

LETTER TO THE EDITOR

Unifying control over the body: consciousness and cross-cueing in split-brain patients

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Sir,

More than half a century of scientific work with split-brain patients has resulted in various profound insights on how the brain works. The generous dedication of these patients has truly transformed how we think about the brain and profoundly inspired the developing field of cognitive neuroscience. However, several questions raised by the work with split-brain patients still evoke controversy, one of the most prominent being whether separating the two cerebral hemispheres by cutting the corpus callosum may lead to two distinct conscious systems or not. In other words, is it possible to assume that a patient could be seen as two patients after the surgery?

In their recent study, Pinto and colleagues argued that their empirical data represent evidence for the notion that while (visual) perception in split-brain patients is divided, the resulting pair of perceptual systems are integrated into one conscious agent (Pinto *et al.*, 2017c). In a review that preceded their original manuscript, Pinto *et al.* (2017a) referred to this idea as the ‘conscious unity, split perception model’. In our recent review, we addressed the interpretation offered by Pinto and colleagues and offered an alternative explanation: the reported experimental observations may well be explained by cross-cueing between the hemispheres, without the need for a single integrated conscious control (Volz and Gazzaniga, 2017). Pinto and colleagues now argue against our perspective in a recent letter, stating that we did not present ‘substantive evidence’ for our interpretation (Pinto *et al.*, 2017b). While we want to avoid a repetitive exchange on methodological aspects of the performed experiments, we do believe that something can be gained from the careful interpretation of split-brain findings, especially regarding their implications for our understanding of consciousness. Accordingly, we briefly address the points made by Pinto and colleagues in their response

to the caveats we outlined regarding the interpretation of their work.

One of the most essential points that Pinto *et al.* addressed is the lack of a formal definition of cross-cueing, rendering a meaningful discussion rather difficult. We agree with the authors, as the portrayal of cross-cueing in their manuscript does not overlap too much with ours: ‘... cross-cueing (one hemisphere informing the other hemisphere with behavioural tricks, such as touching the left hand with the right hand)...’ (Pinto *et al.*, 2017c). While such a simple description may potentially be accurate when testing a patient immediately after surgery, we have to emphasize the fact that the investigated patients underwent surgery many years prior to testing. Hence, the separated perceptual systems had ample time to learn how to compensate for the lack of commissural connections. For example, subtle cues may be given by minimal movements of the eyes or facial muscles, which might not even be visible to an external observer but are capable of encoding, for example, the location of a stimulus for the hemisphere that did not see it. Conversely, encoding the identity of a stimulus, i.e. what kinds of objects were presented to one visual field, seems far more complex. The resulting empirical prediction regarding Pinto *et al.*’s experiments would hence be that information on the location of a stimulus may be readily transferred between hemispheres via cross-cueing (enabling accurate stimulus localization in the ‘incongruent condition’), while the identity of a unihemispherically presented stimulus remains lateralized (not allowing stimulus identification in the ‘incongruent condition’). Indeed, this is exactly what Pinto and colleagues observed: the split-brain patient was able to report the location but not the identity of a stimulus in the incongruent condition, e.g. correctly locating a stimulus with the right hand or verbally (i.e. using the left hemisphere) even if it was exclusively

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presented to the left visual field (i.e. to the right hemisphere) (Pinto *et al.*, 2017c). The authors now discard the alternative cross-cueing explanation by pointing out that the reaction times in the ‘congruent’ and ‘incongruent’ conditions were not significantly different when stimulus location was indicated with the right or left hand (Pinto *et al.*, 2017b). In other words, if cross-cueing were to explain these results, it would have to be nearly as fast as the intrahemispheric information processing in the ‘congruent condition’. While this seems unlikely for a neural system that is accustomed to relying on interhemispheric integration via the corpus callosum (healthy volunteers or patients immediately after surgery), it is critical to note that the tested patients underwent surgery many years before these tests were carried out and had to rely on the efficient integration of information between hemispheres in the absence of callosal connections ever since. For example, when navigating through the world by walking or driving, making the location of an obstacle suddenly appearing in one visual field (i.e. visible to one hemisphere) accessible to the other hemisphere in order to enable a coordinated motor response (e.g. to avoid a collision) seems to constitute a crucial skill. Hence, as elaborated below, the empirical observations reported by Pinto *et al.* are neither surprising nor entirely novel.

