ABSTRACT

What, where, and when are the core aspects of psychological research. Psychological research is the study and analysis of the experiences and behaviors of human beings. Human conscious experience is built from three core types of information: what, where, and when. Psychological research is also based on the same three core types of information: what, where, and when. Psychological research then is aptly suited to the study of human conscious experience. A neural correlate for human conscious experience has been found in the human brain. This neural correlate is precisely modeled by Einstein’s special theory of relativity; conscious experiences are organized according to the principles of special relativity. The hippocampus continuously encodes what, where, and when information as the subject moves around the environment. The hippocampus essentially encodes a spatiotemporal representation of the environment for spatiotemporal function (conscious experience, spatial memory, episodic memory, cognition, and intentional goal-directed behavior). Conscious experience, cognition, and behavior are all essentially based on what, where, and when information. The where and when information provides a context for the what, i.e., a setting by which the what can be fully assessed and understood. This is important as a specific context can support the coherent construction of intentional goal-directed adaptive behavior. In effect, the behavior appears to arise directly from conscious experience. Setting up an appropriate context (where and when) that suitably represents the experience or behavior in question is of crucial importance for any psychological study. Space-time intervals are the fundamental relationships computed from the where and when information that are extracted from the hippocampus by the neocortex (mainly the prefrontal cortex and posterior parietal cortex) for the organization of coherent conscious experiences, cognition, and behavior. Space-time intervals account for the subjective aspect of human conscious experience (i.e., they explain why conscious experience appears to us the way it does). Ultimately, conscious experience is an orientation in space, time, and identity; an understanding of the position of the observer in space and time. This is important for cognition and the generation of intentional goal-directed actions. Relativistic principles have relevance to the design, interpretation, and application of psychological research. Understanding this concept can increase the efficacy of psychological research, provide additional understanding of mental disorders, suggest some treatments for these disorders, and benefit normal cognition (perception, learning, memory, planning, reasoning, problem-solving, and decision-making) in everyone.

INTRODUCTION

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Human conscious experience is subjective. By subjective, is meant, the way conscious experience appears to the person having it. If you examine your current conscious experience, its subjectivity is revealed in that some events are experienced simultaneously, but in different locations; while other events are experienced at the same location, but at different times. This is the way conscious experience appears to the person having it (its subjectivity). The main problem in explaining conscious experience is explaining how something subjective like conscious experience can arise in something physical like the brain. This is known as the hard problem of consciousness. The subjectivity of conscious experience also indicates that human conscious experience is organized in space and time. As will be seen, the representation of events in space and time in the human brain is responsible for the subjectivity of human conscious experience (i.e., is responsible for the way conscious experience appears to us). The representation of events in space and time (space-time) in the brain (in the hippocampus) makes possible the computation of space-time intervals. Space-time intervals are the fundamental relationships computed by the brain to organize coherent conscious experiences. Conscious experience is not just an observation of conscious events, but is an orientation in space, time, and identity; an understanding of the position of the observer in space and time. This is important for cognition (the mental processes involved in the acquisition of knowledge and understanding; perception; awareness) and the creation of intentional (purposeful) goal-directed behaviors and actions.

**Subjectivity and Scientific Research**

Science is the creation of knowledge. There is an increasing appreciation for the role that subjectivity (conscious experience) plays in scientific research. The way conscious experience appears to us (our subjectivity) can affect scientific research (including psychological research). Studies of quantum phenomena, for instance, have shown that subjectivity (the presence of an observer, measurement) can alter the course of an experiment and affect the results obtained. This has been demonstrated by the famous two-slit experiment of Thomas Young to demonstrate quantum wave-particle duality. In these experiments, coherent light is beamed through two adjacent slits onto a screen. An interference pattern indicating wave-like propagation of light through the slits is observed on the screen when the light is observed to pass through both slits simultaneously. However, when only one slit is observed, a point-like pattern of light is seen on the screen, indicating particle-like (photon) propagation of light through the slit. Our subjectivity (the way we observe, or conscious experience, the experiment) determines the course of the experiment and the results and conclusions reached.

How conscious experience appears to us (its subjectivity) has an effect on scientific research (including psychological research) in another way. Whenever you experience events occurring simultaneously, but in different locations, you know that these events occur at the same time, occur at different locations, are separate, have only a spatial relationship, are part of the context, and do not have cause-effect or past-future relationships. When you experience events occurring at the same location, but at different times, you know that these events occur at the same location, occur at different times, are related only by time, have a past-future relationship, and may have a cause-effect relationship. Our subjectivity thereby facilitates and conditions
perception and cognition, bringing forth additional details, thoughts, and ideas about the events, which may alter the course of an experiment and affect the results and conclusions reached.

