

# Visual perception: **Mind and brain see eye to eye**

Cassandra Moore and Stephen A. Engel

**Recent functional imaging studies have identified neural activity that is closely associated with the perception of illusory motion. The mapping of the mind onto the brain appears to be one-to-one: activity in visual ‘motion area’ MT is highly correlated with perceptual experience.**

Address: University of California, Los Angeles, Department of Psychology, Franz Hall, 405 Hilgard Avenue, Los Angeles, California 90095-1563, USA.

**Current Biology** 1999, 9:R74–R76  
<http://biomednet.com/elecref/09609822009R0074>

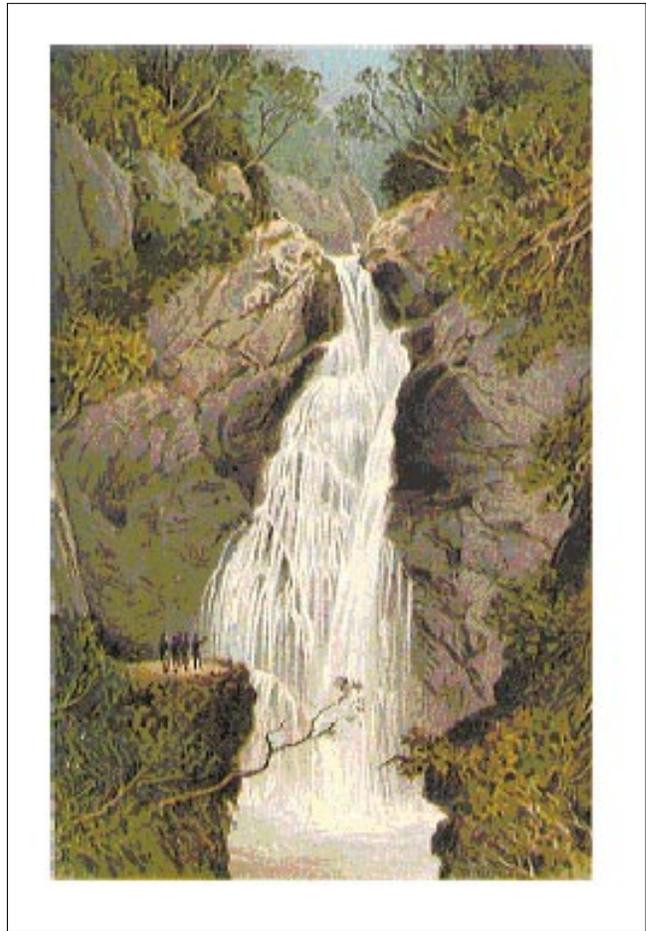
© Elsevier Science Ltd ISSN 0960-9822

One of the ultimate goals of neuroscience is to map the mind onto the brain. The possibility of discovering laws relating human experience to activity in neural tissue seems closer with the continuing development of neuro-imaging techniques. While few of these laws have been firmly established, researchers are beginning to test hypotheses relating specific perceptual experiences to neural activity. One challenge in this endeavor is to design experiments that can separate neural signals reflecting perceptual experience from those that simply reflect properties of the stimulus. This separation of perceptual experience and visual stimulus underlies, for example, many perceptual illusions in which a single visual stimulus yields two strikingly different percepts. Recent functional magnetic resonance imaging (fMRI) studies have used an illusion known as the motion aftereffect to isolate neural activity related to the processing of visual motion.

One of the first observations of the motion aftereffect was reported by Robert Addams in 1834. After staring fixedly at a waterfall in Scotland for an extended period, he shifted his gaze to the adjacent rocks and noticed that they appeared to move upward (Figure 1). The motion aftereffect, or ‘waterfall illusion’ as Addams called it, is the appearance of directional motion in a static object viewed after adapting to real visual motion in the opposite direction [1].

