Spatial Vision, Vol. 15, No. 3, pp. 377–386 (2002)

Also available online - www.vsppub.com

Fixating on the wallpaper illusion: a commentary on 'The role of vergence in the perception of distance: a fair test of Bishop Berkeley's claim' by Logvinenko *et al*. (2001)

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Received 27 July 2001; accepted 30 July 2001

INTRODUCTION

Is vergence state a reliable cue to absolute distance? The answer to this seemingly simple question has been the subject of a long-standing and controversial debate in the vision literature. It is somewhat sobering, but perhaps also an indication of the complexity of the problem, that vision researchers have not been able to communicate effectively with one another in order to answer definitively this question. A recent attempt to answer this question was undertaken by Logvinenko *et al.* (2001). These authors traced the issue back to Bishop Berkeley (1709/1910), who hypothesized that vergence might serve as a cue to absolute distance. In particular, Logvinenko *et al.* attempted to resolve this issue through studying the relation between vergence eye movements and the wallpaper illusion, a relation on which several authors have commented including Helmholtz (1910/1962), and concluded that vergence is not a reliable cue to absolute distance. To mention just one other study, Richards and Miller (1969) traced formal experimental attempts to answer this question to Wundt (1862) and cite Hillebrand (1893), Irvine and Ludvigh (1936), Gogel (1961) and Ogle (1962) as other authors who have also

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commented on the issue. Richards and Miller attempted to answer the question using a cue-conflict paradigm and concluded that, for some observers, vergence is a reliable cue to absolute distance. As this cursory review of the literature indicates, the question asked by Logvinenko *et al.* has a long, rich, and complicated history and its answer requires careful scrutiny.

This commentary questions the validity of Logvinenko *et al.*'s (2001) inference that vergence does not serve as a cue to distance because it was based on the finding that, once obtained, the wallpaper illusion remains stable despite changes in eye position. We argue that reafferant information, confirming that the eyes had changed position and not the illusory wall, was the basis for the stability of the wallpaper illusion in their experiment. Furthermore, we assert that had Logvinenko *et al.* used more than one initial fixation point to produce their wallpaper illusion they would have likely found that its perceived distance is not fixed but changes as a function of initial fixation. Given their experimental design, we also question, using two thought experiments (*Gedankenexperiments*), whether Logvinenko *et al.*'s use of the wallpaper illusion is germane to the question of whether vergence state is a cue to absolute distance. In our first thought experiment, we use a simpler but analogous stimulus to that of Logvinenko *et al.*'s and present three different physical stimulus situations with the same proximal information. We argue that any inferences made about perception, eye movements, or their relation must necessarily apply to all three stimulus situations, provided that the state of the visual system is the same in all three situations. We then demonstrate in our first thought experiment that the inference that vergence is not a cue to distance is not warranted in either a real or its counterpart illusory stimulus situation. By extension, we demonstrate in our second thought experiment that the inference made by Logvinenko *et al.* cannot be made conclusively from a real stimulus situation and, in turn, from their corresponding illusory situation. We then argue that though inferences logically apply to corresponding real, illusory, and virtually real stimulus situations, the allure of the wallpaper illusion is that we are more likely *persuaded* by our inferences when they are based on a manipulation or prediction of an illusion.

BERKELEY'S (1709/1910) HYPOTHESIS

We begin by stating our understanding of Berkeley's hypothesis. Consider the situation in which two stimuli are located at two different absolute distances (see Fig. 1a, for example). When an observer converges to the near stimulus from the far one, vergence increases, and when the observer diverges to the far stimulus from the near one, vergence decreases. According to Berkeley's hypothesis, vergence angle becomes a cue to absolute distance, because 'the mind has by constant *experience* found the different sensations corresponding to the different dispositions of the eyes . . . (p. 16)'. Of course, based solely on this co-variation or on this 'connexion', to use Berkeley's term, one would neither infer that vergence is nor is not a cue to distance; other variables are confounded with vergence information in this situation. As is well known, Berkeley also listed other cues to distance such as accommodation, the size of known objects, interposition, and aerial perspective. Since the publication of his list, the question has been whether these variables can be shown empirically to serve as cues to distance. Note that regardless of which stimulus is being fixated, the near stimulus is seen as near and the far stimulus is seen as far. That is, the percept is stable, and this stability does not negate whether any of the items on the list, including that of vergence, serve as a cue to distance. This stability can be explained by the reafferent stimulation created by the eye movements (i.e. feedback signals from the movement of the eyes). The visual reafferent information for the situation in which two stimuli are located at two different distances consists of the following. Converging to the near stimulus from the far one brings the images of the near stimulus to the corresponding centers of the foveae and the images of the far one to retinally noncorresponding points.[1]