All scientific concepts, whether quantum or classical, are described, studied, and understood only through subjective conscious experience. They are in effect deduced through conscious experience. Quantum phenomena (e.g., tunneling, entanglement, uncertainty, etc.) are always described, studied, and understood only through subjective conscious experience (e.g., construction of Feynman Diagrams, thought experiments, imaginings). The uncertainty principle, for example, dictates that the more you know about one aspect of a fundamental particle, such as its position, the less you can know about another related aspect of that particle, such as its momentum—and vice versa (Hossenfelder, 2015). The entire phenomenon is represented, described, and understood only through conscious experience. The paradoxical behavior of “entangled” particles (pairs of particles that share a common quantum state) unfolds as follows (Hossenfelder, 2015): imagine (conscious experience) an unstable particle with a spin of zero decaying into two daughter particles, which speed off in opposite directions. Conservation laws dictate that the spins of those two daughter particles must add up to zero; one particle, then, could possess a spin value of “up,” and the other could have a spin value of “down.” The laws of quantum mechanics dictate that neither of the particles possesses a definite spin, until one of the two speeding entangled particles is measured (that is, represented in conscious experience). The whole phenomenon unfolds in conscious experience (just reading the preceding description manifests the entire phenomenon in conscious experience). In effect, the quantum phenomenon is deduced through conscious experience. All quantum phenomena similarly are deduced through conscious experience. The way these conscious experiences appear to us (their subjectivity) allows us to describe, study, and understand (deduce) quantum phenomena. According to Bohr’s Correspondence Principle and the Copenhagen Convention, as the quantum numbers of a system increase (the size of a quantum system increases), classical physics emerges (the system becomes describable with classical physics), i.e., when a quantum system becomes large, quantum physics and classical physics give the same answers (Bohr, 1976; Jaeger, 2014; Tipler & Llewellyn, 2008). One way to make a quantum system large is to describe it in conscious experience. When quantum phenomena are expanded to the conscious level, classical physics emerges and these phenomena can be described using classical physics. Quantum phenomena are always expanded to the conscious experience level so that they can be described, studied, and understood using classical physics. The Schrödinger equation is central to quantum mechanics and describes how the quantum state of a physical system changes in time. It defines the permitted stationary states of a quantum system and provides a means of predicting the probability of measurement results. Measurement appears to collapse quantum wave functions into defined subjective conscious experiences. Schrödinger’s equation provides the means for predicting conscious experiences which may evolve from a quantum system. The concepts of classical physics are also all described, studied, and understood only through conscious experiences. Scientists like Einstein, Newton, Galileo, Aristotle, and many others used imagination, thought experiments, and diagrams (subjectivity, conscious experiences) to come up with their greatest discoveries. Whenever we describe, study, interpret, or understand any scientific concept, we do so at the conscious level, i.e., as conscious experience and classical physics. All scientific concepts (including those of psychology) therefore are essentially
deduced through conscious experience. The subjectivity of conscious experience enables classical physics to emerge and provide a description, interpretation, and understanding of a scientific concept. In this way, subjectivity can have a powerful effect on the evolution of human thought and knowledge.

Our subjectivity (conscious experience) is very important, not only in the acquisition of knowledge, but also for characterizing us as human beings. Our subjectivity allows us to observe and interpret the world. The subjectivity of conscious experience separates human beings from their environment. We are separate entities, individuals, or selves. Through conscious experience we observe the world and develop a point of view. We utilize our point of view to operate on the environment. Subjectivity creates agency, i.e., the capacity to make choices and to act (Angus, 2003). We are the authors of our own experiences, thoughts, and actions. We interact with the world in our own particular way, with our own particular interests, purposes, and goals. The point of view achieved through conscious experience makes possible cognition and the creation of intentional goal-directed new or novel adaptive actions and sequences of actions (skeletal movements, ocular movements, speech, reading, writing, thought, emotion). Cognition allows an individual to achieve particular goals and interests, even abstract ones. It makes possible the planning and performance of long chains of sequential actions to achieve particular goals (planning and going on a trip, writing or reading a book, scanning a crime scene, playing a game, solving a problem, making a decision, calculating, reasoning, thinking, etc.). Our subjectivity is important in the development and application of ethics, i.e., our moral constitution (Angus, 2003; Long & Sedley, 1987; Sieb, 2017). All ethics is developed and implemented via conscious experience (Sieb, 2017). How events appear to us in conscious experience (their subjectivity) determines our moral reaction to them. It is interesting to note that the prefrontal cortex and posterior parietal cortex involved in the creation of conscious experience are the same neocortical areas that are involved in the making of ethical or moral decisions (Bzdok et al., 2011; Sieb, 2017). Ethics plays a large role in determining the direction and acceptance of scientific research, especially psychological research (use of humans or animals as subjects, use of invasive procedures, amount and type of information supplied to subjects, not causing harm, cognitive liberty, etc.). Ethics in one way or the other can also affect the evolution of human knowledge and thought.

