patterns 8.10 and 8.1.

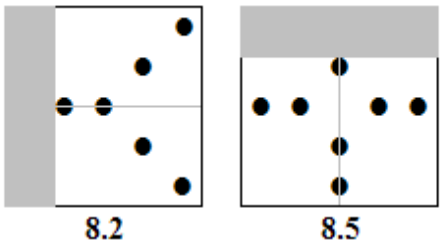

Figure 15. The property of local symmetry within patterns 8.2 and 8.5

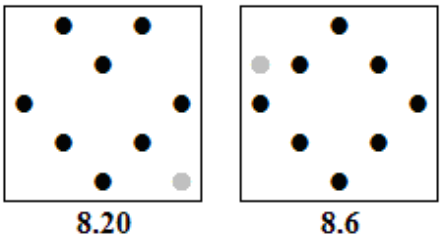

Figure 16. The property of near global symmetry within patterns 8.20 and 8.6

In Figure 14, the property of continuation within the pattern is shown with a 'connect-the-dots' approach. In both Figures 15 and 16, there are demonstrations of how a pattern without symmetry can undergo a simple manipulation that creates bilateral symmetry. The above analysis is purely speculative as it is impossible to determine from this experiment what properties of stimulus structure affected the organization ratings made by participants. However, the above analyses did demonstrate the significant relationships between pattern organization, speed of processing, and ratings of pattern happiness. The differences in processing for patterns that were more or less organized indicate that other aspects of stimulus structure in addition to bilateral symmetry influence both processing efficiency and rating judgments.

General Discussion

In the three experiments conducted for this thesis, I presented a consistent pattern of results that support the integration of the information processing and fluency attribution perspectives. To accomplish this, I created a stimulus set that allowed me to quantify information content using an established RRS metric. In Experiment 1, patterns that were more symmetric were processed faster in a same-different task and were better liked. In Experiment 2, patterns that were more symmetric were better recognized and better liked. Thus, the amount of

stimulus structure affected both the speed and the strength of memorial storage and retrieval processes. Experiment 3 provided a replication of Experiment 1 but rather than making judgments about pattern preference, participant's made judgments about the mood of each pattern. However, the replication of the same-different task in Experiment 1 only occurred after more stringent cutoffs were imposed on the reaction time data. Thus, although I conclude that the results of Experiment 3 provide converging evidence for the results in Experiments 1 and 2, that claim must be considered a weaker claim and should be treated cautiously as a start point for additional work to examine the source of the different results in the same-different tasks. Regardless, the greater processing efficiency for more symmetric patterns was correlated and in light of the findings of the mediation analysis, attributed to pattern happiness. The third experiment thus provided support for the decision mechanism that accounts for higher preference judgments for more fluently processed stimuli.

Data Editing

Given the sensitivity of RT studies to outlier effects, I believed it was necessary to filter the RT data for responses deemed either too soon to reflect a decision process, or too delayed, which could indicate a lapse in attention. Thus, all RT data less than 150 ms or greater than 1500 ms was excluded from the analysis of Experiments 1 and 3. In addition, to minimize any potential speed accuracy trade-offs, data from participants that failed to achieve an overall accuracy of 90% on the speeded recognition task were not included in any of the experimental results. Since these decisions removed 12 participants and 1.58% of data from Experiment 1 analysis, and 18 participants and 1.31% of data from Experiment 3 analysis, I reran the main experimental analyses to determine whether these decisions affected the results and the conclusion drawn from those results.

In Experiment 1, neither of these data editing procedures affected the experimental results in any significant manner. The liking ratings over all 87 participants were significantly different over all pairwise comparisons with a Bonferroni correction. As well, RT data for same responses was identical when the median was used; all pairwise comparisons corrected with the Bonferroni correction method were significant at $\alpha = .05$ except for a null difference between responses for RRS 2 and RRS 4 patterns (See Appendix B for a more in-depth analysis).

