

Supplementary Information: Turning the periodic table upside down

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Introduction

Scientific aesthetics is one of the oldest fields in psychology, beginning with early work of Fechner ¹. A long-standing goal is to find laws relating objective stimulus properties to subject preferences. Although this is challenging ², several reliable laws have been established nevertheless ³. People tend to prefer symmetrical to asymmetrical patterns ^{4,5}, blue-green colours to brown-yellow colours ⁶, and curved lines to sharp angles ⁷. People also like images with properties resembling natural environments, even when the associations are subtle ^{8,9}.

Our visual preferences are not solely a function of objective image properties, but change over time as things that were original and novel become familiar. Even simple repetition of a neutral stimulus can increase liking. This ‘mere exposure effect’ was most famously documented by Zajonc in 1968 ¹⁰, and since then it has been replicated many times under slightly different conditions ¹¹. There is probably an upper limit to the mere exposure effect, where the over-familiar stimuli eventually become boring ^{11,12}. This may

partly explain the changing dynamics of design and fashion¹³. Several theoretical accounts of visual preference formation are indirectly supported by the mere exposure effect^{14,15}.

We were interested in whether the periodic table is preferred in its conventional, non-inverted or inverted orientation. There are scientific reasons why the inverted periodic table is superior. But are there any aesthetic advantages to turning it upside down? We might expect the non-inverted version with hydrogen at the top to be preferred simply because it is familiar. However, this could be offset by other factors: It may look more symmetrical or life-like in the inverted orientation, or the non-inverted orientation might now be over-familiar for many.

Figure 1 shows the full range of periodic tables we presented. All letters and numbers were removed. On each trial, participants observed one periodic table for 3 seconds, before entering their judgments on a 0-100-point scale. We hypothesised that participants would report (i) increased liking (ii) increased level of symmetry and (iii) increased association with living creatures for the inverted periodic tables. We had no directional hypotheses for the mirror versions, which were included to increase variability and to mask the purpose of the study. We also manipulated the aspect ratio and individuation of the element panels to further increase variability in our stimulus set.

As well as measuring preferences, we also used an eye tracker to examine how people explored periodic table with their eyes. Although the image projected onto the retina spans around 170 degrees, visual acuity is far higher in a central region (of just 3-5 degrees). This visual hotspot is called the 'fovea', and people typically move their eyes several times per second to bring objects of interest onto the fovea. The eyes scan static images with purposeful sequence of saccades (sudden jumps in eye position) and fixations (when the eyes are still). Fixations tell us about a person's current attention and interest¹⁶,

and are influenced by the task that the person is trying to perform¹⁷. It could be that non-inverted and inverted periodic tables are scanned in different ways, as people fixate the salient regions. Familiar images might also elicit a familiar sequence of eye movements, and this 'oculomotor fluency' could contribute to preference itself¹⁸.

Methods

Participants

Twenty-four participants were recruited (19 female; 23 right-handed; mean age 21.96 years, SD = 3.8 years). The study had University of Manchester research ethics committee approval. Participants gave written, informed consent and were compensated with course credit or expenses. All participants were involved in higher education. 15/24 were undergraduates, 2/24 were Masters students, 5 were PhD students and 2 were Post docs. All were studying Psychology or related topics at the University of Manchester, except 1 management undergraduate and 1 business and management undergraduate.

Materials

Sixteen images of the periodic table were used as stimuli (Figure 1). These were generated using either square or portrait-shaped panels for each element. Panels were either rendered as a silhouette or with the individual panels visible (rows in Figure 1). Each of these 4 variants was presented in 4 different orientations (columns in Figure 1). All periodic tables were turquoise, with a white background. The stimuli were presented and responses recorded using PsychoPy (Peirce, 2007).

Participants sat approximately 75 cm away from a 53 X 30 cm LCD screen with a refresh rate of 60Hz. Participants were free to move their heads. The white background

square was 24.5 X 24.5 cm (approximately 18.6 X 18.6 degrees of visual angle at 75cm viewing distance). The remainder of the screen was grey. The periodic tables were around 21 cm along the longest dimension (approximately 15.9 degrees).

Eye movements were recorded from a single eye using an EyeLink 1000Plus eye tracker, calibrated using a standard 9-point calibration sequence. Eye data was recorded for 4 seconds on each trial (-1 to + 3 seconds around pattern onset).