Psychological research is essentially the study and analysis of human conscious experience (our subjectivity) and behavior. Our conceptualization of conscious experience then may have important ramifications for psychological research. How conscious experience itself is created is very important for psychological research. Up to this point of time, a universal characterization of conscious experience has escaped us. What is it? Why do we have it? How is it created? How can something subjective like conscious experience be created in something physical like the brain? Why does conscious experience appear to us the way it does? Why is it subjective? These questions have appeared unanswerable scientifically to date. This has led to a huge proliferation of highly speculative theories about the nature of consciousness. There are so many theories they have been categorized into fields (dualism, monism, materialism, nonmaterialism, epiphenomenalism, physical, metaphysical, quantum). Few of these theories are based on any empirical evidence. Accounting for the subjectivity of conscious experience is the main
problem. This is known as “the hard problem of consciousness” (how can something subjective like conscious experience arise in something physical like the brain). However, the spatiotemporal nature of conscious experience suggests answers to the above questions. Recently, a neural correlate for human conscious experience has been found in the human brain (Sieb, 2015, 2016a, 2016b). This neural correlate is modeled by Einstein’s special theory of relativity. Special relativity is relevant here because conscious experience may be considered a small local region of flat space-time (a four-dimensional frame of reference) and special relativity is based on the analysis of small local regions of flat space-time (four-dimensional frames of reference), where gravity is negligible. This neural correlate is based on a large amount of empirical evidence and accounts for the subjectivity of conscious experience. It solves the hard problem of consciousness. It is hoped this new conceptualization of conscious experience will provide a useful framework for the study of consciousness and the mind (psychology), for increasing the efficacy of psychological research, for the analysis and treatment of psychiatric and psychological disorders, for improved educational practices, and for improved cognition in everyday life.

The Spatiotemporal Nature of Human Conscious Experience, Cognition, Behavior, and Psychological Research

Human conscious experience, cognition, behavior, and psychological research all have a spatiotemporal structure. This might be expected as cognition and behavior appear to evolve from conscious experience (which has a spatiotemporal structure) and psychological research is the study and analysis of human conscious experience, cognition, and behavior. In humans, knowing the world occurs through spatiotemporal experiences and interpretations (Maniadakis & Trahanias, 2011). Emmanuel Kant apparently foresaw the spatiotemporal nature of conscious experience by prophetically concluding that space and time are not discovered by humans to be objective features of the world, but are part of a systematic framework for the organization of our experiences (Lucas & Hodgson, 1985). Conscious experience may be directly observed to have a spatiotemporal organization. If you observe your current conscious experience, you can see that it consists of some events which occur simultaneously, but in different spatial locations; while other events occur at the same location, but at different times (Sieb, 2015, 2016a, 2016b). This indicates that conscious experience is organized in space and time. Conscious experience, in essence, is built from three core types of information: what, where, and when. What refers to what (events) we experience, where refers to the three-dimensional positions in space of the what, while when refers to when in time the what occurs. What, where, and when essentially describe the composition of conscious experience. This is quite important. Conscious experience is our direct observation of external physical reality (the world). Hence we observe (experience) the world in terms of what, where, and when information. As will be seen, where and when forms a context for the what, i.e., a setting by which the what can be fully assessed and understood. The result is that conscious experience is an orientation in space, time, and identity, an understanding of the position of the observer in space and time.

Everything we are aware of (consciously experience) throughout the day arises from the integration of what, where, and when information. A person’s entire awake (conscious) state is based on the integration of what, where, and when information as the person moves around the environment. You get up, have breakfast, clean-up, get dressed, and go to work all through the integration of what, where, and when information that is gathered as you move around. Your
entire work day or school day is based on the integration of what, where, and when information (what events occur, where they occur, and when they occur) into conscious experience. If you go to a doctor or dentist, the doctor’s or dentist’s diagnosis and treatment is based on what, where, and when information (what the signs and symptoms are, where they occur, and when they occur). If you do an athletic activity, again the performance of the activity is based on the integration of what, where, and when information (what the activity is, where you do it, and when you do it). The integration of what, where, and when information is the basis of all our conscious experience that guides us through the day. It is the basis of our conscious life.

