I'm not a bot

Split-brain surgery, or corpus calloscotomy, is a drastic way of alleviating epileptic seizures, the occurrence of sporadic electrical storms in the brain. The procedure involves severing the corpus callosum, the main bond between the brains left and right hemispheres.After a split-brain surgery, the two hemispheres do not exchange information as efficiently as before. This impairment can result in split-brain syndrome, a condition where the separation of the hemispheres affects behavior and agency. Michael Gazzaniga and Roger W. Sperry, the first to study split brains in humans, found that several patients who had undergone a complete calloscotomy suffered from split-brain syndrome. In patients with split-brain syndrome, the right hemisphere, which controls the left hand and foot, acts independently of the left hemisphere and the persons ability to make rational decisions. This can give rise to a kind of split personality, in which the left hemisphere give orders that reflect the persons rational goals, whereas the right hemisphere issues conflicting demands that reveal hidden desires. Gazzaniga and Sperry's split-brain research is now legendary. One of their child participants, Paul S., had a fully functional language center in both hemispheres. This allowed the researchers to question each side of the brain. When they asked the right side what their patient wanted to be when he grew up, he replied, "an automobile racer." When they posed the same question to the left, however, he responded, "a draftsman." Another patient pulled down his pants with the left hand and back up with the right in a continuing struggle. On a different occasion, this same patient's left hand made an attempt to strike the unsuspecting wife as the right hand grabbed the villainous limp to stop it. Split personality is a rare consequence of a split brain. In some cases, impaired interhemispheric communication leaves personality intact but still allows people to use the two hemispheres to complete independent intellectual tasks.An MRI scan of the savant Kim Peek, who inspired the fictional character Raymond Babbitt (played by Dustin Hoffman) in the movie Rain Man, revealed an absence of the corpus callosum, the anterior commissure and the hippocampal commissure, the three cables for information transfer between hemispheres. As a consequence of this complete split, Peek, who sadly died last year, was able to simultaneously read both pages of an open book and retain the information. He apparently had developed language areas in both hemispheres. Peek was a living encyclopedia. He spent every day with his dad in the library absorbing information. Among his most impressive feats was his ability to provide traveling directions between any two cities in the world. Today, hemisphere interaction can be studied using devices that measure the electric or magnetic fields surrounding the skull. Unlike split-brain surgery, these techniques are non-invasive.A team of researchers from UC Santa Barbara, led by Gazzaniga, recently tested information transfer using MEG. Language is processed in areas of the temporal lobe on the left side of the head. When you read with your left eye, the information first ends up in the right hemisphere and must be transferred to the left hemisphere via the corpus callosum to be processed. To test the efficiency of the hemispheric transfer, the researchers showed a randomized list of words and nonsense words to the left or right eye of a number of research participants. They then measured how effectively the subjects would be able to distinguish words from nonsense words. The study showed that subjects were significantly more efficient in determining the nature of the string of letters when the information was fed directly to the left hemisphere via the right eye. Apparently, the brain has difficulties processing information that has had to travel long distances. What Is Personality? Take our Agreeableness Test Find a therapist near me The researchers didn't compare both-eye exposure to single-eye exposure. At first glance, it may seem that it would be an advantage to get information from both eyes. However, one can also imagine that hemispheric transfer has a hampering effect on language processing. If this is true, you might want to wear a pirate eye patch covering your left eye when completing the verbal section of the GRE. At the very least, be careful not to shut your right eye while under time pressure. References K. W. Doron, D. S. Bassett, M. S. Gazzaniga. Inaugural Article: Dynamic network structure of interhemispheric coordination. Proceedings of the National Academy of Sciences, 2012; DOI: 10.1073/pnas.1216402109 Get the help you need from a therapist near youa FREE service from Psychology Today. Atlanta, GA Austin, TX Baltimore, MD Boston, MA Brooklyn, NY Charlotte, NC Chicago, IL Columbus, OH Dallas, TX Denver, CO Detroit, MI Houston, TX Indianapolis, IN Jacksonville, FL Las Vegas, NV Los Angeles, CA Louisville, KY Memphis, TN Miami, FL Milwaukee, WI Minneapolis, MN Nashville, TN New York, NY Oakland, CA Omaha, NE Philadelphia, PA Phoenix, AZ Pittsburgh, PA Portland, OR Raleigh, NC Sacramento, CA Saint Louis, MO San Antonio, TX San Diego, CA San Francisco, CA San Jose, CA Seattle, WA Tucson, AZ Washington, DC More from Berit Brogaard D.M.Sci., Ph.D More from Psychology Today Condition of the human brainThis article is about the human brain condition. For the phenomenon in computing, see Split-brain (computing).Split-brain or callosal syndrome is a type of disconnection syndrome when the corpus callosum connecting the two hemispheres of the brain is severed to some degree. It is an association of symptoms produced by disruption of, or interference with, the connection between the hemispheres of the brain. The surgical operation to produce this condition (corpus callosotomy) involves transection of the corpus callosum, and is usually a last resort to treat refractory epilepsy. Initially, partial callosotomies are performed; if this operation does not succeed, a complete callosotomy is performed to mitigate the risk of accidental physical injury by reducing the severity and violence of epileptic seizures. Before using callosotomies, epilepsy is instead treated through pharmaceutical means. After surgery, neuropsychological assessments are often performed.After the right and left brain are separated, each hemisphere will have its own separate perception, concepts, and impulses to act. Having two "brains" in one body can create some interesting dilemmas. There was a case in which, when one split-brain patient would dress himself, sometimes he pulled his pants up with one hand (the side of his brain that wanted to get dressed) and down with the other (the side that did not). He was also reported to have grabbed his wife with his left hand and shook her violently, at which point his right hand came to her aid and grabbed the aggressive left hand (a phenomenon sometimes occurring, known as alien hand syndrome). However, such conflicts are very rare. If a conflict arises, one hemisphere usually overrides the other.[1]When split-brain patients are shown an image only in the left half of each eye's visual field, they cannot verbally name what they have seen. This is because the brain's experiences of the senses is contralateral. Communication between the two hemispheres is inhibited, so the patient cannot say out loud the name of that which the right side of the brain is seeing. A similar effect occurs if a split-brain patient touches an object with only the left hand while receiving no visual cues in the right visual field; the patient will be unable to name the object, as each cerebral hemisphere of the primary somatosensory cortex only contains a tactile representation of the opposite side of the body. If the speech-control center is on the right side of the brain, the same effect can be achieved by presenting the image or object to only the right visual field or hand.[2]Different sides of the brain specialize in different functions or processes. The same effect occurs for visual pairs and reasoning. For example, a patient with split brain is shown a picture of a chicken foot and a snowy field in separate visual fields and asked to choose from a list of words the best association with the pictures. The patient would choose a chicken to associate with the chicken foot and a shovel to associate with the snow; however, when asked to reason why the patient chose the shovel, the response would relate to the chicken (e.g. "the shovel is for cleaning out the chicken coop").[3]Early anatomists, such as Galen (129 c.216CE) and Vesalius (15141564CE), identified the corpus callosum. They generally described its function as a structure holding together the two halves of the brain.[4] In 1784, Flix Vicq-d'Azyr described the corpus callosum as allowing communication between the two halves of the brain. He proposed that eliminating the corpus callosum would divide the brain into two independent parts.[4] In 1892, Joseph Jules Dejerine reported symptoms in a person who had destruction of part of the corpus callosum (along with damage to the visual cortex: inability to read while retaining the ability to write, now referred to as pure alexia or as Dejerine syndrome.[4] In 1908, Hugo Liepmann observed left-sided apraxia (a motor disorder of motor planning to perform tasks or movements) and agraphia (loss of the ability to communicate through writing) following a lesion in the corpus callosum.