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Is there an Artistry to Lighting? The Complexity of Illuminating Three-dimensional Artworks

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### Abstract

Painters tend to depict a leftward light source more often in works of art (Mamassian, 2008) and even non-artists will light a painting from the left (McDine, Livingston, Thomas, & Elias, 2011). This bias does not appear to persist across mediums, however, as Sedgewick, Weiers, Stewart, and Elias (2015) found a slight rightward lighting bias when non-artists illuminated three-dimensional (3D) sculptures. Given the unexpected finding from 3D stimuli and considering that the majority of aesthetics research uses stimuli which are two-dimensional (2D), we thought it prudent to attempt a replication of Sedgewick et al.'s findings with a simplified version of the sculpture lighting task. We also used the greyscales task, recruited a group of bilingual native right-to-left (RTL) readers, and made additional comparisons with professionally lit sculptures in native left-to-right (LTR) and RTL reading regions of the world. We found a left lighting bias among LTR professionals and an opposite right lighting bias among RTL professionals. LTR and RTL non-artists both showed no bias for lighting and a leftward bias on the greyscales task. However, both professionals in galleries and non-artists in the lab demonstrate congruency between posing and lighting directions. The attenuation of the leftward lighting bias, which is normally observed, may be related to the complexity of illuminating a sculpture. Illuminating more complex stimuli appears to extinguish the bias in non-artists, whereas the leftward lighting bias persists for more rudimentary stimuli from artists and non-artists alike.

*Keywords:* pseudoneglect; posing bias; sculpture; aesthetics; native reading direction

### Is there an Artistry to Lighting? The Complexity of Illuminating Three-dimensional Artworks

The aesthetic experience and evaluation of a piece of art is complex, influenced by the interplay of emotions, knowledge, and perception (Chatterjee & Vartanian, 2014). Elements such as composition, grouping, colour, and lighting are perceived both independently and in combination with each other, helping to form aesthetic preferences. Vision scientists are particularly interested in the artistic element of value, the contrast between light and shadow, which is critical in determining the *where* and *what* of the light source, which helps resolve ambiguities of object *shape* and *colour*, respectively (Mamassian, 2008).

It is no surprise that the human visual system makes the assumption that light comes from above (Ramachandran, 1988). Somewhat surprisingly, the human visual system also makes the assumption that light comes from above and to the left (Sun & Perona, 1998). Our experience in the world, with natural or artificial light routinely coming from a single overhead source, is thought to guide the light-from-above assumption. Kleffner and Ramachandran (1992) and Ramachandran (1988) discovered that when ambiguously shaded two-dimensional (2D) stimuli were illuminated from above a layer of dimensionality was added, such that a circle then appeared as a sphere. However, shifting the light source ninety degrees, illuminating the circle laterally, the perception of three-dimensions (3D) disappeared. Studies using various other simple stimuli report consistent results, suggesting that these biases may be rooted in neural organization (Mamassian & Goutcher, 2001; Mamassian, Jentzsch, Bacon, & Schweinberger, 2003).

The above-left lighting preference does not appear to have an intuitive explanation, but researchers have gained insight through the use of simple 2D stimuli and real-world investigations. Target detection tasks using arrays of shaded spheres reveal that above-left lighting facilitates quicker target finding than lighting from other orientations (McManus, Buckman, & Woolley, 2004; Sun & Perona, 1998); this lateral lighting bias also translates to individually-presented shaded spheres (Elias & Robinson, 2005). Whereas the light-from-above bias may have been born out of necessity, it could be that humans have higher perceptual value for above-left lighting. Archival investigations by Mamassian (2008), McManus (1979), and Sun and Perona (1998) all report a bias by painters across time periods and artistic styles to place the light in the upper left, indicating the importance of examining more complex, real-world, images. Findings from studies examining the contemporary medium of advertisements support the robustness of the above-left lighting bias. Thomas, Burkitt, Patrick, and Elias (2008) found full-page magazine ads were more likely to be lit from the upper left. Further, left lit advertisements were also found to be more effective at influencing future purchase intentions and preferences than right lit advertisements (Hutchison, Thomas, & Elias, 2011).

With these investigations in mind, questions arise about the intentionality behind lighting biases. Is this bias produced by artists? Do artists possess an innate ability to hold, arrange, and manipulate aesthetic elements in a unique way? Or, is the leftward lighting bias a product of selection by the masses? Has the higher perceptual value of left lit paintings lead to their proliferation? Does the higher perceptual value of left lit versions of advertisements result in those being what is mostly viewed the public? There are indications that the higher perceptual value of leftward lighting is not exclusive to artists and the artistically trained. McDine, Livingston, Thomas, and Elias (2011) report that non-artists will more often choose to place the

light in the upper left of artworks when given control over lighting images of abstract paintings.