Cognition and behavior is also based on what, where, and when information. Our perceptions, reasoning, logic, ethics (morality), planning, problem-solving, decision-making, calculating, episodic memory, construction of intentional goal-direct actions (behavior) are all based on what, where, and when information. In all three (conscious experience, cognition, and behavior), the where and when form a context for the what, i.e., the setting by which the what can be fully assessed and understood. A specific context therefore links the three, so that relevant intentional goal-directed behavior seems to evolve directly from conscious experience. Hence conscious experience appears to be the driving force for cognition and behavior and conscious experience thereby enables the direct production of new or novel goal-directed intentional adaptive behavior. It allows human beings to successfully and purposefully immediately interact with and have an impact on their environment. Where and when essentially links conscious experience, cognition, and behavior together to provide a coherent, dynamic, flexible, and versatile interaction between the individual and their environment.

Psychology may be defined as the scientific study of the human mind and its functions. The mind is that element of a person that enables that person to be aware of the world (to consciously experience or observe the world), to think, and to feel; the faculty of consciousness and thought. Conscious experiences essentially make up the content of the mind. Psychological research is the scientific study and analysis of the human mind and its functions (conscious experience, cognition, behavior). Conscious experience is central to psychological research, from defining the questions to be investigated, the procedure followed, the ethics involved, the collection of data, the interpretation of data, and the results and conclusions reached. Psychological research is all about the analysis of conscious experience. Since all conscious experience is based on what, where, and when information and since psychological research is the study and analysis of conscious experience, it is not surprising then that psychological research is also based on the same three core types of information as compose conscious experience: what, where, and when. Typical psychological research encompasses the manipulation, measurement, and interpretation of what, where, and when information. For example, Pause et al. (2013) suggested a paradigm to measure episodic memory deficit in humans. Episodic memory is the encoding and retrieval of personal past conscious experiences. Consciousness is necessary for episodic memory retrieval. Recollection implies a kind of first-person subjectivity. Episodic memory capacity in individuals and patients is exceeding hard to measure and no tests have been developed to adequately accomplish this feat. Episodic memory involves the encoding of three core types of information: what, where, and when (Mizumori, 2013; Pause et al., 2013; Yassa & Reagh, 2013). In the Pause et al. (2013) paradigm, pictures are flashed on four out of eight screens, located in different quadrants, over three sequential trials. The subjects were later tested on their memory of each picture (what), on which screen the picture occurred (where), and in what sequential trial the picture was seen (when), after various delays. A comparison of results obtained for people
with memory deficits (Alzheimer’s disease, dementia, Parkinson’s disease, etc.) with a normal control group provided a measure of episodic memory deficit in the former. One can see how what, where, and when information gathered can be measured and combined to represent a particular psychological phenomenon (episodic memory capacity). This outlines a primary method or framework used in psychological research, abet in any scientific research, for gathering and measuring information about some particular psychological phenomenon. What, where, and when information is collected, measured, and interpreted to describe and explain a particular phenomenon. Particular attention to the accuracy, reliability, and completeness of the what, where, and when information gathered therefore is of primary importance for accurate, reliable, and reproducible psychological research.

A neural correlate has been found in the human brain which gathers what, where, and when information continuously for the organization of coherent conscious experiences, cognition, and behavior, as the subject moves around the environment (Sieb, 2015, 2016a, 2016b). The hippocampus has been shown to continuously encode what, where, and when information for spatiotemporal function as the subject moves around the environment. The hippocampus is critical for the encoding of this information into episodic memory (McDonald et al, 2011; Mizumori, 2013; Pause et al., 2013; Sieb, 2015; Yassa & Reagh, 2013). The where and when information encoded in the hippocampus forms a context for the what, i.e., the setting by which the what can be fully assessed and understood. Space-time interval relations are computed from the what, where, and when information and are the fundamental relationships extracted from the hippocampus by the neocortex (especially the posterior parietal cortex and prefrontal cortex) to organize coherent conscious experience, cognition, and behavior (Sieb, 2015, 2016a, 2016b; Wendelken, 2015). This appears to be the mechanism in the brain by which psychological research is implemented. What, where, and when information is gathered (results) resulting in conclusions. In the human brain, the neural correlate for conscious experience is precisely modeled by Einstein’s special theory of relativity, i.e., the principles of special relativity are utilized by the human brain to organize coherent conscious experiences. Space-time intervals are the fundamental relationships derived from the what, where, and when information that are utilized in the organization of all coherent conscious experiences (as per the principles of special relativity). This means that human conscious experience arises from defined classical physics in the brain. Conscious experiences do not arise from some mysterious process which cannot be explained scientifically, as many philosophers, doctors, scientists, and metaphysics progenitors would have us believe. Conscious experience arises from a defined physical process, according to laws of relativistic physics. Conscious experience therefore has a place in physics (Koch, 2015). Conscious experience has a strong subjective (phenomenological) component, i.e., it appears to us in a certain way. This subjective aspect of conscious experience arises as a natural consequence of the integration of what, where, and when information according to the principles of special relativity (through the computation of space-time intervals). The subjectivity of conscious experience therefore can also be explained scientifically through classical relativistic physics. The modeling of human conscious experience by special relativity is not actually surprising, as Einstein utilized his own imagination, various diagrams, and thought experiments to develop his theories of special relativity and general relativity (Hossenfelder, 2015), i.e., Einstein analyzed his own conscious experiences to develop his theories of relativity. What
Einstein actually discovered in his special theory of relativity was the organization of human conscious experience. Special relativity was composed to explain observed physical reality. This is just what conscious experience is: observed physical reality. The subjectivity of conscious experience is not an additional problem that must be explained, but is a natural consequence of the physical process generating conscious experiences. This essentially solves the “hard problem of consciousness” (how can something subjective like conscious experience arise in something physical like the brain), i.e., it explains why conscious experience appears to us the way it does.

