EFFECTS OF GOLDEN SECTIONING ON SEARCH AND DISCRIMINATION IN MONDRIAN-LIKE GRIDS

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Abstract

The 'Golden Section' ('Golden Mean' or 'Ratio') refers to a particular ratio between two independent stimulus parameters, often two indices of size of a visual item, defined by the equation a/b = b/(a + b). For several centuries this ratio has been thought to possess aesthetic appeal. The golden ratio is commonly associated with aesthetics and from the 19th Century the term aesthetic had come to refer to perceptual forms considered pleasing, emotive or beautiful. In this context, some theorists (e.g. Zeising, 1854, 1855; see also Brion, 1960; Livio, 2003) have argued that many popular works of art include golden sectioning in their composition.

These claims lead Gustav-Theodor Fechner to examine the aesthetic properties of simple rectangular Figures. Using the method of choice, in which subjects choose from a number of alternatives the stimulus they prefer, Fechner (1876) found the golden rectangle to be the most preferred (35% of subjects), with 20.6% expressing preference for the 1.5:1 rectangle (the next least elongated), and 20.0% for the 1.77:1 rectangle (the next most elongated). Subsequent attempts to corroborate Fechner's findings paint a less than conclusive picture: on the one hand there are a number of corroborative studies in which subjects preferentially ranked, or otherwise expressed a preference for proportions at/or close to the golden ratio, however, there are also several results suggesting there is no clear or unimodal preference for stimuli that include the golden section (Godkewitsch, 1974; Schiffman, 1969; Davis & Jahnke, 1991; Boselie, 1992; Konečni, 1997).

The present research sought to investigate whether golden sectioning influences perceptual processing, although we were concerned that the mechanisms that may be influenced by golden sectioning might operate early in visual processing with effects that are not directly available for subjective evaluation and report. Accordingly, and while we measured the relative aesthetic preference for displays sectioned with various ratios between their larger and smaller sections we also employed a visual search task recording reaction time (RT) measures.

Method

Participants: Twelve participants (7 female, 5 male, mean age of 25.27 years +/- 3.41 years, all with normal or corrected to normal vision) took part in the study.

Apparatus and Stimuli: Stimuli were generated using E-prime 2.0 PRO (Psychology Software tools Inc.) on a Pentium 4 PC running Windows XP. Stimulus control and presentation were programmed using native E-prime macro scripts with system integrity checked by means of an E-prime refresh clock test which gave a diagnostic classification of 'good' (measurement error +/- 1 ms). Stimuli were presented on a 19" Magic Displays monitor; model CPD-4402 Trinitron with resolution 1024x768 and refresh rate 75 Hz. Responses were recorded using a two key Ergodex® DX1™ Input System.

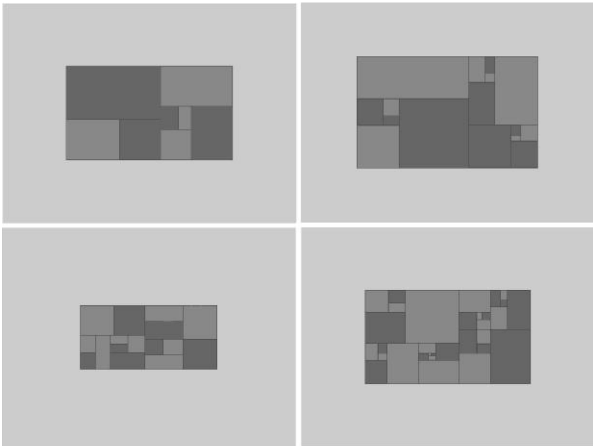

Fig 1: Example grids used in all experiments, from top to bottom, left to right a 4-paired section grid with sections in area ratio 1|0.568, an 8-paired section grid with sections in area ratio 1|0.618 (the golden section), an 8-paired section grid with sections in area ratio 1|0.568 and a 16-paired section grid with sections in area ratio 1|0.668. The participants' task was to respond by button press as rapidly and accurately as possible to the luminance of the smallest section. Grids varied in Grid size with 4, 8 or 16 paired sections and the ratio in area of the sections with ratios of (1|0.468, 1|0.518, 1|0.568, 1|0.618, 1|0.668), where 1|0.618 is the golden section.

