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"Solid Hollows" and *"Reverspectives"*: Similarities and differences

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Abstract

Patrick Hughes' *"Reverspectives"* typically have a three-dimensional structure consisting of *protruding*, truncated pyramids but they appear to *recede* into the distance because of the perspective images on the sides of the pyramids. More recently, PH has created "Solid Hollows" which have a receding (hollow) three-dimensional structure but they appear to protrude. In this paper, we have attempted to describe both the similarities and differences between "Reverspectives" and "Solid Hollows". We conclude that perspective is not a mere "secondary cue" (Helmholtz, 1910) in the perception of Reverspectives but instead perspective dominates over binocular disparity when the viewing distances are greater than 50–100 cm. For "Solid Hollows", perspective also plays a role in the (perceived) reversed depth, as does the visual system's inherent bias for seeing objects as convex.

Keywords

3D perception, binocular vision, depth, optic flow, proprioception, stereopsis, perception

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Background

One of us (PH) is most well-known for his "*Reverspective"* artworks (Figure 1) in which the *protruding* physical structure is seen as *receding* when viewed from 100 cm or more away from the artwork (Hughes, 2018). In contrast, the physical structure of his more recent works - "*Solid*

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Figure 1. (a) A frontal view of Patrick Hughes' "Venice Vista". The physical structure consists of three *protruding* truncated pyramids. (b) Seen from the side, the same *Reverspective* reveals the actual 3-D structure of the artwork.

Hollows" - is *receding* but is seen as *protruding* towards the viewer. PH's first "*Solid Hollow"* was a pair of hollow dice (Figure 2) which is seen as convex (like a normal die) when viewed from 50 cm or more away. PH's dice were first displayed at the Kunsthalle Messmer gallery near Freiburg in Germany in 2022 and 2 months later at the Illusion Night during the 44th ECVP (European Conference on Visual Perception) in Nijmegen in the Netherlands. Over the past three years, PH has created a series of more complex "*Solid Hollows"*[1], all of which share similar characteristics - a hollow, receding form (physically) that is seen as protruding (Figure 3).

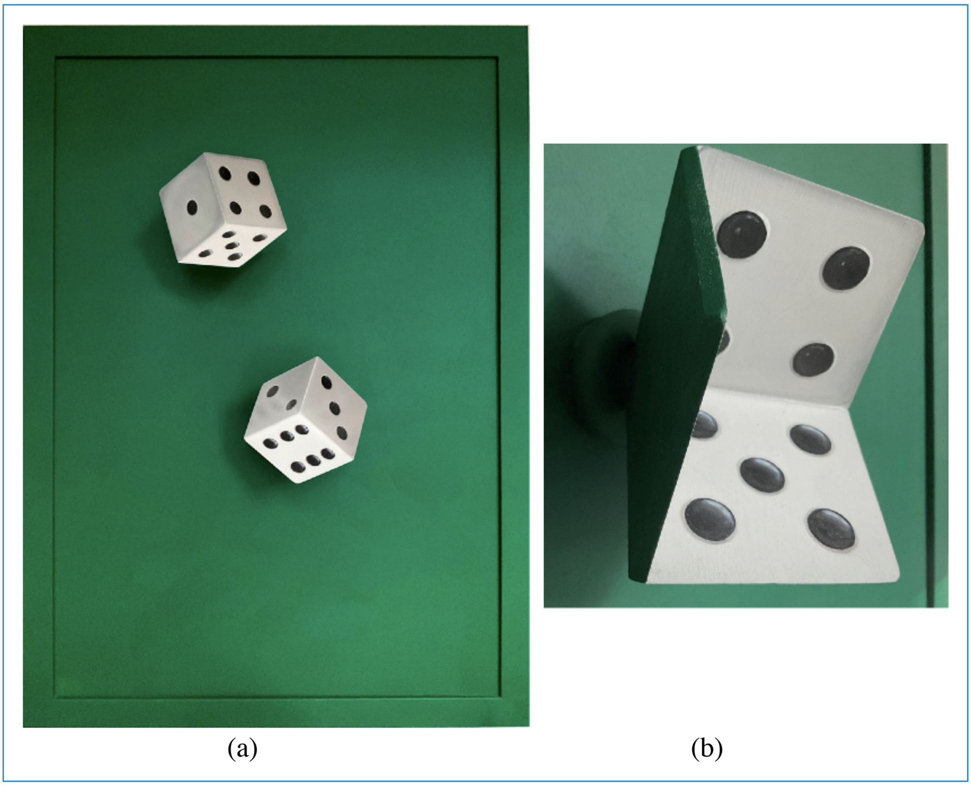

Figure 2. (a) Patrick Hughes' *Hollow Dice*. (b) Seen from the side, the same *Hollow Die* reveals the actual *concave* structure of the dice.