[4]According to Vaddiparti et al. (2021), the first surgical cuts to the corpus callosum, partial corpus callosotomy, were made by neurosurgeon Walter Dandy in order to access and to remove tumors in the pineal gland.[4] In 1936, Dandy described three cases in which he cut the corpus callosum from its posterior (towards the back of the head) across about two thirds of its width. He described these cuts as "bloodless" and that "no symptoms follow[ed] [the] ... division" of the corpus callosum. He concluded that his operations "dispose ... of the extravagant claims to function of the corpus callosum".[5]:40Prior to the 1960s, research on people with certain brain injuries led to the notion that there is a "language center" only in the left hemisphere of the brain. For example, people with lesions in two specific areas of the left hemisphere lost their ability to talk, to read, and to understand speech. Roger Sperry and his colleagues pioneered research showing that creating another lesion (done to relieve otherwise untreatable epilepsy), in the connections between the left and right hemispheres, revealed that the right hemisphere can allow people to read, to understand speech, and to say some simple words. Research over the next twenty years showed that the disconnected right hemisphere is superior to the disconnected left hemisphere in allowing people to understand spatial information (such as maps), music, and emotions, whereas the disconnected left hemisphere is superior in allowing analytical thinking, talking, reading, and understanding speech. This research led to a Nobel Prize in Physiology or Medicine for Sperry in 1981.[6]Sperry's initial colleagues included his Caltech PhD students, Michael Gazzaniga and Jerre Levy. Even though Sperry is considered the founder of split-brain research, Gazzaniga's clear summaries of their collaborative work are consistently cited in psychology texts. In Sperry and Gazzaniga's "The Split Brain in Man" experiment published in Scientific American in 1967 they attempted to explore the extent to which two halves of the human brain were able to function independently and whether or not they had separate and unique abilities. They wanted to examine how perceptual and intellectual skills were affected in someone with a split brain. At Caltech, Gazzaniga worked with Sperry on the effects of split-brain surgery on perception, vision and other brain functions. The surgery, which was a treatment for severe epilepsy, involved severing the corpus callosum, which carries signals between the left-brain hemisphere, the seat of speech and analytical capacity, and the right-brain hemisphere, which helps recognize visual patterns. At the time this article was written, only ten patients had undergone the surgery to sever their corpus callosum (corpus callosotomy). Four of these patients had consented to participate in Sperry and Gazzaniga's research. After the corpus callosum severing, all four participants' personality, intelligence, and emotions appeared to be unaffected. However, the testing done by Sperry and Gazzaniga showed the subjects demonstrated unusual mental abilities. The researchers created different types of tests to analyze the range of cognitive capabilities of the split-brain subjects. These included tests of their visual stimulation abilities, a tactile stimulation situation, and a test that involved both visual and tactile information.The first test started with a board that had a horizontal row of lights. The subject was told to sit in front of the board and stare at a point in the middle of the lights, then the bulbs would flash across both the right and left visual fields. When the patients were asked to describe afterward what they saw, they said that only the lights on the right side of the board had lit up. Next, when Sperry and Gazzaniga flashed the lights on the right side of the board on the subjects left side of their visual field, they claimed not to have seen any lights at all. When the experimenters conducted the test again, they asked the subjects to point to the lights that lit up. Although subjects had only reported seeing the lights flash on the right, they actually pointed to all the lights in both visual fields. This showed that both brain hemispheres had seen the lights and were equally competent in visual perception. The subjects did not say they saw the lights when they flashed in the left visual field even though they did see them because the center for speech is located in the brain's left hemisphere. This test supports the idea that in order to say one has seen something, the region of the brain associated with speech must be able to communicate with areas of the brain that process the visual information.[citation needed]In a second experiment, Sperry and Gazzaniga placed a small object in the subject's right or left hand, without the subject being able to see (or hear) it. When the object was placed in the right hand, the isolated left hemisphere perceived the object and could easily describe and name it. However, when the object was placed in the left hand, the isolated right hemisphere could not name or describe the object. Questioning this result, the researchers found that the subjects could later match it from several similar objects; tactile sensations limited to the right hemisphere were accurately perceived but could not be verbalized. This further demonstrated the apparent location (or lateralization) of language functions in the left hemisphere.[citation needed]In the last test the experimenters combined both the tactile and visual test. They presented subjects with a picture of an object to only their right hemisphere, and subjects were unable to name it or describe it. There were no verbal responses to the picture at all. If the subject was able to reach under the screen with their left hand to touch various objects, however, they were able to pick the one that had been shown in the picture. The subjects were also reported to be able to pick out objects that were related to the picture presented, if that object was not under the screen.[7]Sperry and Gazzaniga went on to conduct other tests to shed light on the language processing abilities of the right hemisphere as well as auditory and emotional reactions as well. The significance of the findings of these tests by Sperry and Gazzaniga was extremely telling and important to the psychology world. Their findings showed that the two halves of the brain have numerous functions and specialized skills. They concluded that each hemisphere really has its own functions. One's left hemisphere of the brain is thought to be better at writing, speaking, mathematical calculation, reading, and is the primary area for language. The right hemisphere is seen to possess capabilities for problem solving, recognizing faces, symbolic reasoning, art, and spatial relationships. [citation needed]Roger Sperry continued this line of research up until his death in 1994. Michael Gazzaniga continues to research the split brain. Their findings have been rarely critiqued and disputed; however, a popular belief that some people are more "right-brained" or "left-brained" has developed. In the mid-1980s Jarre Levy, a psychobiologist at the University of Chicago, was at the forefront of scientists who wanted to dispel the notion we have two functioning brains. She believes that because each hemisphere has separate functions that they must integrate their abilities instead of separating them. Levy also claims that no human activity uses only one side of the brain. In 1998 a French study by Hommet and Billiard was published that questioned Sperry and Gazzaniga's study that severing the corpus callosum actually divides the hemispheres of the brain. They found that children born without a corpus callosum demonstrated that information was being transmitted between hemispheres, and concluded that subcortical connections must be present in these children with this rare brain malformation. They are unclear about whether these connections are present in split-brain patients though. Another study by Parsons, Gabrieli, Phelps, and Gazzaniga in 1998 demonstrated that split-brain patients may commonly perceive the world differently from the rest of us. Their study suggested that communication between brain hemispheres is necessary for imaging or simulating in one's mind the movements of others. Morin's research on inner speech in 2001 suggested an alternative for interpretation of commissurotomy according to which split-brain patients exhibit two uneven streams of self-awareness: a "complete" one in the left hemisphere and a "primitive" one in the right hemisphere.[8]The two hemispheres of the cerebral cortex are linked by the corpus callosum, through which they communicate and coordinate actions and decisions. Communication and coordination between the two hemispheres is essential because each hemisphere has some separate functions. [9] The right hemisphere of the cortex excels at nonverbal and spatial tasks, whereas the left hemisphere is more dominant in verbal tasks, such as speaking and writing. The right hemisphere controls the primary sensory functions of the left side of the body. In a cognitive sense the right hemisphere is responsible for recognizing objects and timing, and in an emotional sense it is responsible for empathy, humor and depression. On the other hand, the left hemisphere controls the primary sensory functions of the right side of the body and is responsible for scientific and math skills, and logic.