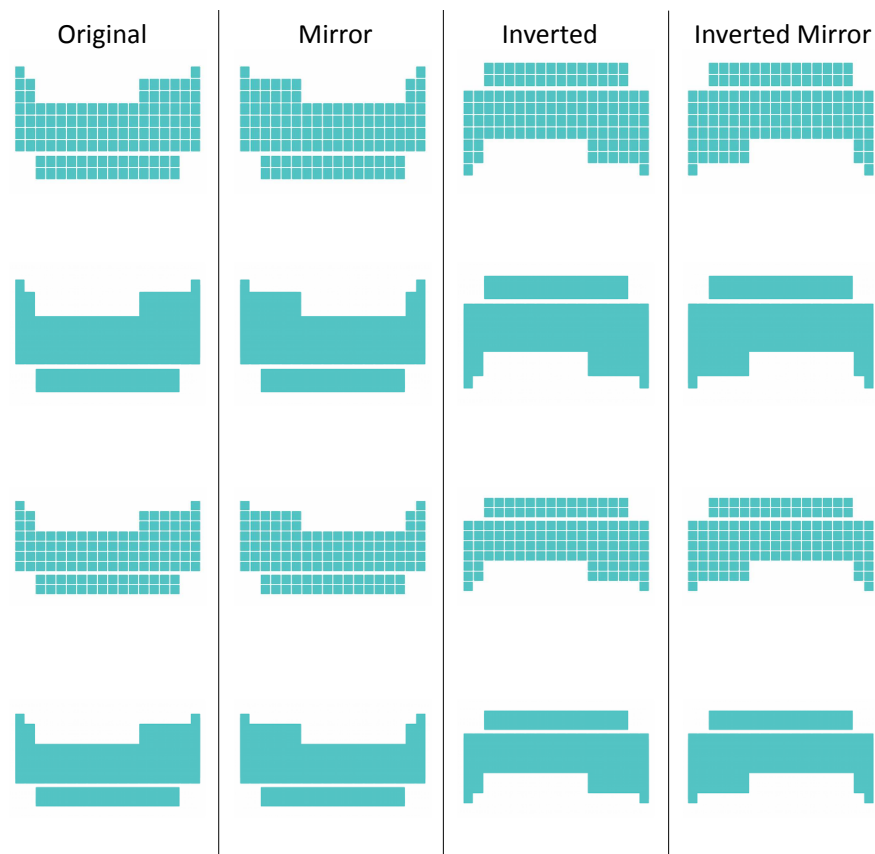


Figure 1. The range of stimuli presented. Each orientation was presented in two aspect ratios (portrait and square) and with and without individuation of the elements.

Procedure

The experiment consisted of three tasks. In each task, participants were given an attribute to rate, *symmetry, preference or life-likeness*. Each trial began with a 1 second central fixation cross. Each stimulus was then presented for 3 seconds, followed by a rating screen with a slider which allowed participants to select a value from 0 to 100 using the mouse. In each task, participants rated each of the 16 stimuli twice (giving 96 trials in total). This was a within participants experiment, with participants completing all conditions and tasks. The tasks were presented in a counterbalanced order and between each task there was an opportunity for a short break and the recalibration of the eye tracker.

At the end of the session, participants were asked if any of the shapes had reminded them of a living creature and if so, they were asked for more details. They were also asked if the shapes had reminded them of anything else. They were also asked about their educational training in science and art.

Analysis

We analysed symmetry, preference and lifelike ratings with separate 2X2 repeated measures ANOVA [Vertical orientation (Non-inverted, Inverted) X Horizontal Orientation (Non-mirrored, Mirror)] using SPSS Version 22. We collapsed over Aspect Ratio (Squares, Rectangles) and Element definition (Silhouette, Tiles) because these factors had limited and mostly non-significant effects in preliminary analysis. None of the ratings data violated the assumption of normality according to the Kolmogorov-Smirnov test ($p > 0.064$). The Greenhouse-Geisser correction factor was applied when the assumption of sphericity was violated (Mauchly's W , $p < 0.05$). All statistical tests were two-tailed.