The argument that a common network of structures within the brain are at the core of the leftward lighting bias is supported by the coherence of results from assumptions about luminance made by the visual system with basic stimuli, lighting preferences of non-artists in the laboratory, and examining artists in the real-world.

Sedgewick, Weiers, Stewart, and Elias (2015) implemented a paradigm where participants were given control of artwork lighting, similar to that of McDine et al. (2011). As much of aesthetics research examines 2D artistic media, Sedgewick et al. used 3D sculptures to investigate lighting biases outside of two-dimensions. Sedgewick et al. report that the move from 2D to 3D stimuli results in a rightward lighting bias and no interaction between lighting direction and posing direction, two atypical findings. As previously outlined, artwork lighting is consistently biased to the left. Further to this, lighting has been found to interact with posing direction. A bias to present the left cheek, known as the leftward posing bias, has been identified in archival examinations of 2D images like portrait painting (McManus & Humphrey, 1973) and photography (Labar, 1973). Grüsser, Selke, and Zynda (1988) and Thomas et al. (2008) examined posing direction in conjunction with lighting direction in portraits and advertisements, respectively. Findings from the two studies were consistent in reporting a congruency between the direction of lighting and the direction of the pose. In an effort to complement aesthetic detail and not over-expose the sculpture, a rightward lighting bias may have emerged, as Sedgewick et al. (2015) propose that lighting from the left may have appeared more intense on 3D sculptures. This rationale comes from a study by McCourt, Blakeslee, and Padmanabhan (2013) where the theory of subjective lighting equality is posited. McCourt et al. reported perceptual lighting

inequalities of more basic 3D stimuli, as 3D cube arrays were perceived as significantly more intensely illuminated when lit from the left.

Atypical lighting biases have also been reported from participants with a native reading direction (NRD) other than left-to-right (LTR), with right-to-left (RTL) NRD participants showing attenuated leftward biases on tasks of both perception and action. RTL participants tend to display a stable trend of preferences significantly different from LTR individuals, however mean scores indicating rightward lighting preferences are typically small and non-significant. This has been demonstrated when forced to indicate a preference between mirror-reversed images, left lit and right lit versions, either presented at the same time one on top of the other (Smith & Elias, 2013) or when rating images one at a time (Smith & Elias, 2018). Additionally, in a study replicating and extending McDine et al.'s (2011) study, Smith, Duerksen, Gutwin, and Elias (2018, *under review*) found that average light placements of RTL participants illuminating paintings were slightly right of centre, significantly rightward of LTR participants' placements but not a significant rightward bias.

RTL participants, like LTR individuals, demonstrate coherence between aesthetic lighting preferences and biases on more rudimentary illumination tasks. Measuring the assumed light source illuminating a group of hexagons Andrews, Aisenberg, D'Avossa, and Sapir (2013) report that both English (LTR) and Hebrew (RTL) participants display a leftward bias. However, a similar pattern of results to the aforementioned aesthetics studies is observed as the bias of Hebrew participants is significantly rightward of English participants. Using simple shaded spheres in a target finding array, similar to that of McManus et al. (2004), Smith, Szelest, Friedrich, and Elias (2015) found that the LTR group identified targets quicker when lighting

was from the upper left, while the RTL group found targets faster than the LTR group under upper right lighting.

The pattern of leftward bias attenuation by RTL participants seen on basic illumination and aesthetics tasks has also been observed on basic spatial attention tasks like line bisection, star cancellation (Rinaldi, Di Luca, Henik, & Girelli, 2014), and greyscales (Friedrich & Elias, 2014; Smith & Elias, 2018). Leftward biases typically observed on these tasks have been explained by *pseudoneglect* (Bowers & Heilman, 1980). Pseudoneglect is the leftward spatial bias common to all humans, driven by specialization of the parietal lobe of the right hemisphere for spatial processing. Rinaldi et al. (2014) have proposed the *Interactive Account of visuospatial asymmetries* that posits the degree of pseudoneglect depends on the interaction of cultural factors (NRD: from monolingual LTR, to bilingual, to monolingual RTL) and biological factors (right hemisphere specialization for visuospatial processing). Smith and Elias (2018) suggest that illumination is foundational to aesthetic preference and hypothesize that leftward biases observed on basic illumination tasks (falling under the umbrella of pseudoneglect) and aesthetics tasks are related. To complement the Interactive Account, Smith and Elias (2018) conceived the *attenuation increases with complexity theory*, which suggests pseudoneglect (importantly, including judgements of illumination) is on a shared spectrum with aesthetic biases. While the strength of the leftward bias depends on the interaction of culture and biology, it is further contingent on task complexity. Higher task complexity appears to attenuate pseudoneglect, and move biases rightward, regardless of NRD. The nature of the task seems to dictate the degree of leftward attenuation, with NRD dictating baseline biases, as starting points for RTL individuals are typically rightward of LTR individuals.