Why do we see both *Reverspectives* and *Solid Hollows* as 3-D structures with a depth that is in the *opposite* direction to their physical shape? In the case of *Reverspectives*, it is generally accepted that the perspective information provided by the images of the receding ground plane and buildings in a *Reverspective* such as "Venice Vista" (Figure 1) overrides the binocular disparity information created by the contours of the physical structure (Papathomas, 2002; Rogers & Gyani, 2010; Rogers & Hughes, 2023; Rogers et al., 2024). This explanation is consistent with fact that viewers perceive the *reversed* structure at *large* viewing distances (when the disparities are *small),* while viewers perceive the structure as *protruding* at *close* viewing distances when the disparities are *large*. We have also noticed that *Reverspectives* that are based on real-world scenes (such as "Venice Vista" in Figure 1) are more likely to be seen as *reversed* in depth compared with those based on more abstract perspective images such as PH's "Purism" (Figure 4).

Overall, it should not surprise us that the *perspective* information provided by a *Reverspective* is a more powerful source of 3-D information than binocular disparities when that *Reverspective* is viewed from beyond the viewer's personal space. Artists, for example, have long appreciated the power of perspective in their flat paintings. Moreover, many paintings typically face the same contradiction as a *Reverspective*: i.e., there is perspective information *within* the painting that contradicts the flatness[2] (uniform disparities) of the canvas on which the scene is painted.

Figure 3. Patrick Hughes' *Solid Hollow*: "Vincent's chair".

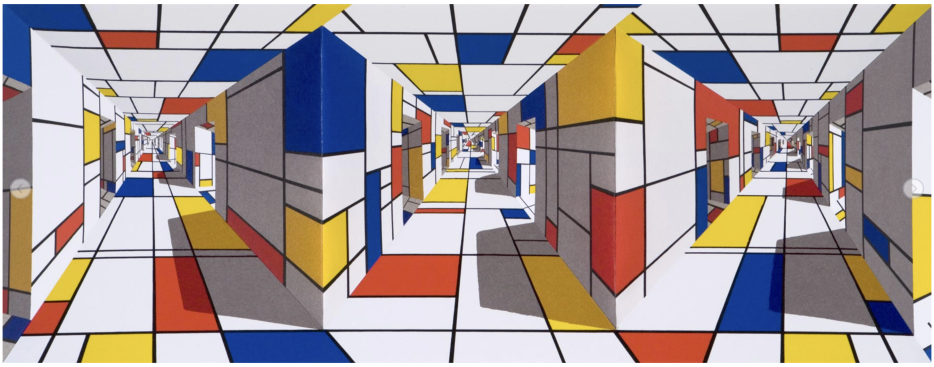

Figure 4. Patrick Hughes' "Purism".

Solid Hollows

Does this explanation of Patrick Hughes' *Reverspectives* also apply to his *Solid Hollows*? In both cases, the binocular disparities created by the actual *physical* structures are ignored or overridden when the viewing distance is greater than ∼70 cm. And in both cases, the perceived depth of the 3-D structure is *opposite* in direction to the *physical* structure. However, the information that is responsible for the perceived depth in *Reverspectives* and *Solid Hollows* is quite different. In *Reverspectives*, the dominant source of contradictory information is *perspective* but bounding contours of the dice in PH's *Hollow Dice* provide only *minimal* (false) perspective, as can be seen in Figure 2b. (N.B. geometry tells us that objects that subtend a *small visual angle* create little or no perspective). Unlike *Hollow Dice*, *Reverspectives* such as "Venice Vista" (Figure 1), subtend a much larger visual angle (from a similar viewing distance) and the sides of the buildings and the width of the water surface have been given a very large amount of perspective, as can be seen in Figure 1a (a 3:1 size ratio). Hence, given that there is minimal (false) perspective in *Hollow Dice*, why do we see the reversed depth? We suggest that there must be a *bias* in the human perceptual system for seeing objects as *convex* rather than *concave*.

