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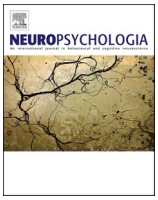

Independent and unified consciousness co-existence in commissurotomy cases

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ABSTRACT

Independent hemispheric consciousness was observed following complete commissurotomy under controlled laboratory conditions that restricted stimulus input and response output to a single hemisphere. Hemispheric specialization was investigated in this way. Consciousness of the self was tested directly as well and found to be represented in each of the hemispheres. Unified consciousness was evidenced in unaltered personality, character, humor, and past knowledge (autobiographical and knowledge of the world). Intact cortico-subcortical projections to intact subcortical regions are offered as explanation for why both unified and independent are possible in the same brain.

Advances into the neural underpinnings of consciousness has led to renewed interest in behavioral findings from "split-brain" studies (de Haan et al., 2020). The recent publications on the topic have questioned interpretations of independent consciousness exhibited by the left and right cerebral hemispheres in the face of unified consciousness as gleaned from complete commissurotomy patients reported in the past (Sperry, 1974), but in doing so have overlooked actual findings and ignored the neuroanatomical bases upon which they rest. Possibly, the unclarity may stem from the misleading, non-clinical term "split-brain"; it implies the whole brain is "split" whereas, in fact, it is a type of therapeutic surgery performed on bundles of white matter fibers, commissures, that run transversely between the two cerebral hemispheres in the neocortex, while leaving the rest of the brain intact (Bogen, 1985). Addressing co-existence of independent and unified consciousness shown in complete commissurotomy studies in Roger Sperry's lab at Caltech, California (Sperry, 1969), can go a long way to un-muddy the waters and contribute to further neural understanding of consciousness.

Unified consciousness was the most remarkable, immediately observed, and repeatedly described outcome following the single-stage surgical complete sectioning of the axons making up the corpus callosum (not removal) along with the two other forebrain commissures, anterior and hippocampal (Sperry, 1974). Everyday behavior, humor, personality traits, character attributes, past knowledge, memories and self-awareness of food and clothing preferences, interests, and family relations attitudes appeared to remain unaltered. The person after the surgery remained the same. In contrast, the independent consciousness of the left and right hemispheres was discovered under laboratory conditions where it was possible to test each hemisphere directly with respect to perception, cognition, memory and consciousness. Together, these observations showed that the unified and the independent consciousness can co-exist in the same brain, the same person, and there is currently no valid scientific reason to view this as a contradiction.

The unified presentation is explained by the fact that hemispheric cortico-subcortical structures and connections to areas "below the forebrain commissures" were not divided surgically, they remained intact. The role of subcortical regions in the unified consciousness presentation has recently been reviewed and emphasized (M. Corballis, P. Corballis, Berlucchi and Marzi, 2018). Furthermore, clinical observations have long pointed to the thalamus and the brain stem for maintaining consciousness (see Koch et al., 2016) and this was confirmed in recent years with neuroimaging (see Uddin, 2020). Thus, the phenomenon of independent and unified in complete commissurotomy can reasonably be explained by the possibility that normally, subcortical regions enable general consciousness through distributed neural networks and that unless activated on a molecular level (action potentials, synapses, neurotransmitters) expressions of genetically determined, developed, and stored hemispheric functions would not be realized and observed.

The very issue of hemispheric consciousness, specifically of the self, was in fact studied with complete commissurotomy cases (Sperry, E. Zaidel, & D. Zaidel, 1979). The study measured both autobiographical and world knowledge. The input consisted of pictorial stimuli lateralized to one hemisphere at a time, requiring explicit yet non-verbal judgment of the content (a verbal response would have biased in favor of the left

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hemisphere and would not have measured the functionality of the right). The results revealed (1) consciousness of the self in each of the disconnected hemisphere, and (2) no significant difference between the two regarding knowledge and awareness of the self. "The results appear to indicate that the concept of the self and general social awareness are both present and well developed in the disconnected minor [right] hemisphere exhibiting a level of involvement essentially comparable to that found in the language dominant [left] hemisphere." (p. 154, Sperry et al., 1979).