The attenuation increases with complexity theory offers an alternate explanation for Sedgewick et al.'s (2015) results with 3D sculptures. For the following reasons it could be argued that Sedgewick et al.'s task was of *high* complexity: i) at the most basic level, aesthetics tasks are more complex than basic spatial or simple illumination tasks; ii) within aesthetics tasks, lighting a sculpture in a pleasing way is more complex than illuminating 2D stimuli; iii) with several lights to toggle and the ability to move around sculptures, Sedgewick et al.'s experimental design was realistic but also added significant complexity (compared to other artwork lighting paradigms, e.g. McDine et al., 2011). The current study considered these points and implemented a simplified experimental design. In an attempt to test the theory behind the Interactive Account and the attenuation increases with complexity theory, bilingual RTL participants were recruited in addition to LTR participants to complete the sculpture lighting task. The same sculpture stimuli used by Sedgewick et al. (2015) were employed in the current study, however they were depicted in a greyscale format on a black background, and light came from only a single source and was simply manipulated by clicking and dragging the computer mouse. Lighting intensity was held constant throughout so that the only manipulation was the location of illumination. Following the sculpture lighting task, participants completed the greyscales task as a measure of perceptual asymmetries (Nicholls, Bradshaw, & Mattingley, 1999). A content analysis examining sculpture lighting in galleries in predominately LTR and RTL regions was also conducted.

We outline three hypotheses: 1) From the content analysis, lighting biases in LTR and RTL regions are predicted to diverge, with sculpture lighting biased leftward in LTR region galleries and either show no significant bias or a rightward bias in RTL region galleries. 2) Light placements of the LTR group compared with those of the bilingual RTL group in the laboratory

may not result in significant differences between groups, however, the LTR group is predicted to show a bias leftward of the RTL group. 3) On the greyscales task both groups are predicted to show leftward biases; however, the magnitude of the bias for the LTR group should be greater than the RTL group.

## Method

### Sculpture Content Analysis

**Images.** Of 1930 images of sculptures, only images with a clear light source were coded and included for analysis. This resulted in the exclusion of 241 images for a final sample of 1689 images. Images were collected and scored by JRS and LJE from online archives of twenty-two galleries from either LTR or RTL regions. Table 1 outlines which gallery archives were used.

LTR Galleries	RTL Galleries	
<b>Museum of Modern Art</b> New York, USA	<b>Israel Museum</b> Jerusalem, IL	<b>Safarkhan Art Gallery</b> Cairo, Egypt
<b>Metropolitan Museum of Art</b> New York, USA	<b>Mayanot Gallery</b> Jerusalem, IL	<b>Karim Francis Gallery</b> Cairo, Egypt
<b>Los Angeles County Museum of Modern Art</b> Los Angeles, USA	<b>Jewish Quarter Reconstruction*</b> Jerusalem, IL	<b>Adam Henein</b> Cairo, Egypt
<b>Art Institute of Chicago</b> Chicago, USA	<b>Tel Aviv Museum of Art</b> Tel Aviv, IL	<b>Picasso Art Gallery Egypt</b> Cairo, Egypt
<b>Museum of Fine Arts Boston</b> Boston, USA	<b>Musa Eretz Israel Museum</b> Tel Aviv, IL	<b>Zamalek Art Gallery</b> Cairo, Egypt
<b>Montreal Museum of Fine Arts</b> Montreal, CA	<b>The Negev Museum of Art</b> Negev, IL	<b>Almasar Gallery</b> Cairo, Egypt
	<b>Design Museum Holon</b> Holon, IL	<b>The Grand Egyptian Museum</b> Giza, Egypt
	<b>Mishkan Museum of Art</b> Ein Harod, IL	<b>ATHR</b> Jeddah, Saudi Arabia

*Table 1.* Sculpture image gallery locations. \*The Company for the Reconstruction and

Development of the Jewish Quarter in the Old City of Jerusalem LTD.

**Coding and scoring.** Of the 1689 final images, 900 were from LTR galleries and 789 were from RTL galleries. These final images were coded for pose and lighting direction. From

LTR galleries there were 317 images with a central pose, 261 with a left pose, and 322 with a right pose and 174 images with central lighting, 400 with leftward lighting, and 326 with rightward lighting. From the RTL galleries there were 271 centre posed images, 239 left posed images, and 279 right posed images and 85 images with central lighting, 316 with leftward lighting, and 388 with rightward lighting. The pose of the sculpture and lighting direction in the image were scored by assigning  $+1$  for rightward,  $-1$  for leftward, and  $0$  for central. Averages were calculated for each region, resulting in an overall negative score indicating a leftward lighting bias and an overall positive score indicating a rightward lighting bias.