Stimuli were rectangular, horizontally oriented Mondrian-like grids with 4-, 8- or 16-paired sections; example grids are shown in Fig. 1. Each grid contained a set of differently sized, paired sections with self-similar dimensions. The ratios of the paired sections examined were 1|0.468, 1|0.518, 1|0.568, 1|0.618*, 1|0.668 (*0.618 is the Golden Ratio, or more precisely the Inverse Golden Ratio, but in this case the two are interchangeable). These ratio intervals and sizes were chosen because they allowed equal increments that would not cause large discontinuities in the appearance of the stimuli across ratios. The grid was overall 0.5 times the area of the screen and centrally placed. The colour of the grid's interior was randomly assigned to one of either of the potential target colours (RGB co-ordinates "192, 192, 192" and "75,75,75"), which correspond to "light gray" and "gray" in VBA/E-Basic designations and with luminance levels of 71 and 120 cd/m^2, respectively. The first sectioning was achieved by multiplying the length along the x-axis to achieve the subdivisions of the relevant ratios. After establishing the first section, the sectioning algorithm then performed the same operation on the smaller area, with the section matching the target ratio being assigned to the smallest of the two areas. This procedure was the same for all ratios in order to establish a consistent layout, and to make sure that the target appears in approximately the same location. The stimuli were rotated such that the target would vary in its location (located equally in the right or left, lower or upper quadrants) more systematically than random allocation would allow. All grids were presented at the center of the monitor screen.

Design and Procedure: The detection experiment used a within subjects design and a 2AFC speeded response task in which participants were asked to respond as rapidly and accurately as possible to the shading (dark – right key, light – left key) of the overall smallest grid section. Each trial started with the presentation of a central fixation cross for 500 milliseconds (ms). The fixation cross was then immediately replaced by the search grid, to which observers responded. Grids remained on screen until a response was recorded. In case of an erroneous response or a time-out (i.e., after a period of 2,500 ms without response), feedback was given by a computer generated tone and an alert was presented for 500 ms at the center of the screen. Each trial was separated from the next by variable intervals of 500 – 1,000 ms. Following a 20-trial practice session participants completed 600 trials in one 15-block session ensuring 40 trials per experimental condition. Grid presentation was fully randomised across all blocks and separately for each participant. The experiment was carried out in a sound proof booth with low ambient lighting with a chin rest used to ensure distance between participants and monitor was kept constant at 55 cm.

In Experiment 2, the aesthetic judgment task used a paired comparisons procedure to investigate whether or not a significant aesthetic preference existed for the golden ratio relative to the other ratios used in Experiment 1. Each stimulus grid employed in Experiment 1 was presented alongside every other grid on 5 separate occasions (presentation orders were fully randomized. There were 40 trials per condition leading to 600 trials overall). Participants were asked to report which grid of the two they thought was the most aesthetic. Aesthetic was here defined in simple terms of which of the two grids the participant preferred. The stimuli, stimulus presentation and experimental conditions were identical to those employed in Experiment 1. The running order of Experiments 1 and 2 were varied such that Experiment 1 was conducted first for 50% of participants.

Results

Experiment 1: Trials with response errors (15% of all trials) were removed from the data prior to subsequent analyses. Error reaction times (RTs) were on the whole slower than correct RTs and an analysis of the probability correct by RT revealed no significant correlation arguing against the correct RT data being contaminated by accuracy-speed trade-offs. Examination of the correct RTs revealed non-normal distribution with pronounced positive skew. A Kolmogorov 'D' test showed the RT distribution to be approximately lognormal and on this basis subsequent analyses were conducted on the anti-logs of the means of the log-transformed RT distributions (for supporting ideas see Box & Cox, 1964, 1982). Fig. 2 presents the correct mean RTs (and their standard errors) as a function of the number of paired grid sections, with separate functions for each ratio.