LOGVINENKO *ET AL.*'S (2001) INFERENCE FROM THE STABILITY OF THE WALLPAPER ILLUSION

Logvinenko *et al.*'s study was presented as providing evidence counter to that presented by previous studies which showed that the perceived distance of the wallpaper illusion varied with vergence state (Helmholtz, 1926; Brewster, 1844; Lie, 1965; Ono *et al.*, 1971). Unlike the Logvinenko *et al.* study, however, in these previous studies the position of the initial fixation aid used to establish the wallpaper illusion was varied systematically across conditions. Depending on the initial vergence angle of the eyes, different wallpaper elements fused with one another resulting in the wall appearing at different illusory distances. The conclusion that vergence is a cue to absolute distance was made, because the apparent distance of the illusory wall varied as a function of the initial vergence state used to create the illusion. That is, usually to create the wallpaper illusion a fixation stimulus is provided until the illusion 'locks in', or stabilizes, and then the fixation stimulus is removed. (Once the illusion has 'locked in' to a given illusory distance, some time is required before a new illusory distance can be perceived, presumably because the visual system must 'resolve' the conflict between cues such as accommodation and vergence position or 'decide' which elements correspond with one another.)

Logvinenko *et al.* (2001) used only one of many possible initial fixation points to obtain the wallpaper illusion.[2] After the illusion 'locked in' they asked their observers to move their eyes in several different ways, including back and forth between a monocular stimulus and the binocularly fused elements of the wall. They found that the apparent distance of the illusory wall did not co-vary with vergence, even when vergence changes were large. Based on the stability of the wallpaper illusion in their experiment, they concluded that vergence does not serve as a cue to absolute distance. One manipulation they failed to perform, however, was to provide their observers with another binocular fixation stimulus in order to 'break out' of the particular illusory distance of the wall and 'lock into' another illusory or real distance. If they had done this, they would likely have confirmed the previous finding of, for example, Helmholtz (1926) and Lie (1965) that the perceived distance of the illusory wall is not stable but varies with initial fixation. Logvinenko *et al.* reported that one of their observers could fixate a monocular stimulus located close to the physical location of the wallpaper stimulus for up to 10 seconds without losing the illusion. It is likely, however, that a monocularly fixated stimulus is not sufficient to break the illusion, because binocular locking is not possible. As mentioned before, other studies on the wallpaper illusion provided a binocular fixation stimulus at an optimal distance to aid fusion of the elements and 'locking in' to a new illusory distance. There was no such fixation stimulus in the Logvinenko *et al.* experiment, and eye movement traces from their study show that none of their observers' eye movements reached the actual physical plane containing the stimuli (the optimal distance to break the illusion) with their vergence. Unless an optimal fixation stimulus is provided and is fixated on for a sufficient period of time, the necessary condition for perceiving the wallpaper illusion is not met (i.e. different wallpaper elements cannot fuse with one another).

[Whether the initial vergence state is the sole determinant of the different apparent distances of the wall is debatable, however. For example, the vergence state in these conditions is confounded with vertical disparity. (See Howard and Rogers, 1995, p. 431.) To keep our argument as simple as possible, however, we postpone the discussion of this point until the end of Thought-Experiment 2.]

The stability (i.e. the apparent locations of the fused and non-fused elements remaining fixed) of the illusory wall found in Logvinenko *et al.*'s (2001) study is analogous to the stability of the visual world we experience in daily life (and in the situation depicted in Fig. 1a). It depends on reafferent retinal stimulation. That the elements remained fused in their study despite large eye movements seems to have puzzled Logvinenko *et al.* even though this is also analogous to the singularity of the visual world we experience in daily life. That is to say, in our everyday visual world, we move our eyes frequently and through considerable extents, yet the visual world remains stable and single. As long as we keep moving our eyes, the stability and singularity of our visual world is maintained, as was the case in Logvinenko *et al.*'s experiment. In their stimulus condition, as in our daily visual world, however, singularity and, in turn, stability depend on frequent eye movements. If we fixate steadily on a particular point but attend to another stimulus with a large disparity it will most likely appear as double. [For a study comparing changes in fixation between two stimuli and fixating on only one stimulus, see Foley and Richards (1972).] In the case of the wallpaper illusion, if observers fixate a point in front or behind the wall, the elements of the wall will initially be seen as diplopic. With a fixation stimulus at an optimal distance, however, the 'double' elements of the wall will fuse, but the wall will now be perceived at a different apparent distance, the fixation distance. Just as the inference that vergence information is not a cue to distance cannot be made from the stability of our everyday visual experience, nor can it be made from the finding of Logvinenko *et al.* that the wallpaper illusion remained stable. This is so because the vergence and version eye movements made in their experimental situation provide reafferent information, which updates the visual system, confirming that the eyes have moved and not the illusory wall. Presumably, for the visual system to override this reafferent information a steady fixation on a stimulus at an optimal distance is required.