In Experiment 3, ratings of happiness were not affected by the inclusion of 16 of the 18 participants originally excluded. Two participants remained excluded from the reanalysis as one participant scored near chance at 56% accuracy, and the other participant indicated at the conclusion of the experiment that they did not understand the task. Again, all pairwise comparisons using the Bonferroni correction were significant at $\alpha = .05$ except for a null difference between happiness ratings for RRS 2 and RRS 4 patterns. As well, with the inclusion of the initially excluded 16 participants and the use of median RT data as the dependent measure in the same-different task, the results of the same-different task in Experiment 3 replicated those of Experiment 1. Median RT differed significantly as a function of RRS, with all pairwise comparisons significant at $p <. 05$, except for the difference between RRS 2 and RRS 4 patterns. See Appendix C for the revised Experiment 3 results.

As well, as elucidated briefly at the conclusion of the RT analysis in Experiment 3, by using a more stringent RT upper limit cutoff of 1100 ms, the results of the same-different task in Experiment 3 replicated the results of the same-different task in Experiment 1. The upper limit cutoff of 1100 ms eliminated responses greater than the typical response window for the task ((Cousineau & Chartier, 2010), and only 4.16% of total correct responses (See Appendix D).

In summary, the methods used to filter both participants and RT responses did not affect the main experimental results or the conclusions that can be drawn from them.

Processing Fluency

Although it can generally be agreed upon that a more efficiently processed stimulus is one that is processed better, faster, and more accurately, there are other possible measures processing efficiency can take in addition to the ones used in this thesis. In Experiments 1 and 3, I used a speeded recognition task to measure how quickly people can perceive and compare patterns in memory. In Experiment 2, I used a 2AFC task to measure the recognition accuracy for patterns independent of speed demands. I used both measures as proxies for processing fluency and showed that the mediation hypothesis is consistent independent of which measure of fluency I used. However, there are other possibilities for measuring fluency.

Verbal response latency. In a reanalysis of Clement (1964), I found a third measure of processing efficiency that mediates the relationship between pattern symmetry and pattern preference. A verbal response task is another RT measure of processing efficiency. In this task, the participant is required to provide a one-word name for a stimulus. The mean RT to provide a verbal response is then recorded. In Clement (1964), the Garner patterns (Garner, 1962; Garner and Clement, 1963) described in the introduction were used as the stimuli to-be-named. First, 30 participants rated the pattern goodness of dot patterns on a scale of 1 to 7. Next, a different group of 60 participants provided a one-word verbal responses to each pattern. Participants were instructed not to use nouns or interjections in their verbal response.

I conducted a mediation analysis on Clement's (1964) data to evaluate whether the relationship between pattern symmetry (i.e. RRS) and pattern preference (i.e. ratings of goodness) can be understood by their shared variance with verbal response latencies. A

bootstrapped mediation analysis indicated that verbal response latencies partially mediated the relationship between pattern symmetry and pattern preference, $z = 2.21$, $p = .026$. Namely, the smaller the RRS of the pattern, the higher the ratings of pattern goodness, and the faster the median naming response time. As described by Clement (1964), median naming responses are likely faster for good patterns because the patterns have fewer unique elements (i.e. more symmetric) that require a verbal description, unlike poorly rated patterns that contain more unique elements (i.e. less symmetry) and require longer verbal descriptions. In combination with the results in Experiments 1, 2, and 3 reported here, the experiment by Clement (1964) provides yet another example of increased fluency for patterns that are more symmetric.

Fluency Attribution Perspective

In Experiment 3, the rating of 'mood' for a pattern was likely an odd concept to participants as dot patterns are incapable of being emotional. However, a confirmation of the fluency attribution perspective was made when participants' responses to pattern happiness were found to vary systematically as a function of the amount of stimulus structure. This confirmed an assumption of the fluency attribution perspective that states fluency differs as a function of objective stimulus properties (Reber et al., 2004). However, as a pilot study revealed, the nature of the judgment being made about the patterns is important in observing the attribution of fluency to preference. Specifically, I conducted a pilot study that is not reported here where, rather than rating *liking* or *happiness* for patterns, I asked participants to rate the *brightness* of presented patterns. In difference to the results reported here, I observed no systematic variation in brightness judgments and symmetry as measured by RSS. In a questionnaire given to participants after the experiment, participants named reasons for their ratings, for example, the amount of white space a pattern had. It seems then that the perceived pattern brightness when

patterns are of equal luminance produced a judgment that was not free to vary with the stimulus structure.