The above concept emphasizes the importance of the what, where, and when information that is basic to psychological research. As expected, deficiencies in the acquisition of this information, or the acquisition of incorrect information, may lead to erroneous results and conclusions about the phenomenon being studied. Clinically, disordered integration of what, where, and when information may contribute to some of the negative symptoms of psychiatric or psychological disorders, such as distorted or false experiences (delusions and hallucinations respectively), disturbed or distorted cognition, anxiety, and depression which may be very disturbing and injurious to the patients. It might be of benefit to readjust the context (the where and when information) of the what information that the patient is exposed to. For example, by presenting what information in smaller amounts at a time so that each event can be individually processed fully before the next event is introduced has many benefits. This may be called a time-like scenario. The patient processes only a small amount of information at a time instead of being bombarded by a lot of information. This facilitates processing and understanding, reduces anxiety and apprehension, and may lessen depression. The opposing scenario may be called a space-like scenario. This involves trying to process to much information simultaneously. This scenario may overwhelm the patients with too much information and may generate much apprehension, anxiety, and depression. Space-like processing may be part of the reason for the negative symptoms in the first place. Readjustment of the way what, where, and when information is presented (in a time-like manner versus a space-like manner) therefore may greatly benefit patients by removing anxiety and depression, improve their cognition and outlook, and may help them work through their disorders. Similarly, presenting information to students in a time-like manner (smaller amounts at a time) rather than a space-like manner (large amounts at a time) may benefit learning and memory and help in the development of a student’s cognitive abilities. Study in a time-like manner (a smaller amount each day) promotes learning and memory (Dunlosky et al., 2013). Presentation of a smaller amount of information for a shorter period each day allows the gradual building of knowledge about a subject which is remembered for a longer period of time. Study in a space-like manner (too much at once) may overwhelm students and is detrimental to learning and memory. It might also be beneficial to intersperse periods teaching academic subjects (math, language arts, social studies) with periods teaching performance subjects (music, art, physical education). The way what, where, and when information is acquired is also important in everyday life. Time-like processing has many benefits in daily life, including the reduction of anxiety and apprehension and the facilitation of planning, reasoning, decision-making, and problem-solving. For example, a journey to a swimming pool or dentist, the making of a decision, or the solving of a problem may cause much apprehension for a person if a space-like scenario (thinking about all the upcoming steps to the
goal simultaneously-global thinking) is followed, instead of a time-like scenario (thinking about each upcoming step or event individually, only as it comes up-stepwise thinking). Making plans, decisions, or solving problems is easier and more effective if one focusses on each component step or event to the goal separately, as they come up. Do not worry about other upcoming steps until they become eminent. Following a space-like scenario when making decisions or solving problems might also lead to perseverance: one perseveres at a fixed strategy to a solution, even though the strategy repeatedly continues to fail. When a time-like scenario is followed (focussing on one step or event at a time), just a slight variation in the completion of a step or even a complete reversal of thinking about a step (which may be missed in the global space-like scenario) may be found to bring success. I have found that when one is unable to solve a problem or make a decision about something, one has the tendency to repeatedly follow the same fixed strategy to an unsuccessful solution (a space-like strategy). If one can turn a single step completely around, or look at it in a different way (a time-like strategy), one can often find success and rapidly solve the problem (creative thinking). Hence adjustment of the acquisition of what, where, and when information may be of benefit in everyday life. It facilitates and improves cognition. The acquisition of what, where, and when information is extremely important in serious athletics. Following a time-like scenario (learning separately each step in a skilled sequential routine) is important in the initial learning of skills. It is also very important for reliable performance of a skilled routine after it is learned (figure skating, gymnastics, etc.). If one thinks too far ahead or thinks about the whole sequence (space-like processing), disaster may occur. Here again, following a time-like scenario (letting each movement in the skilled performance evolve naturally as it comes up, without thinking about the next movement in the sequence) is the best policy.