### **Sculpture Lighting Paradigm**

**Participants.** Forty-nine participants with a mean age of 20.3 years ( $SD = 2.9$ ) reported having a LTR direction native language. Eight participants were left-handed, 42 were female, and all were undergraduate students recruited through the University of Saskatchewan Psychology Participant Pool, receiving course credit as remuneration.

Thirty participants with a mean age of 29.2 years ( $SD = 5.8$ ) reported a RTL direction native language. Two participants were left-handed, 17 were female, and were either an undergraduate or graduate student recruited through posters on campus or digitally on the university website, receiving \$10 as remuneration.

Native language was determined through self-report using a pen and paper demographic questionnaire which also addressed sex, age, visual or auditory impairments, handedness, and footedness (Elias, Bryden, & Bulman-Fleming, 1998). Farsi was the most common RTL native language at 20 participants, with 6 Arabic, and 4 Urdu participants following. The majority of RTL participants indicated that their native language remained their current primary language with only 7 participants disclosing that English was now their primary language. RTL

participants reported an average time speaking a LTR language of 13.4 years with an average time spent in a primarily LTR culture of 5.4 years.

**Equipment.** Computer programs were presented using a Windows 10 PC with 8 GB of ram and a 3.3 GHz Intel Core i5 processor mated to a 1920 x 1080 pixel display with 32-bit RGB colour, 60 Hz refresh rate, and powered by an NVIDIA GeForce GTX 750 Ti graphics card.

**Procedure.** Ethics approval for this research was granted by the University of Saskatchewan Behavioural Research Ethics Board (Beh-REB #15-31). Participants were seated at a desk for the computer-based tasks after giving informed consent and completing a pen and paper demographic questionnaire addressing sex, age, visual or auditory impairments, handedness, footedness, and NRD (Elias, Bryden, & Bulman-Fleming, 1998). There were no windows in the room and the overhead lights were turned off. Participants first completed the sculpture lighting task followed by the greyscales task. The sculpture lighting task consisted of twenty-two original sculpture orientations and twenty-two mirror-reversed orientations for a total of forty-four trials to balance for posing direction (10 central posed, 17 left posed, 17 right posed). Sculptures were depicted in greyscale on a black background. Five practice trials preceded the test trials and a centrally located fixation cross was presented for 1000 msec. prior to each sculpture. Aural instructions were given to the participant to click and drag the computer mouse around the sculpture and place the light in the location that made the sculpture most aesthetically pleasing to them. Lighting intensity was held constant throughout so that the only manipulation available to participants was the location of the unidirectional light source. The light placement decision was finalized by pressing the return key on the computer keyboard. There were no time constraints, but participants were encouraged to make their decision in a timely manner.

**Coding and scoring.** Final light placement in each trial was coded as left or right, and the pose of the sculpture was coded as centre, left, or right. The pose of the sculpture and final decision about light placement were scored by assigning  $+1$  for rightward,  $-1$  for leftward, and  $0$  for central. Averages were calculated for participants in each NRD group, resulting in an overall negative score indicating a leftward lighting bias and an overall positive score indicating a rightward lighting bias. The time taken to make the final decision about light placement was also recorded as *response time*.

**Greyscales task.** Participants viewed ninety-six pairs of equivalent but not identical greyscales, presented one on top of the other. A greyscale is a rectangular bar, referred to as a luminance gradient, that is black and white at the extremes. The length of the greyscales and amounts of black and white pixels varied between trials. A visual example is provided in Nicholls et al. (1999). Participants were instructed to choose the overall darker rectangle as quickly as possible, while remaining accurate, by pressing the *t* or *b* keys for the top or bottom rectangle. Left and right finger placement was counterbalanced between participants. Stimuli were presented for a maximum of 5000 msec. and were separated by a central fixation cross remaining for 1000 msec. Lateral bias scores on the greyscales task were computed by subtracting the number of times the darker on the left rectangle was chosen from the number of times the darker on the right rectangle was chosen, resulting in a negative score for more leftward choices and a positive score for more rightward choices.