The eye data was processed in Dataviewer (version 2.3.0; SR Research), using the standard procedure for extracting fixations (with no minimum duration specified). Fixation heatmaps were generated in Dataviewer using a Gaussian function based on fixation duration and the lowest 10% of fixations were omitted from the plot (SR Research, 2002-2015). Interest areas were generated using the drawing tools in DataViewer. Statistical tests were conducted in SPSS. Two upper-lower difference score variables violated the assumption of normality according to the Kolmogorov-Smirnov test, but the removal of one outlying participant (number 21) meant that no variable violated normality ($p > 0.065$). The Greenhouse-Geisser correction factor was applied when the assumption of sphericity was violated (Mauchly's W , $p < 0.05$) and all statistical tests were two-tailed. The graphs in Figures 2 and 5C were created using RStudio and code for creating raincloud plots¹⁸. The scripts used to run the experiment during the current study, the stimuli and data generated are available in the OSF repository:

https://osf.io/wzak8/?view_only=7240a7cdcc3746c2a20a078fe5d08821.

Results

Only 6/24 participants recognized the periodic table. The non-inverted periodic tables (with hydrogen at the top) were often associated with beds (7/24 participants). The inverted periodic tables were often associated with four-legged animals (9/24), jelly fish, desks or diagrammatic hairstyles (3/24). Associations were not strongly influenced by horizontal orientation.

Ratings

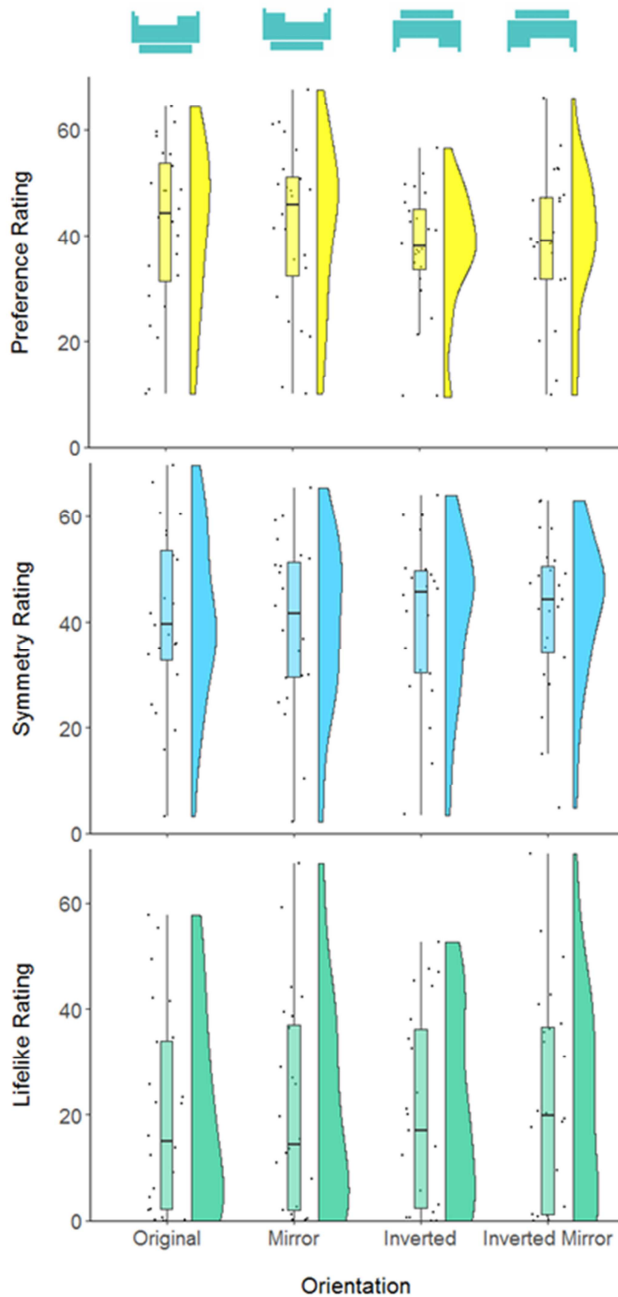


Figure 2 Vertical raincloud plots showing the individual data points, box plots (median and interquartile range) and density of the ratings for original, mirror, inverted and inverted mirror tables. Panels show preference ratings (top), symmetry ratings (middle) and lifelike ratings (bottom). The scale was 0-100.

Preference ratings are shown in Figure 2A. Contrary to our predictions, participants preferred periodic tables in the typical, non-inverted orientations (Main effect of vertical

Orientation $F(1,23) = 5.365$, $p = .030$, partial $\eta^2 = 0.189$). Mixed ANOVA analysis confirmed that this effect was NOT driven by the sub-group of 6 participants who consciously recognized the periodic table ($F(1,22) < 1$). Our opportunity sample included 19/24 females. The main effect of vertical orientation did not interact with gender ($F(1,22) = 2.973$, $p = 0.099$), and was significant in the large female subgroup ($F(1,18) = 7.963$, $p = 0.011$, partial $\eta^2 = 0.307$). Planned pairwise comparisons showed that the preference for the original over inverted orientation was significant ($t(23) = 2.795$, $p = .010$). This effect was found in 16/24 participants ($p = 0.020$, Wilcoxon Test). There were no other effects or interactions ($F(1,23) < 2.661$, $p > .118$).