Although it is not explicitly stated in Logvinenko *et al.*'s (2001) paper, they seem to be suggesting that their measurement of eye movements and perception while an observer is experiencing the wallpaper illusion provides credence to their claim. In the following sections, we demonstrate, through two thought experiments, that Logvinenko *et al.*'s use of the wallpaper illusion did not conclusively test the role of vergence information in the perception of absolute distance.

Thought-Experiment 1

Consider the following three stimulus conditions shown in Fig. 1: (a) the stimulus we considered to discuss Berkeley's hypothesis, (b) the double-nail illusion studied by Krol and van de Grind (1982), and (c) the stereoscopic presentation of (a). Now, further consider measuring the perceived distance of both stimuli [apparent in (b) and (c)] and the eye movements when an observer changes fixation from one to the other. We predict that both the perceptions and the eye movements in the three stimulus situations shown in Fig. 1 will be the same. We make this prediction because the three situations constitute what Ittelson (1960) called 'equivalent configurations' which 'are defined as that family of physical configurations for

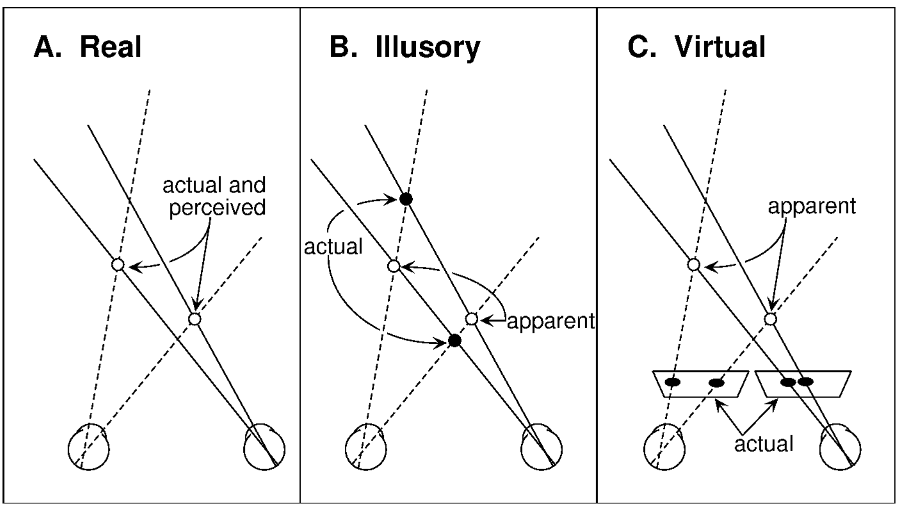

Figure 1. Real, illusory and virtual stimulus conditions for Thought-Experiment 1. The three stimulus conditions constitute a family of equivalent configurations, and the percepts should be the same if the operations of the visual system are the same. For the three conditions to have exactly the same proximal stimulus, the near stimulus (actual) in the double nail stimulus (B) needs to be smaller (see Ono, 1984) and the right one in each half field of the stereogram (C) needs to be smaller.

which impingement is invariant (p. 50)'. He stated, 'The definition of equivalent configurations implies that identical 'incoming messages' can come from different external physical arrangements. *In the absence of other information* (italicized emphasis ours), … equivalent configurations will be perceived as identical, no matter how different they be physically' (Ittelson, p. 51). Consistent with Ittelson's discussion, in our real, illusory, and virtual conditions, the percepts are predicted to be identical. We make the additional point to Ittelson's discussion that if the proximal stimulus and the operations of the visual system are the same across conditions, then any inference made from any stimulus condition within a set of equivalent configurations must necessarily apply to all the other conditions within the set.[3]

In the Brewster (1884), Helmholtz (1926), Lie (1965) and Ono *et al.* (1971) studies, the distance of the illusory wall changed, even though Ittelson's discussion might suggest that the percept should stay constant due to the proximal information being constant. But Ittelson's phrase 'in the absence of other information' is not met here. That is, even though the proximal stimulus stays the same, it is presumably supplemented with 'other information', which in this case is the vergence state of the eyes, and this additional information gives rise to differences in the perceived depth of the illusory wall. In the Logvinenko *et al.* (2001) study, the percept of the illusory wall remained the same, presumably because without an optimal fixation stimulus there is no opportunity for the 'other information' to take effect.