Consciousness and the Four-Dimensional Nature of Conscious Experience

The reticular activating system originates in the upper brainstem reticular core and projects through the intralaminar thalamic nuclei to the cerebral cortex to mediate arousal, attention, and consciousness, i.e., the waking state (Sieb, 2013). The noradrenergic locus coeruleus, the mesencephalic reticular formation, the cholinergic nucleus basalis of Meynert, the dorsal hypothalamus, the intralaminar thalamic nuclei, and the tegmentum make up the reticular activating system (Sieb, 2013). Damage to the reticular activating system results in coma. Bilateral damage to the intralaminar thalamic nuclei produces lethargy or somnolence. Partial destruction or inhibition of the reticular activating system results in a partial loss of consciousness known as acute confusion state or delirium. The reticular activating system and the cerebral cortex are necessary to maintain consciousness.

Conscious experience has an intrinsic subjectivity. Conscious experience appears to us in a certain way that is particular only to the person having it, i.e., it is subjective. Conscious experience makes up the content of consciousness, i.e., what is in consciousness (Sieb, 2004, 2007, 2011, 2013, 2015, 2016a, 2016b). Conscious experiences are self-generated internal explicit states, arise rapidly in recurrent systems, take time to form, have a prolonged duration, are seamless, structurally-complex, ineffable, transparent, bounded, unified and coherent, informative, serial, limited in capacity, subject to interference, new or novel, variable, flexible, project outwards, can gain access to other systems, and arise from attention (Sieb, 2004, 2011, 2013). No two conscious experiences are ever exactly the same, as the conditions under which
they are formed are never exactly the same. Conscious experiences emerge in a nonlinear fashion (Sieb, 2004, 2007, 2011, 2013). Each conscious experience is particular only to the person having it and cannot be experienced or precisely predicted in advance by another individual. Hence specific wind chill and humidex temperatures that are repeatedly released by a weather service are completely invalid (such as when a weather person says it will feel like -20°C outside today). No one can precisely predict or accurately describe the conscious experience (the subjectivity, the “feeling”) of another individual (ask a person to try and explain what -20°C feels like, this is not possible). This illustrates the difficulty in describing subjective conscious experience.

A precise characterization of conscious experience is essential for extending scientific knowledge and for scientific research. A number of questions arise in understanding conscious experience. How does something subjective like conscious experience arise in something physical like the brain? Why does conscious experience appear to us the way it does? Why do we have conscious experiences? How did they evolve? What is the neural correlate of conscious experience? What principles of physics govern subjective conscious experience? How does subjective conscious experience drive cognition (mental processes involved in the acquisition of knowledge)? How is a subjective conscious experience encoded in memory and retrieved (episodic memory)? How can subjective conscious experience and episodic memory be modeled? How can subjective conscious experience be studied or investigated? For centuries, scientists have pondered these questions. The understanding, measurement, and treatment of impairments of cognitive function as well as the understanding and treatment of a number of neurodegenerative diseases and psychiatric conditions would greatly benefit from a complete characterization of conscious experience. The relativistic concept of conscious experience provides answers to all these questions and outlines a framework for organizing psychological research, for improving learning and memory, and for improving the study and treatment of psychological, psychiatric, and organic brain disorders.

Conscious experience may be observed to have a four-dimensional organization (three dimensions of space, one dimension of time). This can be observed in your current conscious experience. If you look around you, some conscious events are observed simultaneously, but at different three-dimensional spatial positions; other conscious events are observed at the same position, but at different times. For example, when I examine my conscious experience of this room, many conscious events (door, window, light, light switch, walls, ceiling, floor, desk, chair, computer, monitor, keyboard, hands, mouse, gloves, etc.) are observed simultaneously, but in different three-dimensional spatial positions. These events are separated only by space (since they are observed at different spatial positions), but not by time (since they are observed simultaneously). I observe other conscious events (my finger and the power button on the computer, my hand and the mouse, my hands and the gloves, a glass and a cup) at the same spatial positions (when I press the button, move the mouse, put the gloves on, or replace the glass with a cup), but at different times. These events are separated only by time (since they are observed at different times), but not by space (since they are observed at the same spatial positions). Notice that the conscious events separated by time also have cause-effect and past-future relations. Separation in time gives rise to causality and past-future relationships. This organization is typical and characteristic of conscious experience in general (all conscious experiences are organized in this manner) and indicates that conscious experience is organized in
space and time. Since there are three dimensions of space (length, width, height) and one
dimension of time (Petkov, 2010), conscious experience can be said to have four dimensions.
We observe (experience) the world in four dimensions.