The recent investigations of the neural basis of the motion aftereffect build on a long history of experiments, using a variety of techniques, which have suggested that important stages of the processing of visual motion occur in a region of the visual cortex known as area MT (for ‘middle-temporal’, describing the anatomical location of the equivalent area in the owl monkey brain) [2–4]. Most experiments implicating MT in motion processing have observed neural responses in this area that are selective for

**Figure 1**



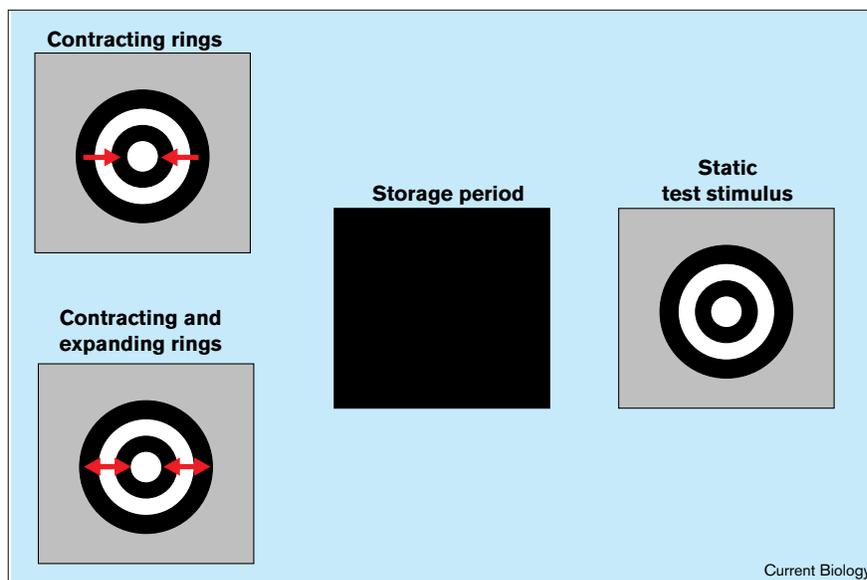
An artist's depiction of the Falls of Foyers, near Loch Ness in Scotland, where Addams first observed the “...sombre age-worn rocks immediately contiguous to the waterfall...as if in motion upwards...”. (From [9].)

moving stimuli. Only a few experiments have correlated activity in area MT with the actual *percept* of motion.

The first fMRI experiment designed to investigate the neural basis of the motion aftereffect found that area MT was selectively active when subjects perceived the illusory motion [5]. Subjects adapted to a unidirectional moving pattern that generated a robust motion aftereffect in the illusion condition, and an oscillating pattern that did not generate a motion aftereffect in the control condition (Figure 2). Subjects then viewed a static pattern that revealed any motion aftereffect. Tootell *et al.* [5] found that activity in area MT was higher when the motion aftereffect was experienced than when it was not. These

Figure 2

A motion aftereffect is perceived when a static display (far right) immediately follows unidirectional motion (top left), but not when it follows oscillating motion (bottom left). The motion aftereffect can also be 'stored' during an intervening period of darkness, and later experienced when the static pattern appears.



Current Biology

results suggested that activity in area MT signals the perception of visual motion, even when no physical motion is present in the stimulus.

The results reported by Tootell *et al.* [5] allow an alternative interpretation, however. Following both adaptation conditions, activity in area MT declined rapidly while the observer viewed the static stimulus. The activity declined more slowly in the motion aftereffect condition compared to the control condition, leading to a relative surplus of activity associated with the motion aftereffect. This differential decline may represent neural firing that signals the presence of motion. Alternatively, the slower decline in activity might simply reflect a more gradual return to the baseline level when the neurons were exposed to unidirectional motion relative to oscillatory motion. If the rate of return to baseline were the cause of the differential decline, the residual activity in the adapted neurons is unlikely to cause the experience of a motion aftereffect, in part because the perceived motion in the motion aftereffect is in the *opposite* direction to the adapting motion.

Two groups of researchers [6,7] have now provided more conclusive demonstrations, and indeed converging evidence, that activity in area MT really does underlie the motion aftereffect. Both groups exploited an aspect of the motion aftereffect known as 'storage'. When observers close their eyes immediately after viewing motion, the motion aftereffect is 'stored' until the eyes are opened and the static inducing stimulus is viewed (Figure 2). If activity in area MT leads to perception of the motion aftereffect, then neither the motion aftereffect, nor activity in area MT, should occur during the storage period.

Both groups found that activity in area MT declined during the storage interval, but the decline was slower after viewing unidirectional motion than after viewing oscillatory motion. As no motion was perceived during storage, these results could be seen as support for the 'alternative' interpretation mentioned above. The two types of motion might simply cause differential rates of return to baseline. But importantly, both experiments then showed post-storage increases in activity in area MT coincident with the onset of the motion aftereffect.

Culham *et al.* [6] used a version of the storage phenomenon in which subjects were in a sealed room with no stray light. Following adaptation, the stimulus was extinguished, leaving subjects in total darkness. After the storage interval subjects were presented with the static stimulus. Neural activity in area MT declined dramatically during storage, then rose substantially when the static inducing stimulus was presented. The increase in neural activity was accompanied by the onset of a motion aftereffect; the activity declined as the perceptual experience of the motion aftereffect waned.