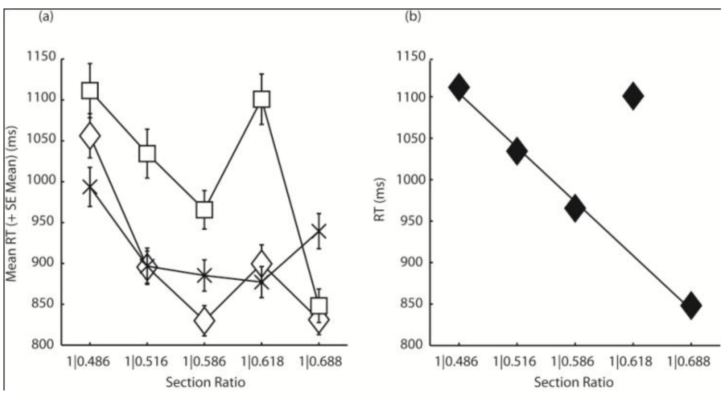

Fig 2: (a) shows mean RTs and their standard errors as a function of ratio for the three grid sizes 4-paired sections (diamonds), 8-paired sections (squares) and 16-pairted sections (stars), respectively. In (b) is shown the regression line of RTs over ration when the golden section is excluded from analysis alongside diamonds signifying the mean RTs for all ratio conditions.

A repeated-measures ANOVA was carried out on the factors Ratio (1|0.468, 1|0.518, 1|0.568, 1|0.618, 1|0.668) and Grid Size (4, 8, 16 paired sections). Mauchly's test for sphericity indicated that the assumptions for sphericity had been violated for the main effect of Ratio and the degrees of freedom were corrected using Greenhouse Geisser estimates for sphericity. There was a significant main effect for Ratio, [$F(2.1, 23.8) = 41.24$, $p < .0001$], and Grid Size, [$F(2, 22) = 16.9$, $p < .0001$] while the interaction was also significant [$F(3, 33.46) = 13.25$, $p < .0001$]. Fig. 2 shows that RTs did not increase linearly as a function of increasing Grid size as might be expected if participants engaged in serial grid search for the target pairing, with the 8-paired section grid producing much slower RTs than either of the other Grid conditions (accounting for the Grid main effect). Fig. 2(a) also indicates the interaction to be complex: RTs decreased overall with increasing Ratio, accounting for the Ratio main effect although this effect was significantly weaker in magnitude for the 16-paired section grids than the other Grid conditions (indicating the denser grids to be relatively unaffected by Ratio). Where these trends appear to differ is in the 8-paired section grid condition, which is characterized by notably slower RTs to golden sectioned grids. As illustrated in Fig. 2(a), the different Grid x Ratio RT means were likely to be explained by different models and as a result, subsequent analyses sought to establish the model that best described the decrease in RT with Ratio for each Grid Size separately. RTs decreased nonlinearly with increasing Ratio for the 4- and 16-paired section grids [logarithmic $r2 = .752$, $F(1,3) = 9.072$, $p = 0.057$ and quadratic $r2 = .964$, $F(2,2) = 26.4$, $p < .05$, respectively]. The 8-paired section grid was explained by a near perfect linear function only following removal of the golden ratio RT ($r2 = .996$, $F(1,3) = 454.8$, $p < .005$), and not on the basis of analysis of the full range of Ratio RTs [linear $r2 = .448$, $F(1,3) = 2.43$, ns, see Fig. 2(b)]. Note that the logarithmic fit of RT over ratio also improved slightly for the 4-paired section grids following removal of the golden ratio RTs, but this failed to improve significance (logarithmic $r2 = 0.862$). Because RTs did not decrease linearly with increasing Grid Size we might conclude that RT variability relates more to discrimination at the target location than it does to search. Following on from this, an interim conclusion is that golden sectioning has an effect on discrimination at the target location that relates to the particular compositional structure of the whole grid.

The RT results indicate the relationship between grid size and ratio is complex with both RT and the rate of reduction in RT influenced by different factors for different grid sizes. However for all grid sizes, RTs were explained by functions with negative slopes. This is with the exception of the 8-paired section grids for which golden sectioning significantly increased RTs contrary to an otherwise near perfect linear reduction in RT over Ratio. Analysis of errors sought to throw light on this pattern. An ANOVA of arcsine transformed error data (with the same main terms as RT data ANOVA) revealed similar effects to those found from analysis of the RT data: there were main effects for both Ratio and Grid Size [$F(2.1, 23.4) = 39.8$, $p < .0001$, Greenhouse Geisser, adjustment; $F(2, 22) = 123.2$, $p < .0001$) and a significant Ratio x Grid Size interaction (F 7.16, 78.8) = 24, $p < .0001$, Huynh-Feldt adjustment]. The 8-paired section grids produced substantially more errors than the other Grid Size conditions, the significance of which was supported by simple main effects analysis (both *p*'s < .0001). The 4- and 16-paired section grids did not result in significantly different patterns of error production. In the 4- and 8-section paired grid condition errors decreased with increasing Ratio, brought about by a decrease in the difficulty to perceptual discriminate the smaller of the smallest two sections in grids with ratios closer to unity. However this effect did not obtain for the 16-paired section grids which also produced the least overall number of errors (another pattern of effects arguing against the use of search strategies for task completion), while the slope of the reduction in the 4-paired section grids was substantially reduced (-.065) relative to that of the 8-paired section grids [-.169, 16-section grid was -.011)]. It seems overall the 8-paired sections grids produced the highest RTs alongside the highest rate of error production, however unlike the RTs the errors for golden ratio conditions were significantly higher than those of neighbouring ratios (all *p*'s < .05) but were non significantly different to errors to 1:0.468 ratio grids, while they were significantly lower in frequency than errors to