[10] The extent of specialized brain function by an area remains under investigation. It is claimed that the difference between the two hemispheres is that the left hemisphere is "analytic" or "logical" while the right hemisphere is "holistic" or "intuitive".[11] Many simple tasks, especially comprehension of inputs, require functions that are specific to both the right and left hemispheres and together form a one-direction systematized way of creating an output[clarification needed] through the communication and coordination that occurs between hemispheres.[12]The corpus callosum, highlighted in red, is the main neural pathway between the two hemispheres.The corpus callosum is a structure in the brain along the longitudinal fissure that facilitates much of the communication between the two hemispheres. This structure is composed of white matter: millions of axons that have their dendrites and terminal boutons projecting in both the right and left hemisphere. However, there is evidence that the corpus callosum may also have some inhibitory functions.[13] Post-mortem research on human and monkey brains shows that the corpus callosum is functionally organized.[14] This organization results in modality-specific regions of the corpus callosum that are responsible for the transfer of different types of information. Research has revealed that the anterior midbody transfers motor information, the posterior midbody transfers somatosensory information, the isthmus transfers auditory information, and the splenium transfers visual information.[15] Although much of the inter-hemispheric transfer occurs at the corpus callosum, there are trace amounts of transfer via commissural pathways, such as the anterior commissure, posterior commissure, habenular commissure, and the hippocampal commissure.[16]Studies of the effects on the visual pathway on split-brained patients has revealed that there is a redundancy gain (the ability of target detection to benefit from multiple copies of the target) in simple reaction time. In a simple response to visual stimuli, split-brained patients experience a faster reaction time to bilateral stimuli than predicted by model.[17] A model proposed by Iacoboni et al.[18] suggests split-brained patients experience asynchronous activity that causes a stronger signal, and thus a decreased reaction time. Iacoboni also suggests there exists dual attention in split-brained patients, which implies that each cerebral hemisphere has its own attentional system.[19] An alternative approach taken by Reuter-Lorenz et al.[20] suggests that enhanced redundancy gain in the split brain is primarily due to a slowing of responses to unilateral stimuli, rather than a speeding of responses to bilateral ones.The simple reaction time in split-brained patients, even with enhanced redundancy gain, is slower than the reaction time of normal adults.[citation needed]Following a stroke or other injury to the brain, functional deficiencies are common. The deficits are expected to be in areas related to the part of the brain that has been damaged; if a stroke has occurred in the motor cortex, deficits may include paralysis, abnormal posture, or abnormal movement synergies.[21] Significant recovery occurs during the first several weeks after the injury. However, recovery is generally thought not to continue past six months. If a specific region of the brain is injured or destroyed, its functions can sometimes be transferred and taken over by a neighboring region. There is little functional plasticity observed in partial and complete callosotomies; however, much more plasticity can be seen in infant patients receiving a hemispherectomy, which suggests that the opposite hemisphere can adapt some functions typically performed by its opposite pair. A study performed by Anderson et al. (2005) proved a correlation between the severity of the injury, the age of the individual, and their cognitive performance. It was evident that there was more neuroplasticity in older childreneven if their injury was extremely severethan in infants who suffered moderate brain injury.[22] In some incidents of any moderate to severe brain injury, it mostly causes developmental impairments and in some of the most severe injuries it can cause a profound impact on their development that can lead to long-term cognitive effects. In the aging brain, it is extremely uncommon for neuroplasticity to occur; "olfactory bulb and hippocampus are two regions of the mammalian brain in which mutations preventing adult neurogenesis were never beneficial, or simply never occurred".[22]The picture is about a normal brain and a person with a split brainCorpus callosotomy is a surgical procedure that sections the corpus callosum, resulting in either the partial or complete disconnection between the two hemispheres. It is typically used as a last-resort measure in treatment of intractable epilepsy. The modern procedure typically involves only the anterior third of the corpus callosum; however, if the epileptic seizures continue, the following third is lesioned prior to the remaining third if the seizures persist. This results in a complete callosotomy in which most of the information transfer between hemispheres is lost.[23]Due to the functional mapping of the corpus callosum, a partial callosotomy has fewer detrimental effects because it leaves parts of the corpus callosum intact. There is little functional plasticity observed in partial and complete callosotomies on adults; the most neuroplasticity is seen in young children but not in infants.[24]It is known that when the corpus callosum is severed during an experimental procedure, the experimenter can ask each side of the brain the same question and receive two different answers. When the experimenter asks the right visual field / left hemisphere what they see the participant will respond verbally, whereas if the experimenter asks the left visual field / right hemisphere what they see the participant will not be able to respond verbally but will pick up the appropriate object with their left hand.[25]It is known that the right and the left hemisphere have different functions when it comes to memory.[26] The right hemisphere is better at recognizing objects and faces, recalling knowledge that the individual has already learned, or recalling images already seen. The left hemisphere is better at mental manipulation, language production, and semantic priming but was more susceptible to memory confusion than the right hemisphere.[27] The main issue for individuals that have undergone a callosotomy is that because the function of memory is split into two major systems, the individual is more likely to become confused between knowledge they already know and information that they have only inferred.[27]In tests, memory in either hemisphere of split-brained patients is generally lower than normal, though better than in patients with amnesia, suggesting that the forebrain commissures are important for the formation of some kinds of memory. This suggests that posterior callosal sections that include the hippocampal commissures cause a mild memory deficit (in standardized free-field testing) involving recognition.[28] This makes first-person accounts hard to consider and to assess as scientists do not know if the consciousness was split as well.[29]In general, split-brained patients behave in a coordinated, purposeful, and consistent manner, despite the independent, parallel, usually different, and occasionally conflicting processing of the same information from the environment by the two disconnected hemispheres. When two hemispheres receive competing stimuli at the same time, the response mode tends to determine which hemisphere controls behavior.[30][verification needed]Often, split-brained patients are indistinguishable from normal adults. This is due to the compensatory phenomena; split-brained patients progressively acquire a variety of strategies to get around their interhemispheric transfer deficits.[31][self-published source?] One issue that can happen with their body control is that one side of the body is doing the opposite of the other side, called the intermanual effect.[citation needed]Experiments on covert orienting of spatial attention using the Posner paradigm confirm the existence of two different attentional systems in the two hemispheres.[32] The right hemisphere was found superior to the left hemisphere on modified versions of spatial relations tests and in locations testing, whereas the left hemisphere was more object based.[33] The components of mental imagery are differentially specialized: the right hemisphere was found superior for mental rotation,[34] the left hemisphere superior for image generation.[35] It was also found that the right hemisphere paid more attention to landmarks and scenes whereas the left hemisphere paid more attention to exemplars of categories.