As an aside, we note that the fact that our three conditions, real, illusory, and virtual in Fig. 1, give rise to the same percept neither confirms nor refutes Berkeley's (1709/1910) idea about solipsism. It indicates, however, that the visual system has access to the proximal stimulus but not the distal stimulus, and as such, does not 'know' what 'reality' is. Indeed, the wallpaper illusion in this context reflects the fact that the visual system does not have access to reality (i.e. the actual distance of the wall).

The point we wish to make with Thought-Experiment 1 is that one cannot make a conclusion about whether convergence is responsible for the perceived distances in the three conditions. That is, no one would infer that vergence is not a cue to distance from any one of the three conditions discussed above. Also note that there is no logical advantage to examining the real, the illusory, or the virtual situations; any inference that can or cannot be made from the real situation must necessarily apply to the illusory or simulated situations and vice-versa.

Thought-Experiment 2

Now consider the stimulus situation of Logvinenko *et al.* (2001) depicted in Fig. 2 and do the following. First, keep the outer two rods where they are, remove the middle four rods and prepare five rods that match the retinal image size of the two rods when they are placed at the illusory distance. Second, place each of the five rods in each of the five apparent locations shown in Fig. 2. Finally, use Polaroids to provide the same monocular proximal stimulation of the non-

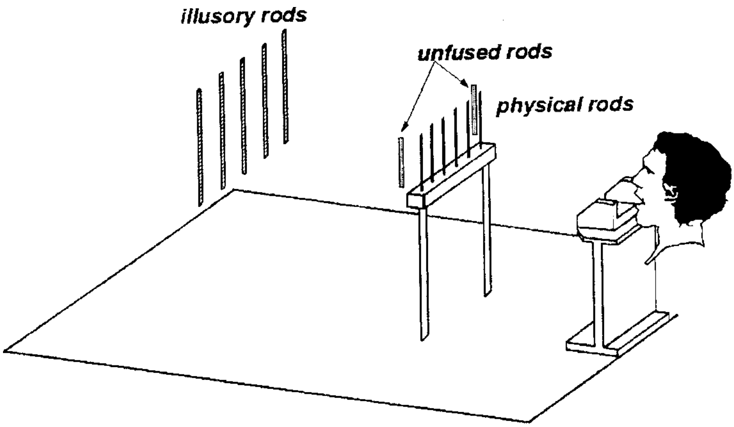

Figure 2. The wallpaper illusion stimulus used by Logvinenko *et al.* (2001).

fused elements. This new stimulus situation will provide the identical proximal stimuli as those from their six rods and corresponds to the 'real' stimulus situation (a) in Thought-Experiment 1. Now, construct a stereogram that has six bars in each half field, and place it in a stereoscope so that the bars on the temporal side will not fuse. This stimulus situation corresponds to the 'virtual' stimulus situation (c) in Thought-Experiment 1. For these two new stimulus situations and the condition of Logvinenko *et al.*'s study, which conceptually corresponds to condition (b) in Thought-Experiment 1, repeat the same eye movements performed in the experiment described in their paper.

Generalizing from Thought-Experiment 1 and Ittelson's discussion, we predict that the perception and the eye movements will be the same in our two new conditions as that reported by Logvinenko *et al.* (2001). As we argued in Thought-Experiment 1, when three stimulus situations produce the same proximal stimulus and the same reafference, then any inferences made from the three situations must be the same. Likewise, any inferences made from the real and virtually real conditions in Thought-Experiment 2 and the Logvinenko *et al.*'s stimulus situation must be the same as well. And, none of the three conditions should lead us to the conclusion that convergence is *not* a cue to absolute distance any more than the three conditions in Thought-Experiment 1.

DISCUSSION

Given that the three conditions of Thought-Experiments 1 and 2 provide identical proximal stimulus information and given that any inference made from one condition necessarily applies to the others, one might ask, "What is the value of the wallpaper illusion, if its proximal stimulus can be reproduced with a 'real' wall?" We attempt to address this issue by considering another thought experiment similar to those done by Brewster (1844), Helmholtz (1910/1962), Lie (1965) and Ono *et al.* (1971) but with an improvement suggested by Howard (Howard and Rogers, 1995). Howard suggested varying the initial fixation distance while presenting 'a repeating pattern consisting only of vertical lines or of a row of dots confined to the horizontal horopter (p. 431)'. Under these conditions, vertical disparity is eliminated as a confounding variable.