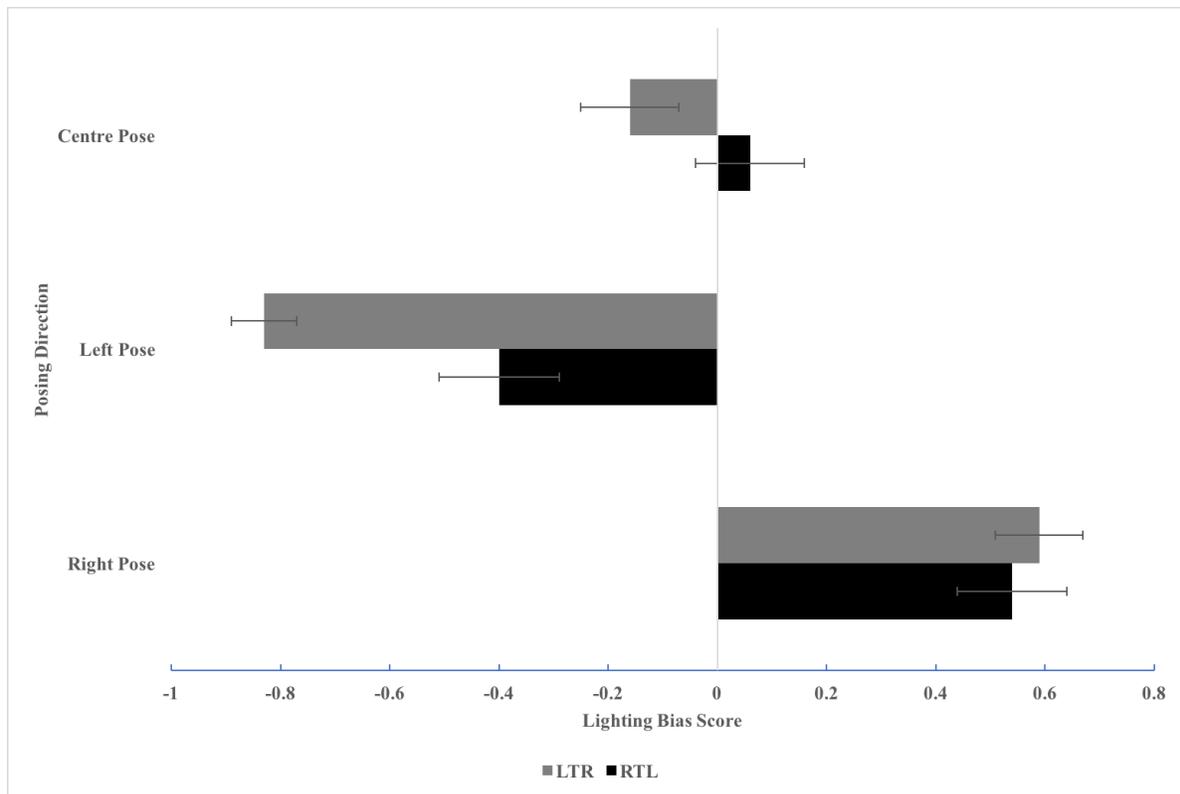
Completion of both tasks typically did not take longer than thirty minutes. After finishing both tasks participants were given a debriefing form and a brief explanation of the aims of the experiments.

## Results

### Sculpture Content Analysis

One-sample  $t$ -tests against a midpoint of zero were used to determine if lighting was biased in a certain direction when applied to sculptures. In LTR galleries, leftward lighting was used significantly more,  $t(899) = -2.76, p = 0.006$ , whereas in RTL galleries an opposite rightward lighting bias was found,  $t(788) = 2.73, p = 0.007$ . As the Levene's test for equality of variances was violated a  $t$ -statistic not assuming homogeneity found the difference in lighting biases between galleries in LTR and RTL regions to be significantly different from each other,  $t(1633.19) = -3.868, p < 0.001$ .

Chi-square tests were carried out to determine the association between the direction of lighting and posing respective to samples from galleries in both NRD region. In LTR region galleries there was a significant association between posing and lighting directions,  $\chi^2(4) = 492.51, p < 0.001$ , as well as in RTL region galleries,  $\chi^2(4) = 178.25, p < 0.001$ . Congruency between pose and lighting direction was revealed using follow up one-sample  $t$ -tests against a midpoint of zero, with  $p = 0.001$  to correct for multiple comparisons. In LTR and RTL regions lighting direction was significantly biased leftward for left poses (LTR:  $t(260) = -26.95, p < 0.001$ ; RTL:  $t(238) = -7.04, p < 0.001$ ) and biased rightward for right poses (LTR:  $t(321) = 14.47, p < 0.001$ ; RTL:  $t(278) = 11.07, p < 0.001$ ). In LTR regions lighting was also biased leftward for centre poses,  $t(313) = -3.61, p < 0.001$ , while no significant lighting bias for centre pose sculptures in RTL region galleries was revealed, despite a mean positive score,  $t(270) = 1.16, p = 0.245$ .