[36]The surgical operation to produce this condition (corpucallosotomy) involves transection of the corpus callosum, and is usually a last resort to treat refractory epilepsy. To lower the degree and ferocity of epileptic convulsions, partial callosotomies are first done; if these are unsuccessful, a callosotomy is next carried out to reduce the risk of unintentional bodily harm. Epilepsy is first managed with medications rather than callosotomies. Neuropsychological evaluations following surgery are frequently carried out.Patient WJ was the first patient to undergo a full corpus callosotomy in 1962, after experiencing fifteen years of convulsions resulting from grand mal seizures. He was a World War II paratrooper who was injured at 30 years old during a bombing raid jump over the Netherlands, and again in a prison camp following his first injury. After returning home, he began to suffer from blackouts in which he would not remember what he was doing or where, and how or when he got there. At age 37, he suffered his first generalized convulsion. One of his worst episodes occurred in 1953, when he suffered a series of convulsions lasting for many days. During these convulsions, his left side would go numb and he would recover quickly, but after the series of convulsions, he never regained complete feeling on his left side.[37]Before his surgery, both hemispheres functioned and interacted normally, his sensory and motor functions were normal aside from slight hypoesthesia, and he could correctly identify and understand visual stimuli presented to both sides of his visual field. During his surgery in 1962, his surgeons determined that no massa intermedia had developed, and he had undergone atrophy in the part of the right frontal lobe exposed during the procedure. His operation was a success, in that it led to decreases in the frequency and intensity of his seizures.[37]Funnell et al. (2007) tested patient JW some time before June 2006.[38] They described JW asa right-handed male who was 47 years old at the time of testing. He successfully completed high school and has no reported learning disabilities. He had his first seizure at the age of 16 and the age of 25, he underwent a two-stage resection of the corpus callosum for relief of intractable epilepsy. Complete sectioning of the corpus callosum has been confirmed by MRI. [39] Post-surgical MRI also revealed no evidence of other neurological damage.[verification needed]Funnell et al.'s (2007) experiments were to determine each of JW's hemisphere's ability to perform simple addition, subtraction, multiplication and division. For example, in one experiment, on each trial, they presented an arithmetic problem in the center of the screen for one second, followed by a central crosshair JW was to look at. After one more second, Funnell et al. presented a number to one or the other hemisphere / visual field for 150 mstoo fast for JW to move his eyes. Randomly in half the trials, the number was the correct answer; in the other half of the trials it was the incorrect answer. With the hand on the same side as the number, JW pressed one key if the number was correct and another key if the number was incorrect.[38]Funnell et al.'s results were that performance of the left hemisphere was highly accurate (around 95%)much better than performance of the right hemisphere, which was at chance for subtraction, multiplication, and division. Nevertheless the right hemisphere showed better-than-chance performance for addition (around 58%).[40]Turk et al. (2002) tested hemispheric differences in JW's recognition of himself and of familiar faces.[41] They used faces that were composites of JW's face and Dr. Michael Gazzaniga's face. Composites ranged from 100% JW, through 50% JW and 50% Gazzaniga, to 100% Gazzaniga. JW pressed keys to say whether a presented face looked like him or Gazzaniga. Turk et al. concluded there are cortical networks in the left hemisphere that play an important role in self-recognition.[citation needed]Patient VP[42] is a woman who underwent a two-stage callosotomy in 1979 at the age of 27. Although the callosotomy was reported to be complete, a follow-up MRI in 1984 revealed spared fibers in the rostrum and splenium. The spared rostral fibers constituted approximately 1.8% of the total cross-sectional area of the corpus callosum and the spared splenial fibers constituted approximately 1% of the area.[39] VP's postsurgery intelligence and memory quotients were within normal limits.[43]One of the experiments involving VP attempted to investigate systematically the types of visual information that could be transferred via VP's spared splenial fibers. The first experiment was designed to assess VP's ability to make between-field perceptual judgments about simultaneously presented pairs of stimuli. The stimuli were presented in varying positions with respect to the horizontal and vertical midline with VP's vision fixated on a central crosshair. The judgments were based on differences in color, shape or size. The testing procedure was the same for all three types of stimuli; after presentation of each pair, VP verbally responded "yes" if the two items in the pair were identical and "no" if they were not. The results show that there was no perceptual transfer for color, size or shape with binomial tests showing that VP's accuracy was not greater than chance.[citation needed]A second experiment involving VP attempted to investigate what aspects of words transferred between the two hemispheres. The set up was similar to the previous experiment, with VP's vision fixated on a central crosshair. A word pair was presented with one word on each side of the crosshair for 150 ms. The words presented were in one of four categories: words that looked and sounded like rhymes (e.g. tire and fire), words that looked as if they should rhyme but did not (e.g. cough and dough), words that did not look as if they should rhyme but did (e.g. bake and ache), and words that neither looked nor sounded like rhymes (e.g. keys and fort). After presentation of each word pair, VP responded "yes" if the two words rhymed and "no" if they did not. VP's performance was above chance and she was able to distinguish among the different conditions. When the word pairs did not sound like rhymes, VP was able to say accurately that the words did not rhyme, regardless of whether or not they looked as if they should rhyme. When the words did rhyme, VP was more likely to say they rhymed, particularly if the words also looked as if they should rhyme.[citation needed]Although VP showed no evidence for transfer of color, shape or size, there was evidence for transfer of word information.[44] This is consistent with the speculation that the transfer of word information involves fibers in the ventroposterior region of the spleniumthe same region in which VP had callosal sparing. VP is able to integrate words presented to both visual fields, creating a concept that is not suggested by either word. For example, she combines "head" and "stone" to form the integrated concept of a tombstone.[citation needed]Kim Peek[45] was arguably the most well-known savant. He was born on November 11, 1951, with an enlarged head, sac-like protrusions of the brain and the membranes that cover it through openings in the skull, a malformed cerebellum, and without a corpus callosum, an anterior commissure, or a posterior commissure. He was able to memorize over 9,000 books, and information from approximately 15 subject areas. These include: world/American history, sports, movies, geography, actors and actresses, the Bible, church history, literature, classical music, area codes/zip codes of the United States, television stations serving these areas, and step-by-step directions within any major U.S. city. Despite these abilities, he had an IQ of 87, was diagnosed as autistic, was unable to button his shirt, and had difficulties performing everyday tasks. The missing structures of his brain have yet to be linked to his increased abilities, but they can be linked to his ability to read pages of a book in 810 seconds. He was able to view the left page of a book with his left visual field and the right page of a book with his right visual fields so he could read both pages simultaneously.[46] He also had developed language areas in both hemispheres, something very uncommon in split-brain patients. Language[46] is processed in areas of the left temporal lobe, and involves a contralateral transfer of information before the brain can process what is being read. In Peek's case, there was no transfer abilitythis is what led to his development of language centers in each hemisphere. Although Peek did not undergo corpus callosotomy, he is considered a natural split-brain patient and is critical to understanding the importance of the corpus callosum. Kim Peek died in 2009.[46]Lateralization of brain functionLeft brain interpreterConfabulationBrain asymmetryDual consciousnessDivided consciousnessBicameral mentalityAlien hand syndromeSociety of MindParallel computingLateralityMindbody problemPhilosophy of mindTheory of mindIdeomotor phenomenonCognitive NeuroscienceAgenesis of the corpus callosumOf Two Minds (book)^ Coon, Dennis; Mitterer, John O. (January 1, 2012). Introduction to Psychology Gateways to Mind and Behavior. Cengage Learning. p.65. ISBN9781111833633.^ De Haan, E. H.; Corballis, P. M.; Hillyard, S. A.; Marzi, C. A.; Seth, A.; Lamme, V. A.; Volz, L.; Fabri, M.; Schechter, E.; Bayne, T.; Corballis, M.; Pinto, Y. (2020). "Split-Brain: What We Know Now and Why This is Important for Understanding Consciousness". Neuropsychology Review. 30 (2): 224233. doi:10.1007/s11065-020-09439-3. PMC7305066. PMID32399946.^ Gazzaniga, Michael S. (July 1, 2000). 