Hemispheric specialization in the brain describes separate yet complementary functions across multiple domains of human cognition (knowledge, problem solving, memory). Since consciousness is part and parcel of this arrangement, one could reasonably posit, "no consciousness, no hemispheric specialization." Investigations into consciousness have not yet identified level, degree, stability, or "amount" of consciousness in each hemisphere with neural signatures or otherwise. Such qualitative and quantitative features might be entirely under subcortical control. The possibility that general consciousness can be neurally translated by such subcortical regions into specialized hemispheric-type consciousness is reasonable although it has yet to be investigated. What is obvious is that whenever problem solving, understanding, remembering, feeling, or sensing is underway one assumes from the behavioral response that conscious awareness is present. That consciousness can be functional even in a single hemisphere is evidenced in patients who have undergone hemispherectomy (Uddin, 2020), thus concluding that it can be present in two hemispheres, albeit neocortically disconnected, in the same brain is parsimonious. Countless studies with complete commissurotomy have revealed hemispheric differences (as well as similarities) across multiple intellectual domains (see E. Zaidel, D. Zaidel and Bogen, 1999). These abilities would not have been observed if conscious awareness was absent.

In considering the neuroanatomical underpinning of consciousness, it is worth noting that not all surgical interruptions of corpus callosum fibers are identical, consequently the behavioral outcomes cannot validly be compared across the board. Unlike complete commissurotomy, for example, behavioral studies of partial commissurotomy (incomplete sectioning of the corpus callosum) found presence of interhemispheric transfer for all tasks, thus hindering demonstration of hemispheric specialization, or even independent hemispheric consciousness, with the same methodology as applied with complete commissurotomy (Sperry, 1974). Similarly, corpus callosotomy alone (sectioning only the corpus callosum) can allow for some interhemispheric transfer via intact anterior or hippocampal commissures. These two fiber bundles are part of the forebrain commissures and contain axons synapsing on neurons in the temporal lobes and the hippocampus, which themselves send projections to other brain areas (Di Virgilio, Clarke, Pizzolato and Schaffner, 1999). Moreover, clinical "split-brain" groups are spread across geographical locales and continents, contributing to lack of uniformity in the patient population, spanning varying degrees of developmental plasticity (young children, teens, and adults) intelligence levels, extra callosal damage, and disease etiology (see de Haan et al., 2020). Even the surgical approach has not been identical, with some undergoing multi-staged and others single-staged operation (Caltech, California cases underwent single-stage); it is the difference between completing the structural disconnection on the same day versus in segments over a period of weeks or months, thereby introducing the confounding issue of functional reorganization (Bogen, 1985; Sperry, 1974; E. Zaidel et al., 1999). With such lack of uniformity, collapsing results across groups is not conducive to reaching parsimonius conclusions on hemispheric consciousness.

Inter-hemispherically, the role of the corpus callosum in mediating consciousness is poorly understood. Rather than being a cluster of neurons in grey matter, the corpus callosum is a huge tract of non-uniform white matter, varying in width, length, and shape, consisting of axons of different diameters, which connect mostly homotopic cortical regions, transmitting both excitatory and inhibitory action potentials with speed efficiency affected most likely by axonal diameter size (Aboitiz et al., 2003). What is transferred interhemispherically along this bridge, then, is initiated not on a callosal level but rather on a cortical level, in the neurons that give rise to the axons. To obtain insights into consciousness, particularly hemispheric, future research would benefit from focusing on those cortical neurons from whence callosal fibers emanate, and on their reciprocal projections.

"The brainstem reticular formation, paramedian thalamus and perhaps parts of the postero-medial cortex are likely to provide background conditions for full consciousness. By serving as activating influences and cortical hubs, they enable effective interactions among the cortical areas that directly contribute conscious content." (p 316, Koch et al., 2016). To emphasize, none of these regions and their projections have been compromised by the complete commissurotomy surgery or otherwise.

What can be learned from single-stage complete commissurotomy, as with the Caltech, California cases, is that each hemisphere is fully consciously aware, independently of the other hemisphere, displaying both asymmetric and symmetric functional specialization. Despite the surgical disconnection of the cerebral hemispheres, unified consciousness is also displayed, attributed most reasonably to intact subcortical projections synapsing on intact subcortical structures. Future studies with functional neuroimaging and similar techniques might shed light on why the phenomenon is not inherently contradictory; it would potentially help advance our understanding of the neural underpinnings of consciousness throughout the brain, in health and disease.

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