Symmetry ratings are shown in Figure 2B. There was a trend for participants to rate inverted periodic tables as more symmetrical, however this effect was non-significant ($F(1,23) = 4.136$, $p = .054$, partial $\eta^2 = 0.152$). There were no other main effects or interactions ($F(1,23) < 1$). Lifelike ratings are shown in 2C. Participants tended to give low ratings here compared to the other dimensions. There were no significant main effects or interactions ($F(1,23) < 1$).

Eye Data

The pattern of fixations was first examined by generating heat-maps for each of the four orientations, for each aspect ratio (averaged across tiled versus silhouette, Figures 3 and 4). As is typical for most visual images, participants began fixating centrally for all stimulus orientations. However, the heat-maps showed that but their later fixations were clearly influenced by inversion. In the upright, non-inverted conditions, the eyes are drawn upwards and outwards (towards the left and right appendages). In the inverted conditions, the eyes tended to be drawn downwards and outwards (to a lesser extent).

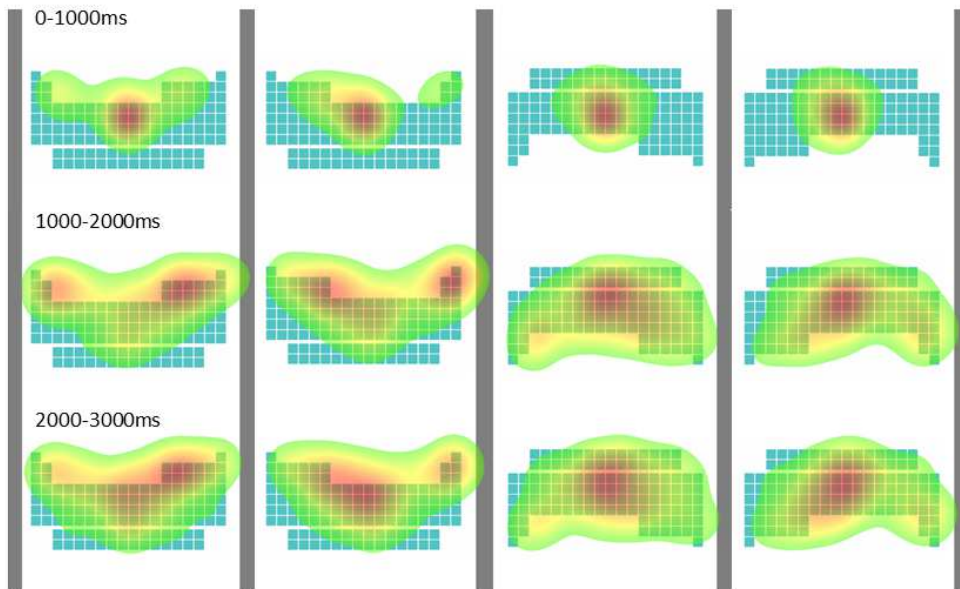


Figure 3. Heat-maps (based on duration) for the square aspect ratio split into 1000ms epochs for the 4 stimulus orientations, collapsed across task. Red indicates the maximum duration, where people fixated longest, and green the minimum duration (with the lowest 10% omitted).