As reported recently in *Current Biology*, He *et al.* [7] capitalized on the topographic organization of area MT, adapting only a portion of the visual field while the rest remained unadapted. Following adaptation, the static inducing stimulus was placed alternately in either the adapted or non-adapted part of the visual field. When the static stimulus was in the adapted region, viewers experienced the motion aftereffect and neural activity in area MT increased; when the static stimulus fell in the non-adapted region, the motion aftereffect ceased and neural activity decreased.

The subjects were adapted for a full 15 minutes, producing a motion aftereffect that lasted long enough to demonstrate this modulatory pattern repeatedly, in a single fMRI scan. The percept and the neural activity rose and fell together as the static stimulus moved between the adapted and the unadapted portions of the visual field.

As a control condition, both experiments were also conducted with an oscillating motion which does not produce a motion aftereffect. In both studies [6,7], neural activity recorded during the static viewing period was greater in the illusion condition than the control condition. The static stimulus was present during both recording periods, but increased neural activity was observed only when the observer experienced the motion aftereffect. Thus, these studies were able to decouple the stimulus from both the percept and the neural activity. In so doing, they observed a correlation between the mental phenomenon and the neural activation.

Several recent neuroimaging studies have taken a similar approach using binocular rivalry, a paradigm in which different images are simultaneously presented to the two eyes. Under these conditions, perception alternates slowly between the two images, as first one image then the other becomes the 'dominant' percept. In the recent study of Tong *et al.* [8], images were superimposed that, when presented alone, selectively activate different cortical regions. During rivalry, each area was more active when the appropriate stimulus became the dominant percept. Once again, a constant stimulus was presented, but neural activity rose and fell with the perceptual experience of the observer.

The two papers investigating the motion aftereffect [6,7] provide excellent examples of how neuroimaging techniques are being used to uncover the relationship between the mind and the brain. He *et al.* [7] have shown that activity in area MT can rise and fall repeatedly in concert with the perceptual experience of the motion aftereffect. Culham *et al.* [6] have shown the same synchrony, but traced out an entire cycle of adaptation, storage and aftereffect, recording substantial neural activity followed by a drop below the resting activity, then a rebound to a near pre-storage level of activity. In the case of the motion aftereffect, the mapping of the mind onto the brain appears to be one-to-one: activity in area MT is highly correlated with perceptual experience. Although the mapping rules governing other perceptual and cognitive phenomena are certain to be more complex, these studies provide an important step in understanding how neural activity gives rise to mental phenomena.

## References

1. Anstis S, Verstraten FAJ, Mather G: **The motion aftereffect.** *Trends Cogn Sci* 1998, **2**:111-117.
2. Allman JM, Kaas JH: **A representation of the visual field in the caudal third of the middle temporal gyrus of the owl monkey (*Aotus trivergatus*).** *Brain Res* 1971, **31**:85-105.
3. Britten KH, Shadlen MN, Newsome WT, Movshon JA: **The analysis of visual motion: a comparison of neuronal and psychophysical performance.** *J Neurosci* 1992, **12**:4745-4765.
4. Zeki S, Watson JDG, Lueck CJ, Friston KJ, Kennard C, Frackowiak RSJ: **A direct demonstration of functional specialization in human visual cortex.** *J Neurosci* 1991, **11**:641-649.
5. Tootell RBH, Reppas JB, Dale AM, Look RB, Sereno MI, Malach R, Brady TJ, Rosen BR: **Visual motion aftereffect in human cortical area MT+ and related visual cortical areas using magnetic resonance imaging.** *Nature* 1995, **375**:139-141.
6. Culham JC, Dukelow SP, Willis T, Hassard FA, Gati JS, Menon RS, Goodale MA: **Recovery of fMRI activation in motion area MT following storage of the motion aftereffect.** *J Neurophys* 1999, **81**:388-393.
7. He S, Cohen ER, Hu X: **Close correlation between activity in brain area MT/V5 and the perception of visual motion aftereffect.** *Curr Biol* 1998, **8**:753-759.
8. Tong F, Nakayama K, Vaughn JT, Kanwisher N: **Binocular rivalry and visual awareness in human extrastriate cortex.** *Neuron* 1998, **21**:753-759.
9. *Souvenir of Scotland: Its Cities, Lakes and Mountains.* London: T Nelson and Sons; 1893.