The convexity bias has been used to explain the well known hollow face illusion. Figure 5 is a photograph of a hollow mask of Beethoven. Figure 5 is only a *flat* picture but when viewing an actual *hollow* mask from a distance, observers see the mask as a protruding, *convex* structure, helped by the fact that there is only (weak) disparity information in the smooth contours of its true *concave* structure (Bülthoff & Mallot, 1988; Rogers & Hughes, 2023). BR's former Ph.D. supervisor, Richard Gregory (1980), suggested that we see the hollow mask as convex because we have had a lifetime of viewing normal convex faces and hence the "perceptual hypothesis" of a hollow face is very unlikely. Hill and Bruce (1993) have suggested an alternative explanation - that the bias towards seeing *convexity* in hollow masks is due to the fact that there are more convex objects in the world compared with concave objects. This statistical bias that has always been present throughout our evolution. The experimental evidence to support Hill and Bruce's suggestion is provided by the fact that the convexity bias also applies to other hollow objects such as their "hollow potatoes", which are also seen as convex (Hill & Bruce, 1994). One could make the stronger claim that *all* objects necessarily have a bounding contour which defines the object as being 'in front' with respect to the background. Objects might have a 3-D structure that includes a concave region (like a cup or glass seen from above) but the object itself stands between the observer and the background and, as a consequence, it occludes that background.

If there is a bias in seeing "objects" as convex then it is not surprising that Patrick Hughes' Hollow Dice are seen as *convex*. Our conclusion is that the convexity bias, together with the limited perspective information, is sufficient to overrule the limited disparity information in the Hollow Dice.

Does the same logic apply to PHs' "*Vincent's chair*" (Figure 3) and his delightful "*Mountain Holiday*" (Figure 6)? Both of these *Solid Hollows* subtend larger angular sizes than the *Hollow Dice* (when viewed from the same distance) and they both provide enhanced (false) perspective information. This can be seen in the photo of "*Mountain Holiday*" (Figure 6a). As a consequence, PH's *Solid Hollows* typically provide sufficient perspective information to specify the *opposite* depth to the actual 3-D structure, just like *Reverspectives*. In addition, the 'objectness' (convexity bias) of this *Solid Hollow* provides additional information to bias our perception in favour of seeing it as a *convex* structure.

One of PH's recent *Solid Hollows*, "*The Rule of Seven"* (Figure 7), provides some important evidence about the roles and strength of these two factors (perspective and convexity bias). Unlike the Hollow Dice shown in Figures 2a and b (which have false (convergent) perspective), each of the faces in the seven cuboid structures in "*The Rule of Seven"* has *parallel* sides. Hence, from an

Figure 5. A hollow mask of Beethoven that is seen as concave.

observer's viewpoint, the receding faces of each of the cuboids provide a small amount of correct, divergent perspective which signals that each of the seven objects is *concave*. (This can be seen in the slight *divergence* of physically "parallel" contours of the cuboids in Figure 7). But this is not what we perceive. We see "*The Rule of Seven*" artwork as a series of *protruding* cuboids. This provides clear evidence for role of a *convexity bias* in the human visual system. However, we have also observed that the "flipping point" (when the perception flips from convex to concave as the observer approaches the artwork) is typically around 2–3 m from the artwork - i.e., at a *greater* distance than the "flipping point" for a typical Solid Hollow. This suggests that the small amount of *divergent* perspective shown in "*The Rule of Seven*" can overrule the convexity bias when the observer reaches a distance of 2–3 m from the artwork.

There is one additional feature of PH's *Solid Hollows* that is worth mentioning. Because both the *Hollow Dice* and the *Solid Hollows* have *concave* (hollow) physical shapes, the *bounding, outer contours* of these artworks are necessarily at some distance *in front* of the background (see Figure 2b and 6b). As a result, those bounding contours provide a *convergent* (or *crossed*) *disparity*

Figure 6. (a) A frontal view of Patrick Hughes' "*Mountain Holiday*". (b) A video of the same *Solid Hollow* that reveals the hollow structure of the artwork.

Figure 7. Patrick Hughes' "*the Rule of Seven*".