Cross-cueing is not the only alternative explanation for the findings presented by Pinto and colleagues. Several seminal studies in split-brain patients have reported that crude information concerning the spatial location of stimuli can be cross-integrated (for further details see Gazzaniga, 2000). As early as 1968, Trevarthen concluded from research in split-brain monkeys that visual projections to the midbrain that subserve orientation in ambient space might be involved in the transfer of information on the location of objects in the split-brain via intact interhemispheric midbrain connections (Trevarthen, 1968; Trevarthen and Sperry, 1973). Such a subcortical transfer of crude information about stimulus location may well have contributed to the accurate localization responses in the ‘incongruent conditions’ of Pinto *et al.*’s Experiment 1.

Alternatively, it was suggested many years ago that either hand can be controlled by either hemisphere for simple pointing tasks (Gazzaniga, 1964, 1966a, b; Gazzaniga *et al.*, 1967). Thus, localizing the stimulus in the ‘incongruent condition’ via hand movements in Pinto *et al.*’s Experiment 1 may have principally been controlled by the hemisphere that also perceived the stimulus. Such an ipsilateral motor control might also account for the lack of a significant reaction time difference between the ‘congruent’ and ‘incongruent conditions’ in Pinto *et al.*’s experiment where subjects responded to a lateralized target’s colour with the right or left hand. Kingstone and Gazzaniga (1995) demonstrated how ipsilateral motor control of the hand could be misinterpreted as a purported transfer of conceptual information between the hemispheres in the absence of the corpus callosum (Sergent, 1990). For example, when Patient JW was shown the word ‘arrow’ in one

hemisphere and the word ‘bow’ in the other, his left hand would draw both a bow and arrow, indicating an apparent integration of concepts. However, that was only illusory. When instead, Patient JW was shown the words ‘hot’ and ‘dog’ in opposite hemispheres, his left hand would first draw a fire (corresponding to the word seen by his right hemisphere) and then draw a dog on top of it (the word seen by his left hemisphere indicating ipsilateral control). At no time, did the patient draw the emergent concept of a hot dog (see also Miller and Kingstone, 2005).

It should be noted that ipsilateral motor control could not explain the finding that split-brain patients made accurate verbal responses to stimuli presented in the left visual field (as in Experiments 2A, 2B, 3A, 3B and 4B of Pinto *et al.*, 2017c). However, when perception and cognition in commissurotomy patients are inferred from their verbal responses, special precautions must be taken to rule out the possibility of cross-cueing of information from the mute right hemisphere to the speaking left hemisphere. Gazzaniga and Hillyard (1971) showed that Patients LB and CC could respond verbally to one of two alternative numbers flashed to the left visual field, but the verbal reaction times for these binary choices were 200–300 ms longer than when the numbers were flashed to the right visual field (i.e. directly to the speaking hemisphere). Most strikingly, Patient LB could make accurate verbal reports to each of a set of numbers from 2 to 9 flashed one at a time to his left visual field, but with reaction time increasing linearly for larger numbers. Patient LB admitted to a (conscious) cross-cueing strategy wherein he (his speaking left hemisphere) counted subvocally until one of the numbers ‘stood out’. Whether this transfer of information between the hemispheres was mediated by subliminal muscular activity or intracranially (subcortically) was not clear. In general, whenever a commissurotomy patient is making a binary choice or selecting from a limited set of response alternatives, cross-cueing must be considered and ruled out, for example by examining reaction time measures. Unfortunately, Pinto and colleagues did not report reaction times for the above-mentioned experiments; if there were reliable reaction time differences between conditions this would strongly indicate a cross-cueing or alternative information transfer mechanism (Gazzaniga and Hillyard, 1971). Empirically controlling for cross-cueing, e.g. via continuously recording eye movements and muscle activation throughout the experiment, or differentiating hemispheric contributions via recordings of neural activity during task performance using EEG, functional MRI, functional near-infrared spectroscopy (fNIRS) or comparable approaches may constitute ways to reveal the nature of task-specific information transfer between the surgically separated hemispheres.

In summary, Pinto and colleagues based fundamental claims regarding the nature of consciousness on behavioural observations that can be interpreted differently, in particular as consequences of cross-cueing, ipsilateral motor control, and/or subcortical information transfer.

In other words, the conclusion that a unified consciousness arises from largely separated systems only seems warranted if a number of alternative explanations has been ruled out. The existing evidence for two separate, independent streams of visual perception and hence visual consciousness in the surgically separated hemispheres seems compelling to us, and the data presented by Pinto *et al.* do not dissuade us. Consider the following two experiments: (i) Holtzman and Gazzaniga (1985) showed that split-brain patients could accurately perceive and remember two separate sequential visual patterns, one in each visual field, and match either of them to a subsequent probe sequence, while intact control subjects could not remember both sequences. (ii) Luck *et al.* (1994) showed that split-brain patients could identify a patterned visual target in a search array roughly twice as fast when the array was divided between the right and left visual fields (with each hemisphere seeing half the array) compared to when the array was presented to one visual field. Normal controls showed no such benefit of dividing the array. Pinto *et al.* argue that such results are not convincing evidence for separate spheres of consciousness because some experiments have shown better performance for divided-field arrays in normal, intact subjects. But the above-cited experiments *did* compare patients with normal controls, and the controls, unlike the patients, showed no evidence of a dual, independent processing capability.

