which are currently well understood. More generally, we note that while much is becoming known of mushroom body neurons, their connectivity and their modulation, there remains a major general lacuna in understanding how these changes result in the wide range of altered behaviours.

Finally, by specifying neurons from which serotonin release and serotonin response occur to modulate a depression-like behaviour, the work lays down a marker for precision in investigating the role of serotonin in mood regulation and reignites the ongoing debate on the serotonin hypothesis for human depression[19].

DECLARATION OF INTERESTS

The authors declare no competing interests.

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Visual motion: Asymmetrical processing differences between the cerebral hemispheres

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Hemispheric differences speak to the functional organisation of the human brain. A new study causally demonstrates such differences are present in bilateral motion-selective areas that are early in the visual cortical hierarchy.

A football goalkeeper making a save does not have time to stop and think. Success depends on tracking the motion of a fast-moving ball, while also monitoring and understanding the movements of the attacking and defending players. These dynamic biological and non-biological visual objects need to be integrated into a unified and coherent percept that can

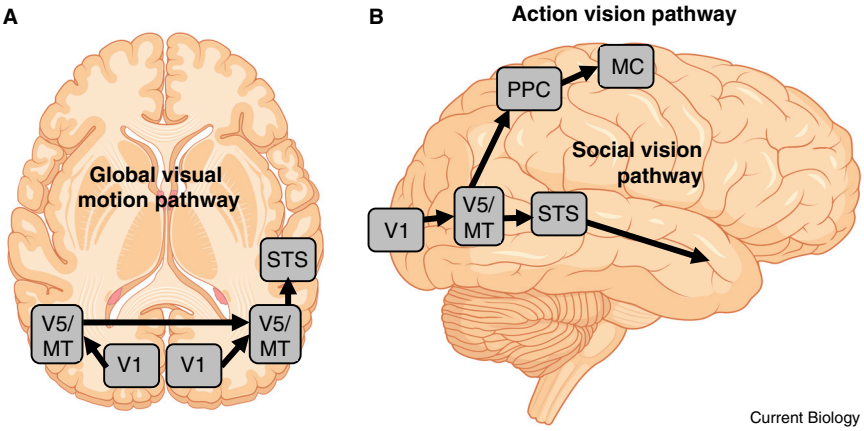

Figure 1. The putative cortical connectivity of the visual pathway for global visual motion processing.
(A) A schematic representation of the cortical pathway for global visual motion processing as suggested by the results of Chiappini, Sel *et al.*[1]. Visual motion information from the two visual fields is initially processed in contralateral V1, before being integrated into a global motion percept in right V5. Neuroanatomical and functional brain imaging data further suggest a functional pathway from right V5 to the right superior temporal sulcus (STS) that is specialised for the dynamic aspects of social perception, such as facial expressions or body movements[13,14]. (B) The extended cortico-cortical connectivity that projects from right V5 to higher cortical areas. These include the posterior parietal cortex (PPC) and motor cortex (MC), brain areas in a functional pathway that is specialised for performing visually guided physical actions[9,10]. Neuropsychological patients exhibiting damage to the right PPC fail to attend to objects in the left visual field[11], causally demonstrating that the right hemisphere is necessary for a global representation of visual space.

facilitate successful behaviours in a split second. Understanding the neural mechanisms that underpin these processes is a central challenge for visual neuroscience. In this issue of *Current Biology*, Chiappini, Sel *et al.*[1] report how they used brain stimulation to demonstrate a functional dissociation between the roles of the two cerebral hemispheres at an early level of the cortical visual hierarchy. Their results causally demonstrate that the integration of visual motion is preferentially processed in the right hemisphere.

The human visual system is organised retinotopically across the two hemispheres. At the earliest level of visual cortex, area V1, visual information from the right visual field is processed in the left hemisphere, and visual information from the left visual field is processed in the right hemisphere. At progressively higher levels, visual cortex begins to exhibit an increasingly greater neural response to visual input from the ipsilateral visual field[2]. In addition to this increase in ipsilateral visual field response, higher visual areas also exhibit selective responses to different visual categories. Motion, one of the most fundamental visual categories, is processed in a bilateral motion-selective area called V5[3] (also called area MT[4]). A contralateral visual field bias is observed in V5, but this bias decreases as the response is measured in the more anterior areas of V5[4]. This suggests that visual motion information from the two visual fields is being integrated and processed across the bilateral V5 areas into a single coherent percept of all the moving objects we track in the world around us. While visual field mapping studies give precise measurements of the response in visual areas, they cannot explain how these areas selectively contribute to the conscious perceptual experience that underpins behavioural responses. One way to do this is to directly stimulate the visual areas of experimental participants.