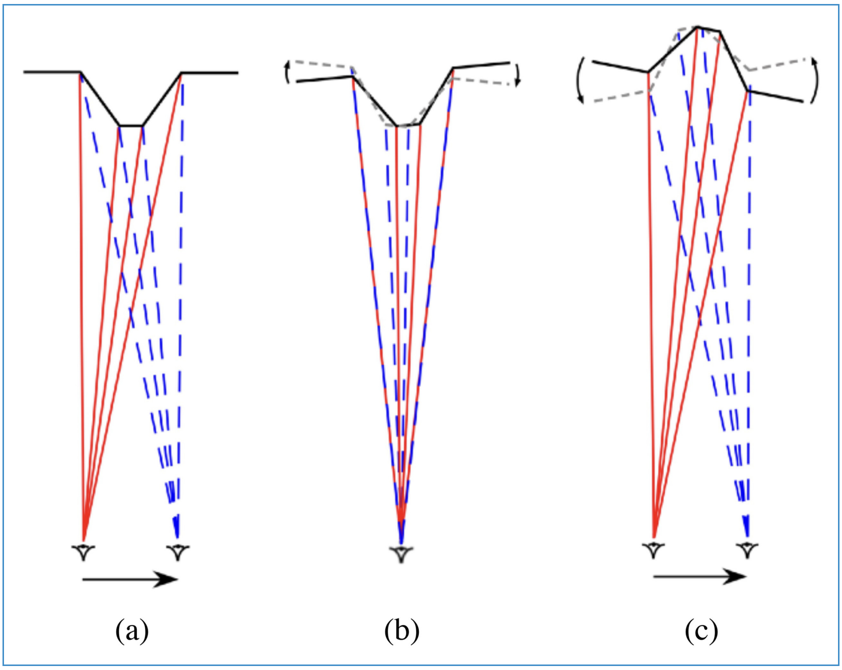

Figure 8. (a) A plan view of the eye of a monocular observer moving from left-to-right while viewing a protruding truncated pyramid (as in a Reverspective). (b) The parallax transformation created by that observer's movement is equivalent to a *clockwise* rotation of the truncated pyramid with respect to the observer's *line-of-sight*. (c) The same parallax transformation is also created when the observer moves left-to-right while seeing a *depth-inverted* truncated pyramid (as a result of the perspective information on the sides of the pyramid), such that it appears to rotate in the *same* direction with respect to the observer's line-of-sight - i.e., *counter-clockwise*.

(with respect to the background) so that those contours are seen to be located well in front of the background - i.e., a *Hollow Die* or *Solid Hollow* becomes an "*object"* that lies in front of the background. However, *within* the bounding contour, the combination of the false perspective and the convexity bias is sufficient to override the *uncrossed* disparities of the enclosed area of the artwork.

The Role of Observer Movement in *Solid Hollows* and *Reverspectives*

For most observers, the perception of the reversed depth in a *Solid Hollow* or a *Reverspective* is striking enough but an even more impressive percept and a greater sense of depth is created when the observer moves from side-to-side (or up-and-down). When the observer moves from side-to-side, the 3-D structure of a *Reverspective* appears to *rotate* around a vertical axis in the *same* direction as observer's movements: i.e., when the observer moves from left to right, the 3-D structure appears to rotate in an anticlockwise direction (as seen from above) and vice versa during observer movements to the left - in other words, the structure "follows" the observer's movements (Figure 8c). In addition to the vivid "following motion", most observers report that the 3-D structure appears to have significantly more *depth,* compared with that seen by a stationary observer.

What is the explanation? In 2010, Rogers and Gyani suggested that the motion parallax created by the side-to-side movements of the observer when viewing the *reversed* 3-D structure of a *Reverspective* is consistent with the *rotation* of the scene in the *same* direction with respect to the