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Inclusion in an NLM database does not imply endorsement of, or agreement with, the contents by NLM or the National Institutes of Health. Learn more: PMC Disclaimer | PMC Copyright Notice Recently, the discussion regarding the consequences of cutting the corpus callosum (split-brain) has regained momentum (Corballis, Corballis, Berlucchi, & Marzi, Brain, 141(6), e46, 2018; Pinto et al., Brain, 140(5), 12311237, 2017a; Pinto, Lamme, & de Haan, Brain, 140(11), e68, 2017; Volz & Gazzaniga, Brain, 140(7), 20512060, 2017; Volz, Hillyard, Miller, & Gazzaniga, Brain, 141(3), e15, 2018). This collective review paper aims to summarize the empirical common ground, to delineate the different interpretations, and to identify the remaining questions. In short, callosotomy leads to a broad breakdown of functional integration ranging from perception to attention. However, the breakdown is not absolute as several processes, such as action control, seem to remain unified. Disagreement exists about the responsible mechanisms for this remaining unity. The main issue concerns the first-person perspective of a split-brain patient. Does a split-brain harbor a split consciousness or is consciousness unified? The current consensus is that the body of evidence is insufficient to answer this question, and different suggestions are made with respectto how future studies might address this paucity. In addition, it is suggested that the answers might not be a simple yes or no but that intermediate conceptualizations need to be considered.Keywords: Epilepsy, Split-brain, Lateralization, Visual perception, Consciousness agentsThe term split-brain refers to patients in whom the corpus callosum has been cut for the alleviation of medically intractable epilepsy. Since the earliest reports by van Wagenen and Herren (1940) and Akelaitis (1941, 1943) on the repercussions of a split-brain, two narratives have emerged. First and foremost is the functional description, pioneered by Gazzaniga, Sperry and colleagues (Gazzaniga, Bogen, & Sperry, 1963; Gazzaniga, Bogen, & Sperry, 1962; Sperry, 1968), in which the intricacies, the exceptions, the effects of different testing conditions, and the experimental confounds have been delineated by decades of extensive research with a relatively small group of patients (Berlucchi, Aglioti, Marzi, & Tassinari, 1995; Corballis, 1994; Corballis et al., 2010; Corballis, 2003; Luck, Hillyard, Mangun, & Gazzaniga, 1989; Pinto, Lamme, & de Haan, 2017b; Volz, Hillyard, Miller, & Gazzaniga, 2018). It is important to note that even in this small group there are differences. In some patients all commissures were severed (commissurotomy), in others only the corpus callosum was cut (callosotomy) and some patients fall somewhere in between these two boundaries. Now, the search term split-brain results in a total of 2848 publications in the database of the Web-of-Science and 29,300 hits on Google Scholar, indicating a wealth of detailed information. The other depiction of split-brain patients entails the first-person perspective of the split-brain. In other words, what is it like to be a split-brain patient? It is especially this perspective that has captured the attention of the general press, popular science books and basic textbooks. By its nature, this second narrative lacks the detail of the functional description of the phenomenon, but it captures the intriguing question of how unity of consciousness is related to brain processes. Dominant in this description is the idea that in a split-brain each hemisphere houses an independent conscious agent. This notion, and particularly the concept of an isolated but conscious right hemisphere that is unable to express its feelings, desires or thinking due a lack of language, has captured the imagination (Gazzaniga, 2014).It is important to clarify what we mean by unified consciousness. Here, we use the term in the sense of subject unity as defined by Bayne (Bayne & Chalmers, 2003; Bayne, 2008; Bayne, 2010). Subject unity is present if all the experiences generated in a system belong to one subject. In other words, if a system contains a first person perspective, then subject unity is preserved if that system only contains one such perspective, but subject unity is absent if the system contains multiple first person perspectives. Thus, in our definition of conscious unity, consciousness in a split-brain is split if each cortical hemisphere houses an independent conscious agent.The view that consciousness is split in a split-brain has significantly impacted cognitive neuroscience at large. For instance, currently dominant theories about conscious awareness - the Integrated Information Theory (Tononi, 2005; Tononi, 2004) and the Global Neuronal Workspace Theory (Dehaene & Naccache, 2001; Dehaene, Kerszberg, & Changeux, 1998) - may be critically dependent on the validity of this view. Both theories imply that without massive communication between different subsystems, for instance cortical hemispheres, independent conscious agents arise. Thus, if the split consciousness view is invalid, these theories may be critically challenged.The idea of split consciousness in a split-brain had its origin in the early split-brain studies (Gazzaniga, 1967; Gazzaniga, 1975; Gazzaniga et al., 1962; Sperry, 1968). These studies tested patients primarily in the two perceptual domains where processing is largely restricted to the contralateral hemisphere, that is vision and touch. In these early studies, stimuli, for instance objects, that were presented to the left hemisphere either physically in the right hand or as an image in the right visual half-field, could be readily named (as the left hemisphere is dominant for language) or pointed out with the right hand (which is controlled by the left hemisphere). The patients behavior became intriguing when the stimuli were presented in the left visual field or in the left hand. Now the patient, or at least the verbal left hemisphere, appeared oblivious to the fact that there had been a stimulus at all but was nevertheless able to select the correct object from an array of alternatives presented to the left hand or the left visual half-field (see Fig.1). In a particularly dramatic recorded demonstration, the famous patient Joe was able to draw a cowboy hat with his left hand in response to the word Texas presented in his left visual half field. His commentary (produced by the verbal left hemisphere) showed a complete absence of insight into why his left hand had drawn this cowboy hat. Another astonishing example involved the same patient. MacKay and MacKay (1982) flashed a digit in the left visual field and trained the patient to play a version of 20 questions across hemispheres. The left hemisphere guessed the answer vocally, and the right hemisphere provided responses by pointing up (meaning guess a higher number) or down with the left hand. In this way the patient managed to vocalize the right answer. This suggests two independent conscious agents communicating with each other (one steering the left hand, the other agent controlling vocal expressions). However, note that an alternative interpretation is possible. Perhaps the patient knows the answer but finds it hard to vocalize. The 20 questions then simply help him in finding the correct vocalization. One of the most well-known split-brain findings is that the patient claims verbally not to have seen the stimulus in the left visual field, yet indicates the identity of it with their left hand. This suggests that the left hemisphere (controlling verbal output) is blind to the left visual field, while the right hemisphere (controlling the left hand) does perceive itThus, these early observations suggested that there is no meaningful communication between the two hemispheres in split-brain patients. This led to the hypothesis that there might be two separate conscious agents, a left hemisphere that is able to talk to us and can explain what it sees and feels, and a mute right hemisphere that cannot communicate in language but that can nevertheless show that it has perceived and recognized objects and words. However, over time this view has eroded somewhat due to several anomalies (even right from the start) that may challenge this view.An early observation, suggesting some remaining unification concerned what Joe Bogen called the social ordinariness of split-brain patients. Apart from a number of anecdotal incidents in the subacute phase following the surgery, these patients seem to behave in a socially ordinary manner and they report feeling unchanged after the operation (Bogen, Fisher, & Vogel, 1965; Pinto et al., 2017a; R. W. Sperry, 1968; R. Sperry, 1984), although their extra-experiment behavior has not been systematically observed in great detail (Schechter, 2018). While the right hemisphere appears to be better at recognizing familiarity from faces, self-face recognition, that is the ability to realise immediately that a presented photograph represents you, appears to be available equally to both hemispheres in a split-brain patient (Uddin et al., 2008; Uddin, 2011). Thus, it seems unlikely that a mute but conscious right hemisphere would not have made itself known one way or the other. Thus, right from the start a paradox arose. The controlled lab tests suggested that consciousness is split in split-brain patients. Yet, everyday experiences of the patient and their close ones suggests that only one person exists in a split-brain. Additionally, it has been suggested that the two separate consciousnesses-hypothesis presumes