1|0.518 ratio grids. Task completion for the 8-paired section grids appears particularly susceptible to errors when ratios are close to unity, and while there is an increase in error rates for golden sectioned grids relative to neighbouring ratios, the patterning in the RT data, particularly the increased golden ratio RTS, seems inconsistent with an explanation related to difficulties in the perceptual discrimination of the smallest section.

Experiment 2: The multiple pairwise comparison data were initially analysed according to the law of comparative judgment (Thurstone, 1927) allowing each grid to be assigned a value (d') on a relative scale of aesthetic judgment. The scaled data were analysed over Ratio using the Kruskal-Wallis one-way ANOVA by ranks. Contrary to the idea that the golden ratio will be ranked as relatively more aesthetic than other Grids, this analysis failed to identify any Ratio as ranking significantly differently to the median ranking [$\chi 2(4, N = 60) = 5.55$, ns.. In spite of variability in individual preferences (that do not necessarily favour golden sectioning, see McManus, 1980), which also apply to compositional preferences (McManus & Weatherby, 1997), only 3 of the 12 participants' preferences were associated with d' values greater than an absolute value of 0.5, while these values tended to be at one or the other extreme of the Ratio range rather than at the golden ratio.

Discussion

In Experiment 2, and similar to many studies, participants showed no particular preference for golden sectioned grids and instead tended to prefer grids at extremes of the range of ratios employed. The effect found in Experiment 1 concerned RTs that were substantially slowed given 8-paired sectioned grids (with a similar trend for 4-paired sectioned grids) relative to an overall decrease in RT with ratio. The pattern of RTs did not correspond with that expected of visual search except in the 16-paired section grids, indicating that it was unlikely that the slowed processing in the less dense grids was related to the mechanisms responsible for serial attentional deployment, and instead related to local processing at the target section location.

The RT effects over grid size tend to suggest that two processes are involved in target discrimination: in the first of these and for the 16-paired section grids, there is a pattern in the RTs characteristic of serial grid search, but no effect of golden sectioning. By contrast, in the 4 and 8-paired section grids perception is drawn to the location of the target with limited, if any, serial target search but with processing prolonged for both grid sizes. Although errors are increased for the 8-paired section grids this is not a function of golden sectioning but a general effect of grid size. It may be due to factors such as discriminating a target as smaller than its paired section. This may be more difficult under 8- relative to the 4-paired section grids simply because in the larger grids there are smaller and harder to discriminate targets than there are in the smaller grids. The possibility that golden sectioning and extended processing may be linked; independent of target-section discriminability might be supported if there were a similar ratio between RTs overall and the residual from the regression equations. However separate examination of both 4- and 8-paired section grid mean RTs finds there is no relation between RTs overall with that of the golden ratio RT means (ratios are approximately 7:1 and 21:1, for 4- and 8-paired section grids respectively). This suggests prolonged processing to golden ratio grids is related to discriminability but this relationship requires further investigation.

While we have demonstrated the effect of golden sectioning on behavior and have provided a description of these effects, a definitive account of golden sectioning remains elusive. One possibility, raised in EEG research carried out by Pletzer et al. (2010) is that at a brain systems level golden sectioning inhibits inter-frequency synchronization. Under circumstances in which two cooperating brain areas were coupled by frequencies in a golden ratio, this might be expected to result in incomplete, unsuccessful or prolonged processing.

This provides an avenue for further enquiry that would be particularly promising if it could be shown that temporal processes linked by means of a golden ratio are directly isomorphic with spatial organizations similarly linked by means of golden sectioning.

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