The difference suggests that fluency attribution occurs in situations where participants judge subjective but not objective and verifiable properties of a stimulus. When the judged property can be assessed objectively or rationally (i.e., the amount of white space), participants override the fluency attribution strategy for one that can be objectively inspected and assessed. Although the distinction is simple, it is important for understanding a condition and boundary of fluency attribution. Namely, fluency attribution can explain decision making in situations where the correct decision is unclear or ill-defined but cannot explain decision making in situations where the correct decision is rational and measurable.

The results of Experiment 3 also confirm another assumption of the fluency attribution hypothesis proposed by Reber et al. (2004). Namely, that highly fluent stimuli are rated positively and elicit a positive affective response. In my experiments, the more fluently a pattern was processed, the happier it was rated. This result is consistent with previous studies with positive responses to primed images (Olds & Westerman, 2012; Zajonc, 1968), more positive feelings towards words that are recalled more accurately (Leboe & Ansons, 2006), and smile responses to fluent images using facial EMG (Harmon-Jones & Allen, 2001; Winkielman & Cacioppo, 2001).

Whereas Experiment 3 provided evidence that participants attributed fluency to happiness, Experiments 1 and 2 provided support that both the speed of processing, and recognition accuracy were competent measures in assessing the processing efficiency for patterns, and eliciting fluency attribution. Thus, the integration of the information processing and fluency attribution perspectives provides a coherent analysis of the cognitive processes

underlying the relationship between pattern symmetry and pattern preference. However, the information processing aspect of the theory requires further inspection, as the metric of RRS is not a perfect index of symmetry.

The Relationship Between RRS and Pattern Symmetry

Although a dot pattern with at least one bilaterally symmetric axis must belong to a specific RRS size, not all patterns within an RRS size necessarily contain a bilateral axis of symmetry. The example used in the introduction of a backwards 'Z' illustrates the point. A backwards 'Z' is not bilaterally symmetric about any axis, yet the full rotation and reflection subset produces 4 unique patterns (i.e. an RRS 4 pattern). However, in the case of this thesis, the number of axes of bilateral symmetry was used in conjunction with the RRS metric that can best be thought of as a tool for the construction and classification of the stimuli. Thus, patterns in RRS 1 contained 4 axes of symmetry, patterns in RRS 2 contained 2 axes of symmetry, patterns in RRS 4 contained only 1 axis of symmetry, and patterns in RRS 8 were asymmetric about all axes. Using symmetry in addition to RRS ensured that all patterns within a specific RRS contained the same amount of information as calculated by the redundancy within the stimulus structure. Since the property of symmetry has both well-researched aesthetic qualities and quantifiability, it was the main independent variable used in this thesis.

Pattern Symmetry, Simplicity, and Complexity

It could be argued that what I have demonstrated in the three experiments is better explained by a preference and processing advantage for simple over complex patterns, rather than symmetric over asymmetric patterns. Given the overlapping nature of these concepts, it is easy to see why this argument would be made. Both objectively in the structure of the stimulus, and subjectively in the persons' experience of the stimulus, symmetry is a determinant of the

simplicity/complexity of a stimulus.

The quantification of the stimulus structure determines objectively the degree of simplicity/complexity. One method of quantification is through counting the number of unique aspects in the stimulus (Kaplan & Kaplan, 1989). With this method, a bilaterally symmetric stimulus like RRS 4 patterns would be less complex than an asymmetric pattern because half its features are repeated over a midline and thus contain fewer unique stimulus features. This repetition is an aspect of redundancy (Jamieson & Mewhort, 2005), which is the intrastimulus predictability of a feature in a stimulus to the stimulus whole (Houston, Garskof, & Silber, 1965). This concept has roots in Shannons' (1948) information calculus which quantifies the complexity of the stimulus through a calculation of the amount of information contained within a stimulus. A predictable pattern has a shorter code and is determined to be simpler than a pattern where a longer code is necessary to reproduce the information. In a basic demonstration of redundancy leading to judgments of simplicity, Houston, Garskoff, and Silber had participants' rate patterns with different redundancies on a scale of *very simple* to *very comple*x. Hamada and Ishihara (1988) also found that greater redundancy was associated with ratings of simplicity using Garner dot patterns varying in amount and type of symmetry (see also Moyles, Tuddenham, & Block, 1965)