Looking at all the evidence, we believe that the most parsimonious and logical conclusion is that the right hemisphere of the commissurotomy patients includes a stream of consciousness that is separate from that of the left hemisphere, but the two hemispheres may interact closely via cross-cueing and subcortical connectivity. The evidence for a separate conscious stream in the right hemisphere includes the following observations: while pictures and objects in the left visual field cannot be named through overt speech, they can be matched with written or spoken words, matched to conceptually related items, stored in short term memory for matching with subsequent probes (Gazzaniga, 1995). Moreover, high-level cognitive judgements of the right hemisphere can initiate appropriate and accurate motor responses without the knowledge of the speaking hemisphere (Gazzaniga, 2000). It is difficult to believe that such a high level of visual cognition could occur without a separate foundation of consciousness in the right hemisphere.

Finally, cross-cueing should not be simply viewed as ‘(unconscious) cheating’ (Pinto *et al.*, 2017b), but as an incompletely understood mechanism that allows for information integration in the absence of direct neural connections and

hence considerably contributes to the quality of life of split-brain patients. Hence, while we argue for a separate stream of visual consciousness in the right hemisphere, we agree with Pinto *et al.* that the seemingly normal, bilaterally integrated behaviour following commissurotomy requires further explanation. Despite illustrating the ingenious capacity of human adaptation, cross-cueing itself may hold valuable insights on how the intact brain integrates information from highly specialized neural systems.

References

- Gazzaniga MS. Cerebral mechanisms involved in ipsilateral eye-hand use in split brain monkeys. *Exp Neurol* 1964; 10: 148–55.
- Gazzaniga MS. Interhemispheric cuing systems remaining after section of neocortical commissures in monkeys. *Exp Neurol* 1966a; 16: 28–35.
- Gazzaniga MS. Visuomotor integration in split-brain monkeys with other cerebral lesions. *Exp Neurol* 1966b; 16: 289–98.
- Gazzaniga MS. Principles of human brain organization derived from split-brain studies. *Neuron* 1995; 14: 217–28.
- Gazzaniga MS. Cerebral specialization and interhemispheric communication: does the corpus callosum enable the human condition? *Brain* 2000; 123: 1293–326.
- Gazzaniga MS, Bogen JE, Sperry RW. Dyspraxia following division of the cerebral commissures. *Arch Neurol* 1967; 16: 606–12.
- Gazzaniga MS, Hillyard SA. Language and speech capacity of the right hemisphere. *Neuropsychologia* 1971; 9: 273–80.
- Holtzman JD, Gazzaniga MS. Enhanced dual task performance following corpus commissurotomy in humans. *Neuropsychologia* 1985; 23: 315–21.
- Kingstone A, Gazzaniga MS. Subcortical transfer of higher order information: more illusory than real? *Neuropsychology* 1995; 9: 321–8.
- Luck SJ, Hillyard SA, Mangun GR, Gazzaniga MS. Independent attentional scanning in the separated hemispheres of split-brain patients. *J Cogn Neurosci* 1994; 6: 84–91.
- Miller MB, Kingstone A. Taking the high road on subcortical transfer. *Brain Cogn* 2005; 57: 162–4.
- Pinto Y, de Haan EH., Lamme VAF. The split-brain phenomenon revisited: a single conscious agent with split perception. *Trends Cogn Sci* 2017a; 21: 835–51.
- Pinto Y, Lamme VAF, de Haan EHF. Cross-cueing cannot explain unified control in split-brain patients. *Brain* 2017b; 140: e68.
- Pinto Y, Neville DA, Otten M, Corballis PM, Lamme VAF, Haan EHF De. Split brain: divided perception but undivided consciousness. *Brain* 2017c; 140: 1231–37.
- Sergent J. Furtive incursions into bicameral minds: Integrative and coordinating role of subcortical structures. *Brain* 1990; 113: 537–68.
- Trevarthen C, Sperry RW. Perceptual unity of the ambient visual field in human commissurotomy patients. *Brain* 1973; 96: 547–70.
- Trevarthen CB. Two mechanisms of vision in primates. *Psychol Forsch* 1968; 31: 299–337.
- Volz LJ, Gazzaniga MS. Interaction in isolation: 50 years of insights from split-brain research. *Brain* 2017; 140: 2051–60.