Historically, conceptualizations of conscious experience involve only the three dimensions of
space (3D or three dimensions). This has greatly undermined the understanding and value of
conscious experience and has led to erroneous assumptions and conceptions of conscious
experience (conscious experience is metaphysical, mysterious, magical, epiphenomenal, non-
physical, and unexplainable). One can see that scientific research based on such assumptions
would be greatly undermined and deficient. However, when a relativistic model which includes
the dimension of time is applied to conscious experience, its true nature is revealed and such
false assumptions and conceptions may be abandoned.

The relativistic concept of conscious experience portrays conscious experience as a four-
dimensional frame of reference in which some conscious events are observed (experienced)
simultaneously, but in different spatial positions; while other conscious events are observed
(experienced) at the same spatial positions, but at different times. Space and time play a critical
role in the organization of conscious experiences. Space is the boundless three-dimensional
extent in which “events” occur and have relative position and direction; time is a continuum in
which “events” succeed one another from past through present to future (any dictionary, 2016).
Space is often conceived in three linear dimensions, but modern physicists usually consider it
with time, as part of a boundless four-dimensional continuum called space-time. Space-time is
any mathematical model that combines space and time into a single continuum (Petkov, 2010).
Conscious experience is a space-time continuum. Einstein’s special theory of relativity is the
most successful model in physics of a small local region of four-dimensional flat space-time. In
fact, what Einstein appears to have developed in his special theory of relativity is a model of
human conscious experience. Einstein used his own conscious experiences (imaginings, thought
experiments, diagrams) to develop his theories of relativity (Hossenfelder, 2015). Hence it is not
surprising that his theories actually model his conscious experience. The observation that
conscious experience has a four-dimensional organization and is modeled by Einstein’s special
theory of relativity is important. It suggests that conscious experience may be organized by
classical physical laws, and by some algorithm. As will be seen, this algorithm is the
formulation for space-time interval. This formulation has the potential to describe the formation
of any conscious experience. Since Einstein’s special theory of relativity depends on frames of
reference (observational perspectives of space described using coordinate systems), subjective
conscious experience may be quantified (described using a four-dimensional Minkowski
coordinate system). This is important in describing the positions of experienced events in space
and time and for the measurement of space-time intervals.

**Einstein’s Special Theory of Relativity**

Special relativity is based on two postulates: (1) the laws of physics are invariant (the same) in
all inertial (constant velocity) frames of reference, and (2) the speed of light is the same for all
observers, regardless of the motion of the light source. Special relativity predicts a wide range of
consequences (which have been experimentally verified). These include length contraction, time
dilation, relativistic mass, mass-energy equivalence \(E=mc^2\), where \(c\) is the speed of light in a
vacuum), a universal speed limit \(c\), and relativity of simultaneity (DiSalle, 2009; Einstein,
2001; Feynman, 1998; Roberts & Schlief, 2007; “Wikibooks”, 2016). Time dilates or lengthens
(slows) and lengths contract (shorten) at higher speeds of a reference frame (observer) relative to another; this keeps the laws of physics, $c$, and space-time intervals invariant (the same) in all inertial frames of reference. In relativity, time cannot be separated from space, because the observed rate at which time passes depends on the relative velocity of the observer. Time and space are interwoven into a single continuum (the space-time continuum). Since conscious experience is a space-time continuum, Einstein’s special theory of relativity is a viable model for conscious experience.

**Space-time Intervals**

An event is the fundamental entity of observed physical reality represented by three coordinates of space and one coordinate of time in the space-time continuum postulated by the theory of relativity. Hence, in relativistic terms, a conscious event is the fundamental entity of observed physical reality (conscious experience) represented by three coordinates of space and one coordinate of time in the space-time continuum postulated for conscious experience. In relativistic physics, an event has a unique position specified by four coordinates $(x,y,z,t)$. The unification of space and time is exemplified by the common practice of selecting a metric such that all four dimensions are measured in terms of units of distance $(x,y,z,ct)$, where “$c$” represents the speed of light in a vacuum and “$ct$” represents distance along the time axis (Petkov, 2010; “Wikibooks”, 2016). Since $c$ is equal to 1, $ct$ reduces to $t$. This enables mathematical description of space-time, the positions of events in space-time, and most importantly, space-time intervals.