that in the intact brain (before surgery) both hemispheres were conscious but connected via the corpus callosum, and they only became dissociable due to the operation. This casts doubt on the viability of the two consciousness view.Crucially, the lab tests themselves were not always supportive of the split-consciousness view. Multiple experimental results showed that capacity for communication between the hemispheres varies both across patients and across tasks. For instance, a central observation in split-brain patients concerns the inability to compare visual stimuli across the midline. In other words, when one stimulus is presented to the left visual hemifield and the other to the right hemifield, the patient cannot accurately indicate whether both stimuli are the same or not, although they can do so when both stimuli are presented within one visual field. This is consistent with the notion that each hemisphere independently perceives the contralateral visual field, and that an intact corpus callosum is necessary for integration. Although there are indeed many examples of split-brain patients who are incapable of comparing stimuli across the midline, prominent examples can also be found of patients who can compare stimuli across the midline (Johnson, 1984; but see Seymour, Reuter-Lorenz, & Gazzaniga, 1994). This points to an important problem in the field, namely, individual differences. One aspect that may be important for individual differences is handedness differences. Variations in handedness may lead to differences in language capabilities in the right hemisphere, and could even underly differences in inter-hemispheric integration.Moreover, under certain circumstances nearly all tested split-brain patients seem able to compare, or integrate, particular types of stimuli across the two visual half-fields (see Fig. 2). An early demonstration of across hemifields integration is the study by Eviatar and Zaidel (1994). They showed that split-brain patients could accurately indicate the identity and shape of upper- and lower-case letters in either hemifield, regardless of with which hand they responded, for instance accurately identifying the letter A in the left visual field with the right hand. Yet these patients were mostly unable to compare these same stimuli across visual fields. In another experiment, two tilted lines were presented with a gap between them. The lines were positioned in such a way that extending them across the gap would either cause the lines to coincide or to run in parallel. When split-brain patients indicate whether the lines are parallel or coincident, they are highly accurate, even when both line segments are located in different half-fields (Corballis, 1995; Pinto, de Haan, Lamme, & Fabri, n.d.; Sergent, 1987; Trevarthen & Sperry, 1973). Another example of visual integration across the midline involves apparent motion. When two dots are presented in succession at a short distance (2 to 14 visual degrees), split-brain patients are able to accurately indicate whether the dots create apparent motion, or that they were presented simultaneously or with delays too long to provoke apparent motion. Critically, they are able to do so even when one dot appears in the left visual field, and the other in the right visual field (Knapen et al., 2012; Naikar & Corballis, 1996; Ramachandran, Cronin-Golomb, & Myers, 1986). Clearly, under specific conditions, there is meaningful communication between the two hemispheres in the absence of the corpus callosum. Although most split-brain patients cannot compare visual features such as shape and object identity across the midline, other features, such as good continuation of lines, and apparent motion, are integrated without a corpus callosumAnother observation that suggests some form of unity across the two visual half fields concerns detection and localization of stimulation, for instance, a brief flash (see, for example, an early study on the response times to light flashes with the ipsi- or contralateral hand: Clarke & Zaidel, 1989). Several investigations (Corballis, Corballis, Fabri, Paggi, & Manzoni, 2005; Pinto et al., 2017a; Trevarthen & Sperry, 1973) have demonstrated convincingly that split-brain patients can accurately report the presence and location of stimuli for any position in the whole visual field, with either hand, and even verbally. Accurate detection and localization appears to be possible for all patients and all stimuli (different shapes, figures, equiluminant stimuli) tested so far. Thus, when patients in earlier studies said that they saw nothing when a stimulus was presented in the left visual half-field, they may have meant that they could see it but that they could not identify or retrieve the name of the object.Other findings point to a crucial difference between the degree of lateralization of visual-perceptual processing and producing overt responses. Perception appears to be more split, while responding remains largely unified. Whether a stimulus appears in the left or the right visual hemifield strongly impacts performance of split-brain patients. However, response type (left hand, right hand or verbally) seems to have a much smaller, or no effect at all. For instance, Pinto et al., 2017a) found that the split-brain patient was much better at matching pictures to sample stimuli in the left visual field. Yet, for the exact same stimuli matching pictures to verbal labels was vastly superior when the stimuli appeared in the right visual field. Crucially, response type did not play any role. The patient was better in matching pictures to sample for stimuli in the left visual field, even if they responded verbally or with the right hand. Similarly, Levy, Trevarthen, and Sperry (1972) presented split-brain patients with chimeric or composite faces, that is, one half-face in each visual field. Subsequently the patient either matched the chimeric face to sample, or attached a verbal label to it. Verbal matching was mostly based on the half-face in the right visual field, while matching to sample was mainly driven by the half-face in the left visual field. But crucially, the latter was the case, independent of whether the patient responded with the left or the right hand.Thus, it seems that in split-brain patients perceptual processing is largely split, yet response selection and action control appear to be unified under certain conditions. This, by itself, does not prove whether a split-brain houses one or two conscious agents. One explanation could be that the split-brain houses two agents, each having their own experiences, who synchronize their behavioral output through various means. Another possible explanation is that a split-brain houses one agent who experiences an unintegrated stream of information who controls the entire body, comparable to watching a movie where sight and sound are out-of-sync. At any rate, these findings challenge the previously mentioned classic split-brain description, which is still found in reviews and text books (Gray, 2002; Wolman, 2012). In this classic characterization the patient indicates that they saw nothing when a stimulus appeared in the left visual field. Yet, to their own verbal surprise, the left hand correctly draws the stimulus. The aforementioned examples of unity in action control suggests that these effects may depend on the type and complexity of the response that is required.There are three, not-mutually exclusive, hypotheses concerning the mechanisms involved in, seemingly, preserved unity in the split-brain. The first notion is that information is transferred subcortically. The second idea is that ipsilateral motor control underlies unity in action control. The third idea claims that information transfer is based on varies forms of inter-hemispheric collaboration, including subtle behavioral cues. The first proposal (Corballis Corballis, Berlucchi, & Marzi, 2018; de Haan et al., 2019; Pinto, Lamme, & de Haan, 2017b; Pinto et al., 2017a; Savazzi et al., 2007; Mancuso, Uddin, Nani, Costa, & Cauda, 2019) suggests that the multitude of subcortical connections that are spared during surgery are responsible for the transfer of information. As was initially pointed out by Trevarthen (1968) and Trevarthen and Sperry (1973) and recently stressed by Pinto, de Haan, and Lamme (2017a) and Corballis et al. (2018), there are many commissures (white matter tracts that connect homologous structures on both sides of the central nervous system) and decussations (bundles that connect different structures on both sides) that link nuclei that are known to be involved in perceptual processing. The importance of these commisural connections for transferring visual information in split-brain patients has been highlighted by Trevarthen and Sperry (1973). Moreover, the role of these connections in a split-brain has recently been demonstrated by bilateral fMRI activations in the first somatosensory cortex, after unilateral stimulation of trunk midline touch receptors (Fabri et al., 2006) and in the second somatic sensory area after unilateral stimulation of hand pain receptors (Fabri, Polonara, Quattrini, & Salvolini, 2002). Uddin and colleagues used low-frequency BOLD fMRI resting state imaging to investigate functional connectivity between the two hemispheres in a patient in whom all major cerebral commissures had been cut (Uddin et al., 2008). Compared to control subjects, the patients interhemispheric correlation