However, not all symmetric patterns are simple and not all asymmetric patterns are complex. To untangle these concepts, Marković and Gvozdenovi (2001) introduced complex-symmetric and simple-asymmetric patterns along with the standard concurrence of simple-symmetric and complex-asymmetric patterns. Participants rated the four configurations of the patterns' 'goodness' on a 7-point scale from *poor* to *good*. The results indicated that whereas symmetry was a reliable predictor of increased goodness ratings for symmetric-simple and

symmetric-complex patterns, the simplicity/complexity of a pattern did not significantly predict the mean ratings of goodness for the patterns. However, 'goodness' ratings in this experiment were not a preference rating, but were rather specified as a rating of how "organized" or "well-arranged" the patterns were. A replication of this experiment with a preference rating scale could further untangle the close relationship between symmetry/asymmetry and simplicity/complexity. If such an experiment were to be conducted, it would be crucial to control for the participants experience with art and aesthetics as artists can find bilaterally symmetric stimuli unpleasant and prefer stimuli that are more complex and asymmetric (Barron, 1953).

Pattern Similarity and RRS 2 Patterns

A stable result throughout the three experiments was poor/slow recognition of RRS 2 patterns compared to RRS 4 patterns. In Experiment 1, error rates for RRS 2 patterns were significantly worse than RRS 1 and RRS 4 pattern error rates in different trials of the same-different task. As well, RRS 2 patterns response times did not differ significantly from RRS 4 patterns in the same-different task. In Experiment 2, the mean recognition accuracy for RRS 2 patterns in the recognition task was worse than the recognition accuracy for RRS 4 patterns at a nearly significant level. The results of Experiment 3 replicated those of Experiment 1; tasks with RRS 2 patterns that required pattern discriminability like the same-different judgment suffered in both error rates and reaction times.

One possible explanation for the poor performance for RRS 2 patterns across the three experiments is that they contain intuitive similarities in configuration and orientation that might make them more difficult to distinguish.

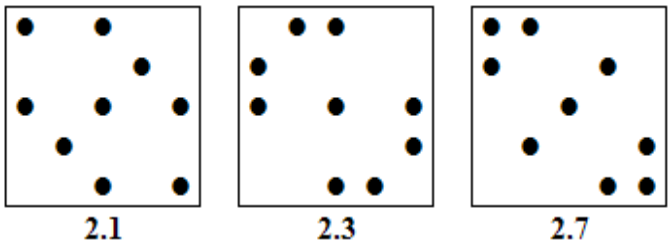

Figure 17. Examples of visual similarity within RRS 2 dot patterns.

To illustrate, Figure 17 represents three out of eight patterns within the RRS 2 set. The rules for RRS 2 pattern construction constrained the type of symmetry possible within this subset. RRS 2 patterns only contained diagonal symmetry and thus were unique compared to both RRS 1 and RRS 4 patterns that exhibited instances of vertical, horizontal, and diagonal symmetry. Although I have no metric to define visual similarity for the dot patterns, other studies have attributed similar experimental findings to visual similarity. In a same-different response experiment similar to Experiments 1 and 3, patterns that were visually similar but not identical were processed significantly slower than dissimilar patterns in the same task (Bagnara, Boles, Simion, & Umilta, 1983). As well, in a recognition task, it was assumed that visual similarity facilitated errors because it makes discrimination more difficult (Cooper, 1976). Both my own results and those in the studies mentioned are consistent with the hypothesis that pattern similarity causes the participant to exhibit caution in making their judgments, thus slowing them down (Bagnara et al., 1983). Unfortunately, the problem of quantified pattern similarity is a more complicated problem that I can address here and so my suppositions remain speculation.