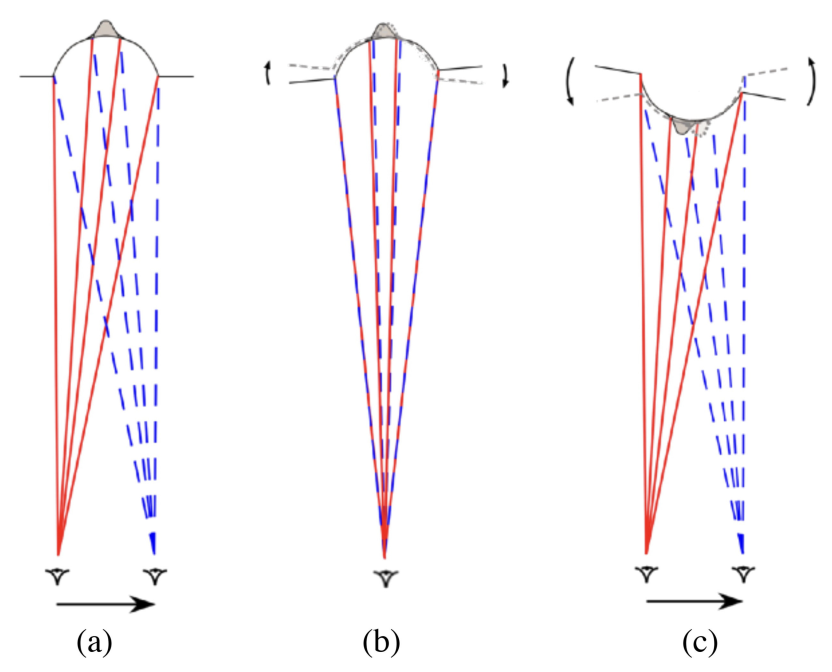

Figure 9. (a) A plan view of the eye of a monocular observer moving from left-to-right while viewing a hollow mask (Figure 5). (b) The parallax transformation created by the observer's movement is equivalent to a *clockwise* rotation of the face with respect to the observer's *line-of-sight*. (c) The same parallax transformation is also created when the observer moves left-to-right while viewing a depth-inverted hollow mask (i.e., when it is perceived to be convex) that rotates in the same counter-clockwise direction with respect to the observer's line-of-sight and with *double* the angle of rotation, in accordance with the geometry.

observer's line of sight (Figure 8c) but see Papathomas (2017). Geometrically, the extent of the rotation should be *double* the angle of rotation with respect to the observer's line of sight (Figure 8c), and this is what many observers report.

Rogers and Gyani (2010) also suggested that the appearance of "following" motion (with respect to the observer's line of sight) when an observer moves from side-to-side while viewing a hollow mask is also consistent with the observer's perception of rotation of the mask in the same direction and double the amount of rotation, with respect to the observer's line of sight (Figure 9c).

We think that a similar explanation can account for the apparent rotation of PH's *Hollow Dice* and *Solid Hollows* when the observer moves from side-to-side. As a consequence, we have found yet another similarity between *Reverspectives* and *Solid Hollows*. While the physical structures of *Reverspectives* and *Solid Hollows* are different - the first a protruding structure and the second a concave structure - the perception of both reversed depth and the "following motion" is common to both (Figures 8c and 9c).

We now have an explanation of why we perceive the "*following"* rotation of *Solid Hollows* and *Reverspectives* but we have neglected an important consequence of the motion parallax. As mentioned previously, the majority of observers report that the perceived depth in both *Solid Hollows* and *Reverspectives* is substantially *enhanced* when they move their heads from side-to-side (Rogers & Hughes, 2023). However, this should not surprise us given that the perceived depth from motion parallax alone can be comparable in magnitude to that produced by binocular disparities (Rogers, 2016; Rogers & Graham, 1979).

Observer-Produced and Object-Produced Motion Parallax

So far, we have only considered the motion parallax that is created by the side-to-side movements of the observer - i.e., "*observer-produced"* parallax (Rogers, 1993; Rogers & Graham, 1979). But motion parallax is also created when a 3-D object translates along a straight line path across the observer's line-of sight - i.e., "*object-produced"* motion parallax. Geometrically, the parallax transformation created is the *same* in both cases and this is evident when a *Reverspective* or *Solid Hollow* is translated along a straight-line path in front of a stationary observer. Most observers report seeing the appearance of reversed depth in both cases. Whilst the optic flow (motion parallax) might be the same in both cases, there is an important difference: in "*observer-produced"* parallax, the optic flow is created by the observer's *own movements*, which can be sensed both proprioceptively and from the vestibular system. (Note that this is also true for the parallax created by the 3-D structure of natural scenes).

It might be assumed that the addition of proprioceptive and vestibular information *enhances* the perception of the 3-D structure and layout of objects in the world, but is this the case? As far as we are aware, there is no experimental evidence to answer this question either way. On theoretical grounds, it could be argued that because *similar* optic flow is created in *both* self-motion and stationary-observer situations, this is what the visual system has evolved to rely on. For example, similar optic flow is created when we are translated through the world by a car or train - situations which produce no (relevant) proprioceptive information and minimal vestibular information when the car or train moves at constant speed. But this does not preclude the possibility that the additional proprioceptive and vestibular information might enhance the observer's perception of depth.