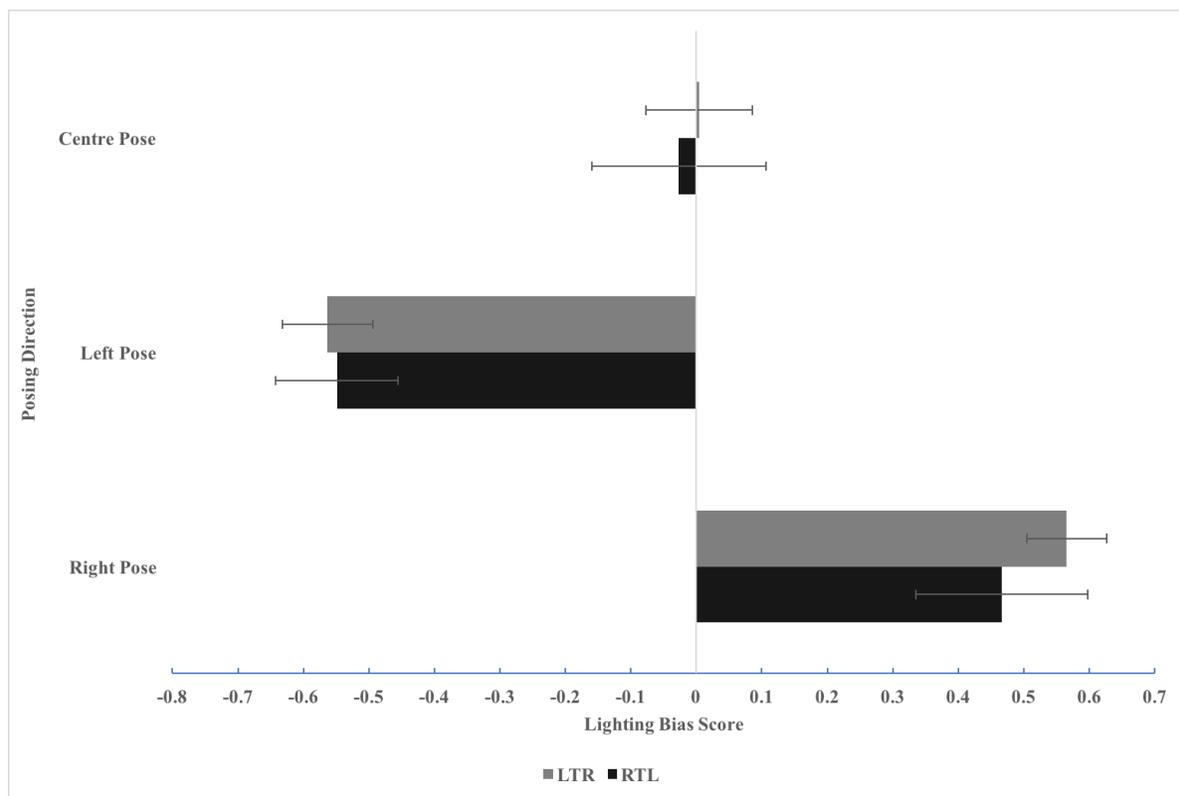
*Figure 1.* Lighting bias association with posing bias in LTR and RTL region galleries. Error bars represent 95% confidence intervals. Lighting bias scores created by coding rightward light placements as +1 and leftward placements as -1; overall negative score indicates a leftward lighting bias.

### **Sculpture Lighting Paradigm**

No significant light placement biases were observed for the LTR or RTL group when mean scores were compared against a midpoint of zero with one-sample *t*-tests (LTR:  $t(49) = 0.11, p = 0.910, M = 0.002, SD = 0.13$ ; RTL:  $t(29) = -0.89, p = 0.380, M = -0.04, SD = 0.22$ ). An independent-samples *t*-test revealed that the mean scores between groups were not different from each other,  $t(77) = 0.96, p = 0.339$ .

Grouping trials by posing direction and analyzing light placements against the midpoint of zero with one-sample *t*-tests for each pose revealed congruency between lighting bias and

posing direction. In the LTR group, the mean score of  $-0.56$  ( $SD = 0.24$ ) for left posed sculptures was significant,  $t(48) = -16.41$ ,  $p < 0.001$ , the mean score of  $0.57$  ( $SD = 0.21$ ) for right posed sculptures was significant,  $t(48) = 18.52$ ,  $p < 0.001$ , and there was no significant lighting bias for centre posed sculptures,  $t(48) = 0.1$ ,  $p = 0.920$  ( $M = 0.004$ ,  $SD = 0.28$ ). While there was a leftward lighting bias for left posed sculptures, ( $M = -0.55$ ,  $SD = 0.25$ )  $t(29) = -12.07$ ,  $p < 0.001$ , and a rightward lighting bias for right posed sculptures ( $M = 0.47$ ,  $SD = 0.35$ )  $t(29) = 7.26$ ,  $p < 0.001$ , there was again no significant lighting bias for centre posed sculptures ( $M = -0.03$ ,  $SD = 0.36$ )  $t(29) = -0.41$ ,  $p = 0.684$ , in the RTL group. Results are presented graphically in Figure 2.