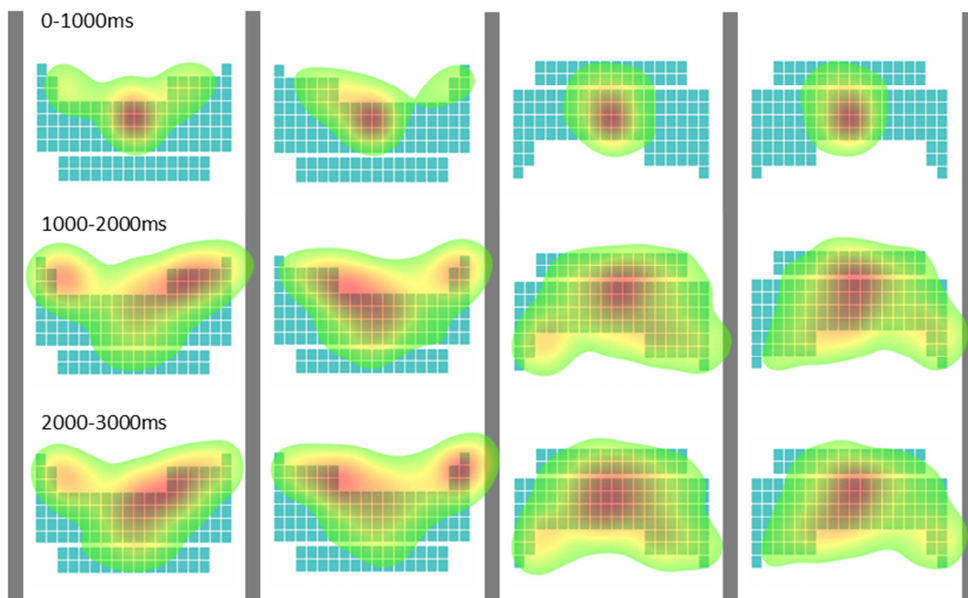


Figure 4. Heat-maps (based on duration) for the portrait aspect ratio, split into 1000ms epochs for the 4 stimulus orientations, collapsed across task. Red indicates the maximum duration and green the minimum duration (with the lowest 10% omitted).

Since there was a consistent pattern across the two aspect ratios, we collapsed across this factor and explored these fixation patterns numerically by dividing the stimulus into 6 equally sized regions of interest (Figure 5A). The percentage of the 3 second viewing time spend in each area was extracted (Figure 5B). We can again see more fixations in the upper left and upper right segments in the non-inverted orientations (green and purple) but more fixations in the lower left and lower right in the inverted conditions (red and dark blue). The pattern is similar across tasks, but the bias for the lower corners for inverted tables was accentuated during the symmetry task.

These impressions were confirmed statistically through analysing participant's upper - lower difference scores $[(\text{Upper left} + \text{Upper right}) - (\text{Lower left} + \text{Lower right})]$. The difference scores are shown in Figure 5C. These were analysed with repeated measures ANOVA [Task (Preference, Symmetry, Life-like) x Vertical orientation (Non-inverted, Inverted) X Horizontal Orientation (Non-mirror, Mirrored)]. There were significant main effects of Vertical orientation, Horizontal orientation and Task (smallest effect $F(1,22) = 7.875, p = .010, \text{partial } \eta^2 = .229$). There were significant interactions of Vertical orientation X Horizontal orientation, Task X Vertical orientation, and Vertical orientation X Horizontal orientation X Task (smallest effect $F(1.852, 40.752) = 4.459, p = .02, \text{partial } \eta^2 = .165$). The interactions partly reflect a stronger upper bias in the non-mirrored than mirrored orientations ($t(22) = 5.119, p < .0005$) and a stronger lower bias for inverted tables in the symmetry task than the other tasks (smallest effect, $t(22) = 2.112, p = .046$).