Fractal Geometry

It became clear with the analysis of pattern organization that stimulus properties other

than bilateral symmetry are needed to develop a complete picture of the cognitive processes underlying preference judgments. Although dot patterns provide an easily quantifiable level of symmetry and have been useful in an examination of cognitive processes, they are artificial. They do not possess the aesthetic qualities that art or natural landscapes possess. There is a type of symmetry that has been studied in detail that provides an easily quantifiable metric while bridging the gap between artificial stimuli, and stimuli more appropriate to a realistic examination of preference judgments. The scalar symmetry present in fractal patterns became an ideal candidate for a more realistic examination of preference judgments as a function of increased fluency attributions for more efficiently processed stimuli.

Fractal patterns have an underlying mathematics that allows for their quantification (Cutting & Garvin, 1987). Fractals are also capable of quantifying natural landscapes such as mountains, coastlines, clouds, and tree lines (Gilden, Schmuckler, & Clayton, 1993; Mandelbrot, 1982). An example of a set of fractal patterns exhibiting scale symmetry is seen in Figure 18.

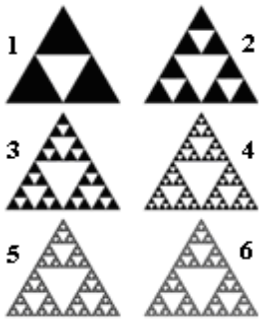

Figure 18. Six iterations of the 'Sierpinski Gasket,' a fractal object exhibiting different levels of scale symmetry from lowest '1' to highest '6.'

Patterns 1 through 6 in Figure 18 were created through a recursive algorithm. Pattern '1'

is copied and redrawn within itself at a smaller scale. This creates pattern '2', which is a representation of pattern '1' redrawn within itself. By extension, if you "zoom into" pattern '2', you will find an exact replica of pattern '1'. The more times the recursion algorithm is applied, the greater the amount of scale symmetry present. Using five fractal patterns and six recursion depths, I conducted a pilot study with a same-different and rating task similar to the ones conducted in Experiments 1 and 3 for the 30 patterns. Unfortunately, a within-subjects ANOVA evaluating scale symmetry as a function of mean same RT or ratings of aesthetic pleasure were both nonsignificant, $p > .05$. Despite the failure of examining processing efficiency with scale symmetry with this small set of fractal patterns and limited sample size, other fractal patterns may be constructed to render more precise examinations of the fluency attribution account of the relationship between symmetry and preference with real-world objects and scenes.

Conclusions

The experiments presented in this thesis confirm the existing data on symmetry and preference judgments, and expand on it through an integration of the information processing and fluency attribution perspectives. With a clear quantification of stimulus structure and multiple measures of processing efficiency, I leveraged the statistical technique of mediation analysis to develop a rational assessment of the hypothesis that efficiency of stimulus processing mediates the relationship between pattern symmetry and pattern preference. In addition, I used the fluency attribution perspective to offer a decision mechanism for the preference judgments and confirmed that participants attributed increased fluency to increased preference for patterns. This was accomplished with a test of the fluency attribution perspective in Experiment 3 that had participants make judgments about pattern 'mood.' Despite the odd judgment task, pattern ratings of happiness were mediated by processing efficiency, just as they were in Experiment 1 and 2 for

a preference judgment of liking.

The purpose of the three experiments in this thesis was not to simply show that patterns with different amounts of symmetry are processed more or less efficiently, and preferred to different degrees. Rather, my aim was to understand how we move from basic cognitive processes of speed and strength of memory retrieval, to understand the fundamental basis of visual pattern preference. In demonstrating that increased fluency is attributed to both pattern liking and pattern happiness, I have come closer to understanding the basic cognitive processes behind subjective preference judgments.

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Appendix A

Example of the wait task used in Experiment 2

Please answer the below math questions in the space provided. Use the cover paper as scrap paper if necessary.