Transcranial magnetic stimulation (TMS) is an experimental method that enables researchers to modulate the neuronal response in a targeted brain area. The impact of this modulation can then be measured using the standard tools of behavioural psychology, for example task accuracy or reaction times. Chiappini, Sel *et al.*[1] used an elegant TMS protocol that enabled them to selectively increase the strength of the neural pathway between left and right V5 across a series of three experiments. This protocol, called cortico-cortical paired associative stimulation (ccPAS)[5], is based on Hebbian principles[6]: it is designed to mimic the neuronal stimulation that induces the spike-timing-dependent plasticity (STDP) that is believed to support the learning and storage of novel information. In practical terms this means that each TMS pulse delivered over left V5 is immediately followed by a TMS pulse delivered over right V5 (or *vice versa*). The first pulse (to left V5) pre-activates the neural pathway to right V5 (via the corpus collosum) prior to the delivery of the second pulse (to right V5), strengthening the connectivity between the two areas and thereby enhancing concurrent behavioural performance.

Chiappini, Sel *et al.*[1] used this ccPAS design in both directions, right to left and left to right, while experimental participants performed a psychophysical task designed to measure the perception of horizontal motion. Their results show a functional dissociation between the two hemispheres: namely that strengthening the pathway from left V5 to right V5 enhanced perceptual sensitivity to horizontal visual motion perception (Figure 1A). This pattern was not observed when strengthening the pathway from right V5 to left V5. Their findings are consistent with a literature demonstrating that the right hemisphere integrates visual input from both visual fields into a coherent global percept[7,8]. But why is this lateralised response to global motion preferentially processed in right V5, a visual area that is relatively early in the cortical hierarchy?

To begin to answer this question it is worth reconsidering the dynamic visual scene that confronts the football goalkeeper. They need to track and predict the movements of both non-biological (the ball) and biological (other players) objects across the entire visual field. A hierarchical model of visual cortex proposes that visually guided physical actions, such as catching a football, are processed in a specialised cortical pathway that projects from early visual cortex, via V5, into the parietal lobe and then into the motor cortex[9,10] (Figure 1B). As with V5, differences between global

and local processing have also been observed in the parietal lobe. One of the most well studied such differences is revealed by the neurological disorder known as visual neglect[11]: patients with visual neglect fail to attend to visual objects presented in the visual field contralateral to their lesion site. Crucially, visual neglect most commonly results from a lesion to right inferior parietal lobule, causing patients to ignore objects in the left side of visual space[11]. Furthermore, a lesion to the right, but not to the left, parietal lobe can cause visuospatial navigation errors[12], again demonstrating that the right hemisphere is necessary for a global representation of visual space.

Predicting the motion of the football is only part of the goalkeeper's job. Success is also predicated on understanding and predicting the actions of the other players. The visual cues we use to interpret the behaviour and intentions of other people are generated by the movements and actions of their faces and bodies. These include facial expressions, eye gaze, body movements and the audio-visual integration of speech. One region of the brain, the superior temporal sulcus (STS), computes the incoming sensory information that facilitates these cognitive processes[13]. A cortical pathway specialised for social perception that projects from V5 into the STS has recently been proposed[14] (Figure 1A,B). This is consistent with the increasing representation of the ipsilateral visual field seen in the posterior to anterior visual motion areas of the STS in macaque monkeys[15] and in human participants viewing moving faces[16]. TMS delivered over the right STS also disrupts facial expression recognition to a greater extent than TMS delivered over left STS[17]. These results are consistent with the findings of Chiappini, Sel *et al.*[1] in showing a greater representation of global processing, for example processing of whole faces, in the right STS. But this conclusion suggests an obvious question, what functional roles are being preferentially performed in the left hemisphere?

One of the most robust structural asymmetries observed between the left and right hemispheres is the size of the planum temporale[18], a brain area adjacent to the STS. The planum temporale is part of the temporal speech cortex and is typically larger in the left hemisphere. This has led to speculation that the right lateralised responses observed in the human STS, for example for moving faces, may have been driven by the development of language specialization in the left hemisphere[19]. A direct test of this hypothesis was performed by comparing the lateralised response to moving faces in humans and macaque monkeys: the results showed that dynamic faces exhibited a right lateralised response in the human STS, but this lateralised response was absent in the macaques.