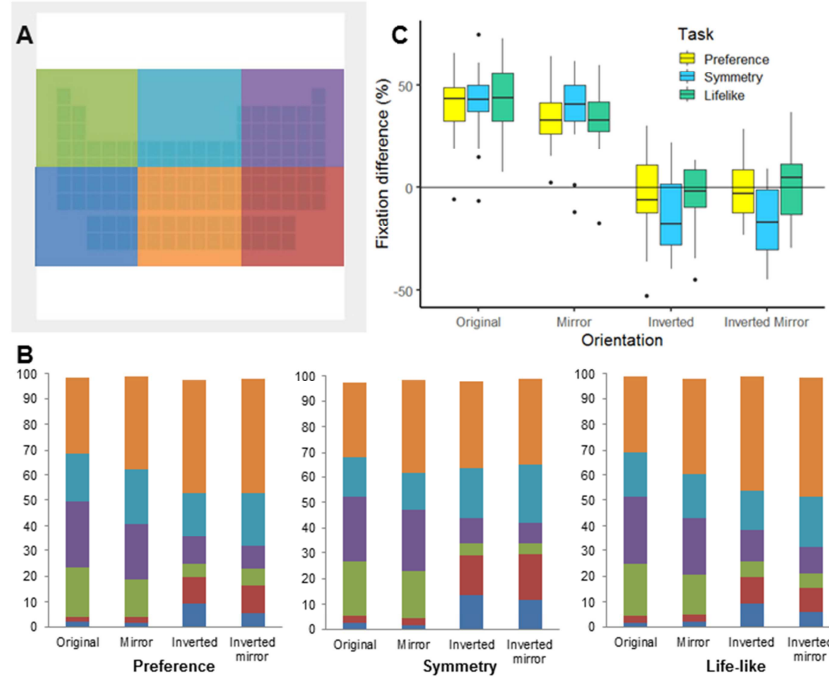


Figure 5. A) The areas of interest for fixation analysis on the screen. **B)** The percentage of total time (3000ms) spent fixating each of the 6 areas of interest in the three different tasks. **C** Boxplots (median and interquartile range) of preference for upper versus lower corners of the stimulus onscreen (% difference) across tasks and stimulus orientation. A positive value reflects more fixation time in the upper corners of the stimulus onscreen. The whiskers indicate 1.5 x IQR, the black dots are outlying participants.

Discussion

Our participants mostly preferred the periodic table in the non-inverted orientations. Although people often like abstract symmetry^{4,5}, this cannot be the explanation for this preference, because if anything the periodic table looked marginally more symmetrical when it was upside down (although this was non-significant). Instead, the preference for the non-inverted tables is consistent with the mere exposure effect – people often like things simply because they have seen them before^{10,11}. Even though only 25% of our participants recognized the stimuli as a period table, the mere exposure effect is sometimes

independent of conscious recollection and can persist over a long time¹¹. Indeed, the form of the periodic table is relatively widespread in popular culture, as well as in educational settings (e.g. <https://www.notonthehighstreet.com/g/periodic-table-gifts>). We also note that a significant preference for original tables over inverted mirror was also seen in a pilot experiment with another 24 participants, only one of whom recognised the periodic table. This increases confidence that our findings are robust. However, the preference for the non-inverted was not strong, and could probably be reversed though exposure to the new inverted version.

It is common to describe the mere exposure effect as if vision were a passive process (the very same 2D images hits the eye repeatedly, and visual areas of the brain get used to it). However, our eye movement analysis highlights important point about visual experience. The 2D image on the screen is not processed passively. People move their eyes in a purposeful way, and consequently the retinal image keeps changing. In the non-inverted orientation, people's eyes were drawn upwards and outwards to appendages of the table (corresponding to the lighter elements). In the inverted forms, they were drawn to these same appendages, which were now positioned in the lower left and right corners (although this bias for the lower positions was not as strong). Therefore, as well as being familiar with the initial 2D image of the non-inverted orientation, people might also be familiar with a predictable sequence of eye movements and changing images that follow. Indeed, previous research has shown that repetition of extended sequences of saccades can illicit positive attitudes to the moving stimuli¹⁸.

While up-down inversions are unmistakable, left-right mirror reversals are often go unnoticed, even though they may subtly reduce aesthetic appeal of films²⁰. We found no reduction in preference for the mirror-reversed periodic tables. However, oculomotor

behaviour *was* significantly altered by mirror reversal: there was a small reduction in the bias towards the upper corners in the mirror conditions.

If mere exposure causes preference for non-inverted tables, why would it not equally cause preference for non-mirrored tables? Again, we note that while inversion and mirroring are equivalent transformations in an objective sense, inversion is much more obvious to human observers (Ernst Mach ²¹ was one of the first scientists to consider the significance of such discrepancies). It is likely that object codes are fundamentally linked to vertical orientation, but relatively independent of horizontal orientation (explaining why the letters b and d are much more easily muddled than b and p ²²). We would thus expect any familiarity-based preferences to be more profoundly disrupted by inversion.

It should also be noted that although oculomotor behaviour was similar across tasks, fixation of the lower corners for inverted patterns was increased in the symmetry task. This could be because asymmetrical appendages were particularly relevant to estimating symmetry (so participants spent more time fixating them, whether they were at the top or bottom of the image). Exploration of the table would undoubtedly be different in Chemistry experts, using it to perform different tasks. Moreover, the conceptual elegance of the periodic table may confer an additional aesthetic element (“cognitive art”) ²³.

In conclusion, people have a slight preference for the non-inverted periodic tables, even though they do not always recognize them as a periodic tables. This may be because of previous exposures which are not always consciously recalled. Oculomotor behaviour was dramatically altered by the inversion. It could be the familiar sequence of images and eye movements that caused people to prefer the non-inverted orientations. However, the preference for the non-inverted versions was not strong, and may easily be reversed if the inverted table were to be more frequently encountered.

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