Now, instead of, say, using three different initial fixation stimuli and a repeating pattern at a fixed location (the illusory condition), place the three physical locations of the repeating wallpaper pattern at the three initial fixation distances so that they correspond, and then measure the perceived distance (the real condition). The former illusory situation and the latter real situation are identical, from the consideration of the proximal stimulus. As a refinement, we can use lenses so that the accommodation requirement for all three conditions is the same. According to what we have argued, we will get the same results in both the former illusory and latter real conditions; logically there is no difference between the two experiments or the inferences that can be made from them. The question, then, is which experiment shall one do. We are inclined to recommend Howard's suggested 'illusory' experiment. In our minds, it is more dramatic to show that the illusory distance of a wall co-varies with convergence when the actual physical location of the wall remains fixed than it is to show that the perceived distances of the wall are seen at their real locations which corresponds with the point of fixation. We are in some sense more 'psychologically' persuaded or convinced that convergence is a cue to absolute distance when the perceived illusory distance varies with convergence than when its perceived distance corresponds to its actual distance, which in turn varies with vergence. Moreover, we have a stronger sense of what causes the wallpaper illusion, because the experiment directly manipulates the illusion. Perhaps, this psychological advantage is the underlying basis of Logvinenko *et al.*'s (2001) choice of using the wallpaper illusion to make their case.

CONCLUDING REMARKS

To end this note, we wish to make two other points. Beside Logvinenko *et al.* (2001) and Logvinenko and Belopolskii (1994), there are other studies that also simultaneously measured apparent distance and convergence angle. Erkelens and Collewijn (1985) and Regan *et al.* (1986) produced and measured vergence eye movements by oscillating a pair of extended dot patterns in a stereoscope and found no change in absolute perceived distance. This result should not be taken as evidence that vergence is not a cue to absolute distance, however, because oscillating a pair of dots (one presented to each eye) in the same way does produce a weak sensation of motion in depth. The lack of an isotropic change in retinal image size is a cue for the absence of motion in depth in the extended dot pattern condition, and the lack of change in perceived distance indicates that retinal image size is a stronger cue than vergence. Finally, this commentary should not be taken as arguing that there is a definitive answer to the question raised by Logvinenko *et al.* We share the sentiment in their introduction that 'Considerably more effort has gone into discussing Berkeley's hypothesis than has been devoted to designing and carrying out appropriate experiments (p. 78, Logvinenko *et al.* (2001))'. We add to this statement, however, that the appropriate experiments are still wanted.

NOTES

1. The horizontal retinal disparity must be 'scaled' by the 'correct' absolute distance information. This is because retinal disparity, by itself, does not determine a particular depth percept; the same retinal disparity, for example, can arise from two objects located close together or far apart depending on the absolute distances of the two objects. (For a discussion of this scaling, see e.g. Wallach and Zucherman, 1963; Ono and Comerford, 1977; Bradshaw *et al.*, 1996.)
2. In Logvinenko *et al.*'s study, a fixation stimulus was not necessary to fuse the elements of their 'wallpaper' and, in turn, obtain the apparent distance they produced. Their observers could either 'fixate' the wall behind the stimulus or 'imagine' fixating an object further away than the stimulus (as is typically done with the now commercially available 'autostereogram'). For the illusion to 'lock in' at an apparent distance closer than the stimulus, however, a fixation stimulus is required for most observers. Fixating beyond a stimulus is easier than fixating in front of it in the absence of an actual fixation point. It is for this reason that autostereograms typically do not require a fixation stimulus, because they are based on uncrossed disparities. To free-fuse an autostreogram that produces a crossed-disparity, however, usually requires a fixation stimulus.
3. The argument that the two different stimulus situations shown in Fig. 1a and 1b provide the same proximal stimulation (or constitute equivalent configurations) is also made in Ono (1984).

Acknowledgements

Author R. P. K. was supported by an NSERC scholarship. Author H. O. was supported by Grant A0296 from the Natural Sciences and Engineering Research Council (NSERC) of Canada. The authors wish to thank L. Lillakas for preparing the figure and editing the paper, and D. O. Clark, O. Espiritu, P. Grove, V. Khokhotva, A. Mapp, A. Reeves and M. J. Steinbach, for their helpful comments and discussions on an earlier version of this paper.

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