*Figure 2.* Lighting bias association with posing bias in the experimental lighting paradigm. Error bars represent 95% confidence intervals. Lighting bias scores created by coding rightward light placements as +1 and leftward placements as -1; overall negative score indicates leftward lighting bias.

**Response time analyses.** A 2 x 2 repeated-measures analysis of variance (ANOVA) was used to determine if response times differed between groups for left or right lit sculptures. The within subjects variable was response time (left light, right light) and the between subjects variable was NRD (LTR, RTL). The interaction between response time and NRD approached significance,  $F(1,77) = 3.86$ ,  $p = 0.053$ ,  $\eta^2P = 0.048$ . Post hoc pairwise comparisons revealed that the effect was driven by differences in response times in the LTR group. Bonferroni corrected pairwise comparisons revealed that the LTR group applied light to sculptures from the left ( $M = 9.5s$ ,  $SD = 3.5$ ) quicker than from the right ( $M = 10.1s$ ,  $SD = 3.5$ ) with this difference approaching significance ( $p = 0.071$ ), while mean response times for left ( $M = 9.6s$ ,  $SD = 5.1$ ) or right ( $M = 9.1s$ ,  $SD = 4.9$ ) lighting placements of the RTL group were not different ( $p = 0.291$ ).

### **Greyscales Task**

Bias scores from one RTL and two LTR individuals were more than two standard deviations greater than the mean score of their group and excluded from the analysis as outliers. The bias score of the LTR group ( $M = -34.8$   $SD = 35.93$ ) was significantly leftward when compared to no bias using a one-sample  $t$ -test with a midpoint of zero,  $t(46) = -6.63$   $p < 0.001$ . The RTL group also made more leftward choices, and when compared to a midpoint of zero in a one-sample  $t$ -test, the group bias score ( $M = -27.0$   $SD = 40.60$ ) was significantly leftward,  $t(28) = -3.58$   $p = 0.001$ . Although the bias score of the RTL group was of slightly less magnitude, results from an independent-samples  $t$ -test show that scores between groups were not significantly different from each other,  $t(74) = -0.88$ ,  $p = 0.719$ .

### **Discussion**

Sedgewick et al.'s (2015) study examining lighting of 3D stimuli revealed new information about individuals' aesthetic preferences when given control of the lighting. Results

from that investigation differ from trends in the related 2D artwork lighting literature in some key ways, first that lighting was biased to the right, and second that lighting direction did not interact with posing direction. In the current study, we attempted to replicate Sedgewick et al.'s (2015) findings using the same stimuli within a simplified experimental design, and including a sample of participants whose NRD was from RTL. Participants also completed the greyscales task as a measure of perceptual asymmetries. Additionally, we carried out a content analysis with images of illuminated sculptures from galleries in LTR and RTL regions in an attempt to examine aesthetic preferences of monolinguals. Contrary to our predictions, average light placements of the LTR and RTL groups were not different from each other and no lateral lighting biases emerged for either group in the sculpture lighting paradigm. As predicted, both groups displayed a leftward bias on the greyscales task; however, even though the bias of the RTL group was weaker than the LTR group, the difference between groups was not significantly different. Our prediction that lighting of sculptures in LTR region galleries would be leftward and significantly different from RTL region galleries was confirmed. Further, sculptures in RTL region galleries were more often illuminated from the right.

Results from RTL participants on both laboratory tasks, as well as the accompanying content analysis from galleries in RTL regions, support the idea that spatial and aesthetic biases are on the same spectrum and allow for the Interactive Account to be extended to cover aesthetics as well. Full support for extending the model, even to the specific area of the aesthetics of lighting, will require rigorous examination using varied stimuli in different paradigms. Within aesthetics, however, the strong rightward lighting bias exhibited by RTL monolinguals revealed through the content analysis contrasted against the lack of bias exhibited by RTL bilinguals in the laboratory follows what would be expected from the Interactive Account. Although the

Interactive Account may predict more attenuation of pseudoneglect on the greyscales task than we observed, our results reflect the dominance of the right hemisphere on this task and could reflect a variable bilingual sample. Further, the smaller magnitude of the bilingual RTL group's bias score on the greyscales task, in the context of the scores of the LTR group, is in line with theory predictions.