'Virtual' *Reverspectives* and 'Virtual' *Solid Hollows*

The majority of earlier studies of *Reverspectives* have used the technique of asking observers to walk towards a *Reverspective* from a distance of several meters (when they see the 3-D structure as *reversed* in depth), until they reach the point when the perceived depth "flips" to that of the actual, physical structure (Papathomas, 2002; Rogers & Gyani, 2010; Rogers & Hughes, 2023). The "flipping point" (Gregory, 2005) is typically at a distance of between 50 and 100 cm. However, the results of experiments that use this technique are open to a number of different interpretations. As the observer nears a *Reverspective*, the disparity differences between the tops of the pyramids and the background *increase* and therefore make it more likely that the observer will see the shape of the actual 3-D structure. But at the same time, the angular size of a Reverspective also increases. Does size matter? In those previous studies of *Reverspectives,* these factors are confounded.

To address this issue, we have created "*Virtual Reverspectives"* in which each of the different factors can be manipulated independently. To do this, we asked observers to view the stereoscopic images presented on *either* a 3-D TV screen with polarising glasses *or* projected onto a non-depolarising screen and viewed with polarising glasses (Rogers et al., 2024). Unlike a conventional *Reverspective*, the disparities presented in a "*Virtual Reverspective"* can be varied in both magnitude and in sign. There is a second advantage of using "*Virtual Reverspectives"* for experimental studies - there is no such thing as the "*real"* or "*physical"* depth. Instead, there is merely depth specified by *disparities* (on the one hand) and depth specified by *perspective* (on the other).

Finally, there is one surprising effect for which we have no satisfactory explanation. Consider the situation in which the disparities in a *Reverspective* are *increased* to the point when the observer reports sees the "flipped" *disparity-specified* 3-D structure (i.e., the depth is no longer reversed). We have noted that, if the observer is asked to move her/his head from side-to-side at this particular distance, most observers report that the perception "flips" back to seeing a 3-D structure with *reversed* depth. Moreover, the reversed depth is also accompanied by "following motion" (with respect to the observer's line-of-sight).

Conclusions

From PH's point-of-view, both *Reverspectives* and *Solid Hollows* are intriguing and beautiful artworks that have been admired and enjoyed by artists and non-artists alike. From BJR's point-of-view, *Reverspectives* and *Solid Hollows* have provided vision scientists with a valuable tool to investigate the role and contribution of different sources of 3-D information. In the nineteenth century, von Helmholtz (1910) suggested that binocular disparities and convergence of the eyes were "primary cues" for 3-D vision, whereas perspective and the other "pictorial" cues were regarded as "secondary". Even today, many people still assume that having two eyes and binocular vision is *essential* for perceiving the 3-D world. In contrast, both *Reverspectives* and *Solid Hollows* clearly show the importance of *perspective*, and the more limited importance of binocular disparities in the perception of scenes that lie beyond the observer's personal space. However, von Helmholtz (1910) was correct in identifying the importance of motion parallax as a source of 3-D information. In the 3rd volume of his "Treatise on Physiological Optics" (pp. 295–296) (written over 150 years ago), he wrote:

> "Suppose, for instance, that a person is standing still in a thick woods, where it is impossible for him to distinguish, except vaguely and roughly, in the mass of foliage and branches all around him what belongs to one tree and what to another .… But the moment he begins to move forward, everything disentangles itself, and immediately he gets an apperception of the material contents of the woods and their relations to each other in space, just as if he were looking at a good stereoscopic view of it."

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Brian Rogers: Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Resources; Writing – original draft; Writing – review & editing.

Patrick Hughes: Conceptualization; Methodology; Project administration; Resources; Writing – original draft; Writing – review & editing.

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Notes

1. PH was not the first to investigate concave (hollow) structures that are seen as convex. David Brewster (1826) described the appearance of intaglios and cameos. There are descriptions of cameos and intaglios as well as chapters on concavities and convexities in Wallin's (1905) book. See also Wade (2016) and Wade and Hughes (2023).
2. Paintings are not 2-D, they are *flat* 3-D objects.

References

Brewster, D. (1826). On the optical illusion of the conversion of cameos into intaglios, and of intaglios into cameos, with an account of other analogous phenomena. *Edinburgh Journal of Science* (4), 99–108.