scores fell within the normal range for at least two symmetrical regions. In addition, Nomi and colleagues suggested that split-brain patients might rely particularly on dorsal and ventral pontine decussations of the cortico-cerebellar interhemispheric pathways as evidenced by increased fractional anisotropy (FA) on diffusion weighted imaging (Nomi, Marshall, Zaidel, Biswal, Castellanos, Dick, Uddin & Mooshagian, 2019). Interhemispheric exchange of information also seems to occur in the domain of taste sensitivity, activation of primary gustatory cortex in the fronto-parietal operculum was reported in both hemispheres after unilateral gustatory stimulation of the tongue receptors (Mascioli, Berlucchi, Pierpaoli, Salvolini, Barbaresi, Fabri, & Polonara, 2015). Note that patients may differ with respect to how many of these connections have been cut, and this might also explain some of the individual variance among patients. Moreover, in all patients subcortical structures remain intact. For instance, the superior colliculus is known to integrate visual information from both hemispheres and project information to both hemispheres (Meredith & Stein, 1986; Comoli et al., 2003). Such structures may support attentional networks, and may enable the right hemisphere to attend to the entire visual field. In turn, attentional unity could help in unifying cognitive and motor control, which may subserve ipsilateral motor control.The second point concerns the ipsilateral innervation of the arms. Manual action is not strictly lateralized, and the proximal (but not the distal) parts of the arm are controlled bilaterally, although the ipsilateral contribution remains undetermined. This could explain why split-brain patients may respond equally well with both hands in certain experimental conditions (Corballis, 1995; Gazzaniga, Bogen, & Sperry, 1967; Pinto, de Haan, & Lamme, 2017a). First, there is substantial evidence that bilateral cortical activations can be observed during unilateral limb movements in healthy subjects. In addition, ipsilesional motor problems in arm control have been observed in patients with unilateral cortical injuries, and finally there is evidence from electrocorticography with implanted electrodes for localization of epileptic foci showing similar spatial and spectral encoding of contralateral and ipsilateral limb kinematics (Bundy, Szrama, Pahwa, & Leuthardt, 2018). While these observations argue convincingly for a role in action control by the ipsilateral hemisphere, they do not prove that a hemisphere on its own can purposefully control the movements of the ipsilateral hand. Thus, the role of ipsilateral arm-hand control in explaining split-brain findings is currently not settled.The third hypothesis argues that in addition to whatever direct neural communication may exist between the hemispheres, they may inform one another via strategic cross-cueing processes (Volz & Gazzaniga, 2017; Volz et al., 2018). The split-brain patients underwent surgery many years prior to testing, and the separated perceptual systems have 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. A cross-cueing mechanism might also allow one hemisphere to convey to the other which one of a limited set of known items had been shown (Gazzaniga & Hillyard, 1971; Gazzaniga, 2013).Finally, it is possible to entertain combinations of the different explanations. For instance, it is conceivable that in the subacute phase following split-brain surgery the hemispheres are ineffective in communicating with each other. During this initial phase, phenomena such as an alien hand - that is a hand moving outside conscious control of the (verbal) person - may be present. In the ensuing period, the patients may have learned to utilize the information that is exchanged via subcortical connections, ipsilateral motor control or cross-cueing to coordinate the processing of the two hemispheres. In such a way, the patient may counteract some of the effects of losing the corpus callosum.This paper aims to contribute to the agenda for the next decade of split-brain research. Full split-brain surgery is rare these days, and it is important that we try to answer the central questions while these patients are still available for study. In order to examine the variations between patients it would be useful to test as many of the available patients as possible with the same tests.One important goal is to map out precisely how much functionality and information is still integrated across hemispheres in the split-brain, and what the underlying principles are. For instance, in some cases the two hemispheres seem to carry out

sensory-motor tasks, such as visual search, independently from one another (Arguin et al., 2000; Franz, Eliassen, Ivry, & Gazzaniga, 1996; Hazeltine, Weinstein, & Ivry, 2008; Luck, Hillyard, Mangun, & Gazzaniga, 1994; Luck et al., 1989), while in other cases functions such as attentional blink, or attentional cueing, seem to be integrated across hemispheres (Giesbrecht & Kingstone, 2004; Holtzman, Volpe, & Gazzaniga, 1984; Holtzman, Sidtis, Volpe, Wilson, & Gazzaniga, 1981; Pashler et al., 1994; Ptito, Brisson, DellAcqua, Lassonde, & Jolicur, 2009). An important challenge is to unveil why some cognitive functions can be carried out independently in the separated hemispheres while other functions engage both hemispheres. Furthermore, it is now clear that accurate detection and localization is possible across the whole visual field, and there is some evidence that even more information concerning visual images can be transferred between hemispheres. Although we have some understanding of what types of information can be transferred in the visual domain, our knowledge base in the somatosensory domain is much more limited. This is probably due to a bias throughout cognitive neuroscience and psychology, leading to a strong focus on vision in split-brain research. It is important to collect converging evidence by investigating the somatosensory system which is also strongly lateralized. Note that in somatosensory processing transfer between hemispheres (about 80% correct for the bimanual conditions) has been observed for basic same-different matching of real objects (Fabri, Del Pesce et al., 2005).Another important goal is to obtain a more detailed description of the perceptual, cognitive and linguistic capabilities of the disconnected right hemisphere. For understanding unity of mind, two capabilities specifically are crucial. First, experiments investigating aspects of the conscious mind often go beyond simple visual processing, and future studies will thus critically depend on testing high-level cognitive abilities of both hemispheres. Specifically, language abilities, crucial for understanding questions and instructions, will likely play a pivotal role. Thus, the first question is to what extent the right hemisphere is capable of language processing. Note that complicated instructions (Gazzaniga, Smylie, Baynes, Hirst, & McCleary, 1984; Pinto et al., 2017a; Zaidel, 1983), for instance relating to mental imagery (Johnson, Corballis, & Gazzaniga, 2001; Kosslyn, Holtzman, Farah, & Gazzaniga, 1985; Sergent & Corballis, 1990), seem to be well within the reach of the right hemisphere. Moreover, right hemisphere language capabilities seem to improve over time (Gazzaniga, Volpe, Smylie, Wilson, & LeDoux, 1979; Gazzaniga et al., 1996). Longitudinal language tests (for instance with a Token test: De Renzi & Vignolo, 1962) would further illuminate the extent of right hemisphere language processing.Second, unveiling to what extent each hemisphere is capable of subserving consciousness at all seems relevant for unity of mind as well. If the disconnected right hemisphere can produce full-blown consciousness, then questions regarding unity of mind are clearly more pertinent then if the right hemisphere only produces minimal amounts of consciousness. Right hemisphere consciousness can be studied through novel neural paradigms (Bekinschtein et al., 2009; Casali et al., 2013; Pitts, Metzler, & Hillyard, 2014; Shafto & Pitts, 2015). For instance, Bekinschtein et al. employed EEG to measure if the brain detected irregularities (as indicated by an event-related potential [ERP] signal called the P3) in different states of consciousness. They found that when consciousness was reduced, local irregularities were still detected - for instance after three high auditory tones a low tone evoked a P3. However, global irregularities - several times a low tone followed three high tones, then on the critical trial three high tones were followed by another high tone - did not evoke a P3 when consciousness was reduced. Crucially, when consciousness was unimpaired both local and global irregularities evoked a P3 response. Right hemisphere consciousness may also be studied in other patient groups where interhemispheric communication is hampered. One particularly interesting group are post-hemispherotomy patients (Lew, 2014). These patients have been surgically treated to disconnect an entire hemisphere (usually for intractable epilepsy), but unlike hemispherectomy patients the disconnected hemisphere remains in place in the cranium and remains vascularized.Clearly, the central question, whether each hemisphere supports an independent conscious agent, is not settled yet. Novel paradigms in this respect could lead to progress. For instance, a pivotal question is whether each hemisphere makes its own