Although overall group means for light placements on the sculpture lighting task did show small variations, each group essentially placed the light nearly directly overhead of the sculptures. This overall lack of lateral lighting bias did not replicate Sedgewick et al.'s (2015) findings, nor did it confirm our hypothesis. However, comparing the overall light placements of the LTR group from the current experiment to Sedgewick et al.'s (2015) findings (LTR participants) in the context of the attenuation increases with complexity theory (Smith & Elias, 2018) does raise an interesting possibility. Although we predicted that simplifying Sedgewick et al.'s paradigm would shift the bias from right to left, the lack of bias with the simplified design does suggest that the leftward bias was in fact inhibited less. Further support for this idea is found in our examination of trial time differences between left and right light placements as there was increased fluency when applying light from the left. Why light placements by non-artistically trained LTR individuals are not consistent between 2D and 3D stimuli is at this point unknown. The fact that the leftward lighting bias typically exhibited by LTR individuals has not been replicated in the current experiment, nor in that carried out by Sedgewick et al. (2015), raises the possibility that our 3D stimuli are in some way remarkable. The lack of biases also exhibited by RTL individuals could be representative but may also support the idea that the exercise of lighting a 3D sculpture does not elicit lateral biases in the same way that 2D artwork lighting does.

Examining differences in the details between stimuli used in 2D and 3D paradigms, in addition to the broad difference of dimensionality, reveal two important considerations about composition. First, 2D abstract artworks do not contain any faces whereas many of the sculptures in the current experiment do. Thomas et al. (2008) suggest that the congruency between lighting and posing serves to highlight the face, and as an interaction between posing and lighting direction occurred in the current experiment, any potential lateral lighting biases may have been masked by the interaction. Second, 2D abstract artwork images used by McDine et al. (2011) and Smith et al. (2018, *under review*) were free from a discernable top, bottom, or sides while top, bottom, and sides of sculptures were obvious in the current study. If lateral lighting biases observed by McDine et al. (2011) are a true representation of attentional asymmetries, rooted in hemispheric inequalities, and biases observed by Smith et al. (2018, *under review*) are also an accurate depiction of hemispheric dominance, in conjunction with the environmental impact of learning to read and write, and emerged because of confound-free stimuli, future experiments evaluating aesthetics, lighting, 3D stimuli, and monolingual and bilingual RTL individuals may take the following steps to draw more certain conclusions. First, simplify the stimuli by using sculptures with no defined sides or orientations. If taking away predefined poses and orientations of 3D stimuli elicits leftward lighting biases among LTR participants, then perhaps an endorsement of the attenuation increases with complexity theory can be made with more certainty. Second, if bilingual RTL participants display a leftward bias that is significantly weaker or rightward of LTR participants or continue to show a lack of lateral bias with the same stimuli, the suggestion that the Interactive Account applies to aesthetic lighting and not just spatial stimuli can be more confidently made. Lastly, research groups with access to RTL

monolinguals could experimentally demonstrate this group's lighting preferences, potentially bolstering the Interactive Account if a rightward bias is confirmed.

Between the laboratory experiment and the content analysis, our study highlights the preferred congruency between lighting direction and posing direction. Our findings are the first to experimentally demonstrate this phenomenon as support for this theory has come previously only come from archival and content analyses (Grüsser, et al., 1988; Thomas et al., 2008). While results from our content analysis confirm that this phenomenon occurs among art experts, our experimental findings from non-experts suggest that congruity between lighting and posing is preferred regardless of art expertise. Further, our study is the first to show that the preference for congruity between lighting and posing endures across NRDs. The persistence of lighting biases across poses appears to also be related to the expertise of the lighting agent. Non-experts do not show overall lighting biases with posed 3D stimuli whereas the attenuation of lateral lighting biases (left for LTR, right for RTL) is overcome if the lighting agent is artistically trained. Our earlier discussion concerned with the possible uniqueness of 3D stimuli and lighting biases may also relate to the separation between experts and non-experts. It could be that lighting a 3D object, even in a relatively simple experiment like the one presented here, is fundamentally more difficult than 2D stimuli. Non-experts with less experience might be making the *obvious* choice and lighting sculptures to highlight posing direction whereas the experience of experts enables them to recognize the higher perceptual value of lateral light (depending on their culture: left for LTR, right for RTL) and deviate from light placements in line with posing when it is aesthetically pleasing.

As others have shown, lighting is an important tool used by artists to enhance the aesthetic value of their artwork. Consistent lateral lighting biases have yet to be observed with

3D stimuli and it is at this point unknown if that results from the complexity of the stimuli or the individual variation of participants tested thus far, pointing to the importance and necessity of future research in this area. Typically, light is biased leftward, but there is evidence to suggest that lateral lighting preferences vary with NRD. Our archival analysis of sculpture lighting in galleries confirms that lateral lighting biases persist among the artistically trained (photographers, curators) when lighting is disconnected from art production and examined in isolation, as left lighting is more prevalent in LTR region galleries and right lighting in RTL region galleries. These lateral lighting biases also persist in isolation among the non-artistically trained when 2D stimuli are used, however the perseverance of these biases is less clear when stimuli are 3D.

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