The results reported by Chiappini, Sel *et al.*[1] are exciting on both a conceptual and methodical level. The causal demonstration that global motion processing is preferentially processed in right V5 builds on long established data from neuropsychological patients[9,11,12]. But in addition, their creative use of the ccPAS TMS protocol suggests exciting potential directions for future research. Studies can be designed to selectively modulate the strength of the neural connectivity between V5 and a range of brain areas (Figure 1A,B) that perform different visual and auditory cognitive functions. For example, direct structural connections between visual (V5) and auditory (planum temporale) motion-selective areas have recently been identified in the human brain[20]. TMS experiments can be designed to investigate the functional roles of these connections, both within and across hemispheres. Such studies would be a methodical tour de force, combining detailed individual structural brain mapping with the causal inferences made possible in brain stimulation experiments.

DECLARATION OF INTERESTS

The author declares no competing interests.

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Microtubule cytoskeleton: Revealing new readers of the tubulin code

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Microtubule networks are thought to be controlled by an elaborate program of tubulin posttranslational modifications and proteins that selectively bind to modified states. A new study identifies proteins that bind tyrosinated tubulin, revealing a novel recognition mechanism.

Microtubules are cylindrical polymers made of thousands of heterodimeric α–β-tubulin subunits, and every α–β-tubulin subunit exhibits a high degree of amino acid sequence conservation across eukaryotes. This gives the impression that the molecular landscape of the microtubule surface may be rather monotone, and unlikely to inform the functional diversification of microtubule networks in cells. However, α and β-tubulin subunits are known to exhibit a wide range of posttranslational modifications (PTMs) that provide potential for biochemical complexity beyond the genetically encoded amino acids in α–β-tubulins. A new study by Hotta and colleagues[1], published in this issue of *Current Biology,* explores this potential and identifies proteins that recognize the presence of a single tyrosine residue on α-tubulin and use this to control the dynamics of microtubule polymers.

Tubulins are targeted for a wide array of PTMs. These include modifications that are common to many other proteins, such as phosphorylation, acetylation, sumoylation and methylation. In addition, there are modifications that are more selective for tubulin such as tyrosination, where a genetically encoded tyrosine can be cleaved and re-ligated to the carboxy-terminus of α-tubulin, and polyglutamylation and polyglycylation, where chains of glutamate or glycine residues are attached to the γ-carboxyl of genetically encoded glutamate residues in the carboxy-terminal tails of α and β-tubulins. Genetic studies where investigators prevent tubulin PTMs by either ablating the modifying enzymes or altering the substrate amino acids reveal a range of defects in microtubule function, from disruption of the axonemal structures in cilia and flagella to neuropathies[2]. This indicates that PTMs play important roles in distinct microtubule functions.

The requirement for specific tubulin PTMs for subsets of microtubule functions gave rise to the 'tubulin code hypothesis', which states that PTMs, either alone or in combination, create a molecular code that is read by microtubule-associated proteins that then go on to affect microtubule functions[3,4]. The tubulin code hypothesis is analogous to the 'histone code' hypothesis, which relates to PTMs on lysine residues in the disordered, amino-terminal tails of histones[5]. It is well-established that histone modifications impart regulatory complexity into the genome by altering the physical properties of nucleosomes and/or the recruitment of regulatory proteins. The histone code and tubulin code models share the same basic components: first, a substrate protein (tubulin or histone); second, enzymes that 'write' the code through catalysing PTMs; third, effector proteins that 'read' the code by selectively binding to the modified or unmodified state of the substrate; and finally, enzymes that 'erase' the code by catalysing the removal of the PTM. The α–β-tubulin heterodimer is a rich substrate for modification. Many of the modified amino acids are located in the carboxy-terminal tail regions of α- or β-tubulin, which are the most divergent regions across tubulin genes, and could thereby add another layer of regulation by altering the availability of substrate through changes in gene expression. Many 'writer' and 'eraser' enzymes for tubulin PTMs have been identified, including enzymes that appear to exclusively target tubulin substrates and those that also target other substrates, such as the methyltransferase SETD2[6]. The recent identification of MATCAP as a new tubulin detyrosinase[7] is evidence that our knowledge of tubulin-modifying enzymes is likely incomplete and remains an important area of