1.	5	x	78	=	_____	**22.**	8	x	49	=	_____
2.	2	x	80	=	_____	**23.**	9	x	17	=	_____
3.	16	x	26	=	_____	**24.**	11	x	72	=	_____
4.	14	x	73	=	_____	**25.**	10	x	36	=	_____
5.	6	x	43	=	_____	**26.**	20	x	41	=	_____
6.	11	x	44	=	_____	**27.**	14	x	71	=	_____
7.	6	x	77	=	_____	**28.**	6	x	13	=	_____
8.	5	x	86	=	_____	**29.**	5	x	66	=	_____
9.	18	x	56	=	_____	**30.**	2	x	68	=	_____
10.	10	x	34	=	_____	**31.**	11	x	81	=	_____
11.	15	x	12	=	_____	**32.**	7	x	43	=	_____
12.	12	x	48	=	_____	**33.**	15	x	3	=	_____
13.	2	x	12	=	_____	**34.**	14	x	4	=	_____
14.	17	x	64	=	_____	**35.**	5	x	39	=	_____
15.	6	x	37	=	_____	**36.**	10	x	60	=	_____
16.	6	x	34	=	_____	**37.**	4	x	79	=	_____
17.	2	x	72	=	_____	**38.**	11	x	2	=	_____
18.	20	x	68	=	_____	**39.**	6	x	75	=	_____
19.	16	x	80	=	_____	**40.**	4	x	18	=	_____
20.	20	x	5	=	_____	**41.**	10	x	65	=	_____
21.	6	x	68	=	_____	**42.**	15	x	19	=	_____

Appendix B

Experiment 1 – Reanalysis of Main Experimental Results

The reanalysis of Experiment 1 paralleled the original analysis with a few important differences. There was no filtering of subjects based on accuracy; data from all 87 subjects was analyzed. For the same-different task RT analysis, median RT scores were used instead of filtered mean scores. Using median rather than mean scores eliminated the need for an outlier filtering procedure.

As can be seen in the table below, other than inflation of error rates in the same-different task due to inclusion of all participants, the key experimental results were identical in trend and significance. A more detailed analysis is presented below.

	Liking Rating		Same-Different Task							
			RT Same				RT Different			
RRS	*M*	*SE*	*M*	*SE*	*% E*	*SE*	*M*	*SE*	*% E*	*SE*
1	5.45	0.14	522	10.2	6.61	0.97	609	9.97	5.75	0.86
2	4.86	0.10	546	8.80	5.75	0.62	616	9.73	8.73	0.85
4	4.53	0.09	548	8.26	6.80	0.54	604	9.50	4.87	0.48
8	3.21	0.09	569	8.57	8.37	0.93	611	8.72	6.87	0.63

Table A1. Mean ratings of liking and standard errors are presented for the rating task. Median RTs, mean accuracy, and standard errors are also presented for same and different trials in the same-different task.

Analysis of Preference Ratings

Results of the liking data were analyzed using a single factor within-subjects analysis of variance (ANOVA). Mean liking rating differed significantly as a function of RRS size, $F(3,258) = 114.47$, $p < .001$. As shown in Table A1, RRS 1 patterns were liked the most, RRS 8 patterns were liked the least, and liking for RRS 2 and RRS 4 patterns was intermediate. A Bonferroni correction to protect against Type 1 error inflation confirmed that all pairwise

comparisons were significant, $\alpha = .05$.

Analysis of RT in the Speeded Recognition Task

RT as a function of RRS on same trials differed significantly, $F(3, 258) = 24.984$, $p < .001$, with the responses to RRS 1 patterns occurring faster than responses to RRS 8 patterns, and with responses to RRS 2 and RRS 4 patterns falling between those two extremes. Analysis of all pairwise differences using a Bonferroni correction on median RTs confirmed that all median RTs differed, except for the difference in median RT for RRS 2 and RRS 4 patterns, $\alpha = .05$. This result is identical to the result found in the original filtered mean analysis in the manuscript.