Bülthoff, H. H., & Mallot, H. A. (1988). Interaction of depth modules; stereo and shading. *Journal of the Optical Society of America*, *5*, 1749–1757. https://doi.org/10.1364/JOSAA.5.001749

Gregory, R. L. (1980). Perceptions as hypotheses. In N. S. Sutherland & H. C. Longuet-Higgins (Eds.), *The psychology of vision* (pp. 181–197). The Royal Society. https://doi.org/10.1098/rstb.1980.0090

Gregory, R. L. (2005). The Medawar lecture 2001. Knowledge for vision: Vision for knowledge. *Philosophical Transactions of the Royal Society London, B Biological Sciences*, *360*, 1231–1251. https://doi.org/10.1098/

Hill, H., & Bruce, V. (1993). Independent effects of lighting, orientation, and stereopsis on the hollow-face illusion. *Perception*, *22*, 887–897. https://doi.org/10.1068/p22088

Hill, H., & Bruce, V. (1994). A comparison between the hollow-face and hollow-potato' illusions. *Perception*, *23*, 1335–1337. https://doi.org/10.1068/p231335

Hughes, P. (2018). *A newer perspective*. Flowers Gallery. https://doi.org/1906412820

Papathomas, T. V. (2002). Experiments on the role of painted cues in Hughes's reverspectives. *Perception*, *31*, 521–530. https://doi.org/10.1068/p3223

Papathomas, T. V. (2017). The hollow-mask illusion and variations. In Shapiro & Todorovic (Eds.), *The Oxford compendium of visual illusions* (pp. 614–619). Oxford University Press. https://doi.org/10.1093/acprof:oso/ 9780199794607.003.0087

Rogers, B. J. (1993). Motion parallax and other dynamic cues for depth in humans. In F. A. Miles & J. Wallman (Eds.), *Visual motion and its role in the stabilisation of Gaze* (pp. 119–137). Elsevier Science Publishers B.V.

Rogers, B. J. (2016). Revisiting motion parallax as a source of 3-D information. *Perception*, *45*(11), 1267–1278. https://doi.org/10.1177/0301006616655816

Rogers, B. J., & Graham, M. E. (1979). Motion parallax as an independent cue for depth perception. *Perception*, *8*, 125–134. https://doi.org/10.1068/p080125

Rogers, B. J., & Gyani, A. (2010). Binocular disparities, motion parallax, and geometric perspective in Patrick Hughes's "reverspectives": Theoretical analysis and empirical findings. *Perception*, *39*, 330–348. https://doi.org/10.1068/p6583

Rogers, B. J., & Hughes, P. (2023). The turn of the dice: Patrick Hughes'. Hollow dice and reverspectives. *i-Perception*, *14*(2), 1–16. https://doi.org/10.1177/20416695231165623

Rogers, B. J., Hughes, P., & Papathomas, P. V. (2024). Depth reversals in Patrick Hughes' Reverspectives: a flippin' problem. *Perception*, 31. https://journals.sagepub.com/pb-assets/cmscontent/PEC/ECVP%202024%20Abstracts-1742366759.pdf?_gl=1*v2hg5k*_up*MQ..*_ga*ODYwOTUwMjMxLjE3NzM2ODUyOTI.*_ga_60R758KFDG*czE3NzM2ODUyOTIkbzEkZzAkdDE3NzM2ODUyOTIkajYwJGwwJGg1MDk4Mzc5NzM

Von Helmholtz, H. (1910). *Treatise on physiological optics*. Dover. 1962. English translation by J P C Southall from the 3rd German edition of Handbuch der Physiologischen Optik. Voss.

Wade, J. N. (2016). *Art and Illusionists - vision, illusion and perception*. Springer. ISBN 978-3-319-25227-8.

Wade, J. N., & Hughes, P. (2023). Reversing the eyes and reverse perspectives: Pseudoscopic amplification of reverspectives. *i-Perception*, *14*(6), 1–5. https://doi.org/10.1177/20416695231215406

Wallin, J. E. W. (1905). Perspectivity in momentary exposures correlations. In J. E. W. Wallin (Ed.), *Optical illusions of reversible perspective: A Vol. of historical and experimental researches* (pp. 99–158). Unknown Publisher. https://doi.org/10.1037/13687-008