decisions independent of the other hemisphere. If each hemisphere produces its own autonomous conscious agent then this should be the case. That is, if two agents are asked to freely choose a random number, then the odds that they consistently pick the same number are small. And vice versa, if each hemisphere makes its own conscious decisions, independent of the other hemisphere, then this seems to rule out unity of mind. Note that each hemisphere making its own decisions is different from information processing occurring independently per hemisphere. Unconscious information processing is almost certainly split across hemispheres in a split-brain. However, this does not prove that consciousness is split or unified. Even in a healthy brain, where consciousness is unified, many unconscious processes run independently, and in parallel.One way to tackle the central question is by having the hemispheres respond to questions in parallel. Overt behavior most likely does not allow for this, due to bilateral motor control processes sketched earlier. However, perhaps parallel responding is possible if the hemispheres produce covert responses. For instance, the patient could be asked to pick one of four options and indicate their choice by carrying out certain content-specific mental imagery tasks. This imagery can then be decoded in parallel from each hemisphere using neuroimaging techniques (see Owen et al., 2006 for a similar approach with vegetative state patients). If each hemisphere harbors an autonomous conscious agent, then it is highly unlikely that the two hemispheres will consistently make the same choices. Thus, if the choices are uncorrelated across hemispheres, then this may critically challenge the unified mind view.Another way to tackle the question of unified consciousness in the split-brain is to employ ERPs as markers of concurrent conscious processing in the left and right hemispheres. For instance, in one study (Kutas, Hillyard, Volpe, & Gazzaniga, 1990) visual targets were presented either separately to the left or right visual field or to both visual fields simultaneously. It was found that the P300 - a signal possibly reflecting conscious processing of a visual target (Dehaene & Changeux, 2011; Dehaene, Charles, King, & Marti, 2014; Salti, Bar-Haim, & Lamy, 2012) - was reduced for bilateral targets. This suggests some type of integration of conscious processing. Studies employing ERPs may indicate whether conscious processing is unified, while unconscious processing is split, which would be suggestive of unified consciousness.In summary, the pivotal issue in split-brain research is whether dividing the brain divides consciousness. That is, do we find evidence for the existence of one, or two conscious agents in a split-brain? Note that intermediate results may be found. Perhaps some measures indicate unified consciousness while others do not. This would then provoke further interesting questions on the unity of consciousness. What are the crucial measures for unity of consciousness? If intermediate results are found, more unconventional possibilities should be entertained as well. For instance, although difficult to fathom, some philosophers have suggested that a split-brain does not contain one or two observers, but a non-whole number of conscious agents (Nagel, 1971; Perry, 2009), for instance one and a half first-person perspectives. If evidence for this position is found, then its implications would stretch beyond split-brain patients. It would suggest that our intuitions on the indivisibility of the experiential self may be mistaken. One way to think of this is as with the difference between conscious and unconscious processing. Perhaps this is not a dichotomous distinction, but a continuum between more or less conscious. Similarly, perhaps the existence of a first-person perspective is not dichotomous, but gradual as well. Another possibility is that a split-brain does contain a whole number of conscious agents, but that consciousness across these agents is only partially unified. That is, the agents share some conscious experiences and decisions, but not all (Lockwood, 1989; Schechter, 2014; Schechter, 2018; Schechter, 2013). Finally, another way to look at this is in terms of dissociation, as in depersonalization (Phillips et al., 2001; Sierra et al., 2002). Perhaps the number of agents is not altered, but the agent feels depersonalized in some situations, and therefore no longer feels that they control the actions, or even experience the information, that has just occurred in their brain.New findings on the unity of consciousness in a split-brain could fundamentally impact currently dominant consciousness theories. Global Neuronal Workspace Theory (Dehaene & Naccache, 2001; Dehaene et al., 1998) asserts that consciousness arises when information that is processed in unconscious (or preconscious) modules is broadcast to a central workspace, primarily residing in frontal regions of the brain. Although not very explicit on the unity of consciousness in split-brain patients, Global Neuronal Workspace Theory seems to endorse the split consciousness idea, given that each hemisphere has its own prefrontal hub, enabling broadcasting of whatever information is processed in that hemisphere.Integrated Information Theory (Tononi, 2005; Tononi, 2004) has specifically addressed the issue of split brain (for instance in Tononi, 2004). Integrated Information Theory asserts that phi, a measure of how integrated information is, determines the level of consciousness. The higher phi, the more conscious a system is. Moreover, local maxima in phi correspond to conscious agents. If in a system all subsystems are highly interconnected, then phi is highest for the system as a whole, and local maxima are absent. Thus, such a system produces only one conscious agent. However, if subsystems only exchange minimal amounts of information, then phi per subsystem is higher than phi for the system as whole. In such a case each subsystem creates its own conscious agent. In a split-brain, connectedness, that is integration of information, is much higher within than across hemispheres. Therefore, according to Integrated Information Theory consciousness should be split in a split-brain.Recurrent Processing theory (Lamme & Roelfsema, 2000; Lamme, 2004; Lamme, 2010) argues for the independence of consciousness from attention, access, or report. This theory has addressed the issue of report specifically, making the case that consciousness and reportability, whether verbal or manual, should be viewed as entirely independent (Lamme, 2006; Tsuchiya, Wilke, Frssle, & Lamme, 2015). Crucially, this theory states that even in the normal mind, islands of unattended yet conscious information reside (Lamme, 2006). In these cases, all the information, although functionally unintegrated, is nonetheless experienced by the same mind. Support for this view comes from findings in multiple object tracking (Pinto, Howe, Cohen, & Horowitz, 2010; Pinto, Scholte, & Lamme, 2012; Pylyshyn & Storm, 1988). Here, evidence indicates that when moving objects in two visual hemifields are tracked, attention is split (Howe, Cohen, Pinto, & Horowitz, 2010) and each hemisphere processes the relevant information in the contralateral visual field independently of the other (Alvarez & Cavanagh, 2005; Cavanagh & Alvarez, 2005; Drew, Mance, Horowitz, Wolfe, & Vogel, 2014). That is, the left hemisphere only tracks the right visual field and vice versa. Yet, although the visual information is not integrated across hemispheres, from a first person perspective, it seems clear that the subject experiences all moving objects across the entire visual field. Another example of the dissociation between consciousness and reportability is the so-called partial report paradigm (Pinto et al., 2017b; Pinto, Sligte, Shapiro, & Lamme, 2013; Sligte, Scholte, & Lamme, 2008; Sperling, 1960). In these paradigms subjects seem to remember more than they can report. Thus, reportability and consciousness are dissociated. Perhaps in split-brain patients this dissociation is simply more pronounced. That is, consciousness remains unified, but reportability has become more dissociated, thereby inducing the appearance of two independent agents. In sum, according to the Recurrent Processing theory, integration of information is not needed for a unified mind, implying that the mind may remain unified when the brain is split. Thus, different theories of consciousness have different predictions on the unity of mind in split-brain patients, and await the results of further investigation into this intriguing phenomenon.This work was supported by an Advanced Investigator Grant by the European Research Council (ERC grant FAB4V (#339374) to EdH and a Templeton grant (ID# 61382, "Towards understanding a unified mind") to YP and VL.The authors report no competing interests.Akelaitis AJ. Studies on the corpus callosum: II. The higher visual functions in each homonymous field following complete section of the corpus callosum. Archives of Neurology and Psychiatry. 1941;45(5):788796. [Google Scholar]Akelaitis AJ. Studies on the corpus callosum: VII. Study of language functions (tactile and visual lexia and graphia) unilaterally following section of the corpus callosum. Journal of Neuropathology & Experimental Neurology. 1943;2(3):226262. [Google Scholar]Alvarez GA, Cavanagh P. 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