Mediation Analysis: Evaluating the Fluency Hypothesis

Using the mean ratings of liking and median RT scores for each of the 60 patterns, a bootstrapped mediation analysis was conducted to determine whether the median RT mediates the relationship between RRS and liking rating. Just as with the filtered mean RT in the original analysis, median same RT partially mediates the relationship between RRS and liking rating, $z = -2.15$, $p = .031$.

Appendix C

Experiment 3 – Reanalysis of Main Experimental Results

The reanalysis of Experiment 3 paralleled the original analysis with a few important differences. Only one participant was removed from analysis based on accuracy as their performance was near chance at 56%. One other participant was excluded from analysis as they indicated that they did not understand the experiment. Thus, the analysis was conducted on 77 participants. For the same-different task RT analysis, median RT scores were used instead of filtered mean scores. Using median rather than mean scores eliminated the need for an outlier filtering procedure.

As can be seen in the table below, other than inflation of error rates in the same-different task due to inclusion of all but two participants, the key experimental results were identical in trend and significance. A more detailed analysis is presented below.

	Happiness Rating		Same-Different Task							
			RT Same				RT Different			
RRS	*M*	*SE*	*M*	*SE*	*% E*	*SE*	*M*	*SE*	*% E*	*SE*
1	5.22	0.14	522	10.7	5.68	0.86	614	11.0	6.01	0.93
2	4.50	0.11	544	8.28	6.41	0.79	612	10.7	9.01	1.04
4	4.38	0.09	542	8.38	6.85	0.76	604	10.5	5.20	0.69
8	3.61	0.10	560	9.08	8.89	0.96	619	10.8	7.43	0.83

Table B1. Mean ratings of liking and standard errors are presented for the rating task. Median RTs, mean accuracy, and standard errors are also presented for same and different trials in the same-different task.

Analysis of Mood Ratings

I analyzed participants' happiness ratings using a single factor within-subjects ANOVA as a function of RRS size (1, 2, 4, and 8). Mean happiness rating differed significantly as a function of RRS size, $F(3,228) = 52.93$, $p < .001$. RRS 1 patterns were

rated the *most happy* and RRS 8 patterns were rated the *least happy*, with RRS 2 and RRS 4 patterns rated intermediate of the two extremes. All pairwise comparisons were significant except for a comparison of RRS 2 and RRS 4 patterns, $\alpha = .05$ (a Bonferroni correction was used to control for Type 1 error inflation).

Analysis of RT in the Speeded Recognition Task

Median same RT differed significantly as a function of RRS, $F(3, 228) = 14.76$, $p < .001$. RRS 1 patterns were responded to fastest, RRS 8 patterns were responded to slowest, and RRS 2 and RRS 4 patterns were responded to intermediate of the two extremes. Analysis of all pairwise differences using a Bonferroni correction on median RTs confirmed that all median RTs differed, except for the difference in median RT for RRS 2 and RRS 4 patterns, $\alpha = .05$.

Mediation Analysis: Evaluation the Fluency Hypothesis

Using the mean ratings of happiness and median RT scores for each of the 60 patterns, a bootstrapped mediation analysis was conducted to determine whether the median RT mediates the relationship between RRS and liking rating. Just as with the filtered mean RT in the original analysis, median same RT partially mediates the relationship between RRS and happiness rating, $z = -2.67$, $p = .008$.

Appendix D

Experiment 3 – Reanalysis of Mean RT in the Speeded Recognition Task

Analysis of RT in the Speeded Recognition Task (Mean RT Filtered 150ms – 1100ms)

A single factor within-subjects ANOVA indicated that RT differed significantly as a function of RRS on same trials, $F(3, 177) = 23.18$, $p < .001$. With a more stringent data filtering criteria, the means for RRS 1 (545ms), RRS 2 (563 ms), RRS 4 (567 ms), and RRS 8 (586 ms) patterns were again in the predicted direction. RRS 1 patterns were responded to fastest, RRS 8 patterns were responded to slowest, and RRS 2 and RRS 4 patterns were responded to intermediate of the two extremes. Analysis of all pairwise differences using a Bonferroni correction on mean RTs confirmed that all mean RTs differed, except for the difference in mean RT for RRS 2 and RRS 4 patterns, $\alpha = .05$.