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What is 'up'? A reply to Bridgeman et al

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The brain considers a stimulus is 'up' if, for example:

(A) It occurs in a *retinal* location that in the past has been associated with things that are considered to be 'up' (the sun, the sky, the ceiling).

(B) It can be foveated by *moving the eyes* (*or head*) in a direction whose motor coordinates have independently been labeled as 'up'.

(C) it has the property *that it can be reached* by an 'upwards' limb motion. Here, importantly, the limb and the visual stimulus are *seen together*.

Co-occurrences such as the above are used to establish, over many years, a coherent visuo-motor frame of reference defining spatial directions.

How is this established frame of reference challenged by the experiment reported by Bridgeman et al? Consider the case where the finger moves downwards on the canthus.

(a) A visual stimulation occurs in the visual field in a position habitually linked with things that are 'up'. Because there is nothing else visible in the visual field, there is nothing to contradict the usual retinal interpretation that the movement is 'up'.

(b) No eye (or head) movements are made to foveate the visually perceived stimulation, so nothing modifies the usual link between retinal stimulation and eye (or head) movements. No change is expected in the usual notion of 'up' from this source.

(c) There is indeed co-occurrence of a finger command which is 'down' on the canthus, but the finger is not simultaneously in view with the visually perceived phosphene. Thus, there is no strong reason to expect modification of the usual link between perceived direction of 'up' and limb position. This point is critical: just having simultaneous upward movement of a phosphene coupled with downward finger action *in some other, unseen, location* is not at all what has been previously used to establish the visuo-motor frame of reference.

(d) There is co-occurrence of downwards tactile stimulation on the eyelid and upward visual movement. But tactile stimulation on one's own skin and stimulation in the visual field are usually not systematically linked and have not in previous experience been used to establish the notion of 'up'. Thus there is little reason for this co-occurrence to modify the perceived direction of 'up'.

In conclusion there is no reason to think that in the Bridgeman et al experiment, subjects' notions of up and down should be modified.

To caricature the experiment, consider using your computer mouse upside down. With practise you can adapt to this, but nobody would expect such adaptation to modify your spatial notions of up or down. The reason is that you are looking at the cursor on the screen, not your hand moving the mouse. If by some video trickery it were possible to arrange things so that when you looked at your hand go up, you saw it go down, then adaptation would be expected. Prism, goggle, and, more recently, rubber-hand experiments indeed successfully use this principle to obtain changes in visual and tactile reference frames.

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