In three-dimensional space, the separation between two objects is measured by the distance between them (the distance is purely spatial and always positive). In space-time, the separation between two events is measured by the invariant *space-time interval* between the events, which takes into account not only their spatial separation, but their temporal separation as well. Space-time interval may be formulated as follows (Petkov, 2010; “Wikibooks”, 2016): the space-time interval “$s$” is equal to the difference between the space coordinates “$\Delta r$” of two events minus the difference between the time coordinates “$c\Delta t$” of the two events (in practice the square is utilized as the sign of the space-time interval “$s$” is indefinite-positive, negative, or zero; $r$ is a displacement vector).

$$s^2 = \Delta r^2 - c^2 \Delta t^2 \text{ or } s^2 = \Delta r^2 - \Delta t^2, \text{ if } c=1$$

**The Light Cone**

Space-time intervals are defined by the light cone. A pulse of light emitted from a point spreads outwards in all directions at $c$. If light is confined to a two-dimensional plane, the light from a flash spreads out in a circle (Figure 1 and 2). If the growing circle is drawn with the vertical axis representing time (as in Figure 1 and 2), the result is a light cone (Penrose, 2005; “Wikibooks”, 2016). In reality, there are three space dimensions, so light would actually form an expanding sphere and the light cone would be a 4D version of a cone. The concepts are easier to visualize with the number of space dimensions reduced to two. A light cone represents the path that a flash of light, emanating from a single event and travelling at the speed of light in all directions, would take through space-time. Light cones are the same for all events and for all observers (since $c$ is a universal constant). Given an event A, all events that can be reached by a light pulse from A form a future light cone, while all events that can send a light pulse to A form an inverted
past light cone (Figure 1 and 2). Three types of space-time intervals are defined by the light cone and the equation for space-time interval. Space-time intervals play a crucial role in the organization of conscious experiences.

**Light-Like Space-time Intervals**

Events on a light cone are separated at light speed (c), such as events occurring to or originating from a photon as it travels along its path (“Wikibooks”, 2016). This separation of events is called a light-like or “null” space-time interval. The difference in the space coordinates of two events on a light cone is exactly equal to the difference in the time coordinates of the events.
The separation of the events in space is balanced by their separation in time. Hence the space-time interval equals zero ($s^2 = 0$). Such occurs when you directly observe a light source or an event (the event is visible because of reflected light). Light-like space-time intervals may help determine the nature of conscious events (what information) through the conveyance of defining information (qualia) about the events to the eyes.

**Time-Like Space-time Intervals**

If the difference in the time coordinates of two events is greater than the difference in the space coordinates of the events ($\Delta t^2 > \Delta r^2$, $s^2 < 0$), the events fall inside a light cone (A and B in Figure 1) and the separation is called a time-like space-time interval ("Wikibooks", 2016). For time-like space-time intervals (inside light cones), there is enough time between the events that signals or information can travel between the events at less than the speed of light. There is a reference frame where two events with time-like separation may be separated only by time, but not by space. The two events may be observed at the same spatial position, but not at the same time. The events may be observed at the same spatial position, but at different times (the events are separated only by time). Time-like space-time intervals could account for the experience of conscious events at the same spatial positions, but at different times (this can occur only with time-like separation of the events).

Because signals and other causal influences cannot travel faster than the speed of light, light cones (Figure 1 and 2) define the concept of causality. Since for time-like space-time intervals (inside light cones), signals or information can travel between the events at less than the speed of light, one event can influence or be influenced by the other event, by signals or information that does not need to travel faster than the speed of light. One event could be the cause or effect of the other event. If B causes A, B exists in the past history (in the past light cone) of A (Figure 1 and 2). If B is caused by A, B exists in the future (in the future light cone) of A (Figure 1 and 2). The past light cone of an event represents the boundary of its causal past and the future light cone the boundary of its causal future. Events with time-like space-time interval separation may be said to have a past or future relation. This can be observed in conscious experience. Events which occur at the same position, but at different times (time-like space-time interval separation) often have a cause-effect relationship and necessarily a past-future relationship. As will be seen, causal inference is a fundamental component of cognition and perception, binding together conceptual categories, imposing structures on perceived events, and guiding decision-making (Cummins, 2014).

**Space-Like Space-time Intervals**

If the difference in the space coordinates of two events is greater than the difference in the time coordinates of the events ($\Delta r^2 > \Delta t^2$, $s^2 > 0$), the events fall outside a light cone (A and C in Figure 1) and the separation is called a space-like space-time interval. For space-like space-time intervals (outside light cones), there is not enough time between the occurrence of the events that signals or information can travel between the events at less than the speed of light. There is a reference frame where two events with space-like separation may be separated only by space, but not by time. The events may be observed at the same time, but not at the same spatial position. The events may be observed simultaneously, but at different spatial positions (the events are separated only by space). Space-like space-time intervals could account for the experience of
conscious events simultaneously, but at different spatial positions (this can occur only with space-like separation of the events).

When a space-like space-time interval separates two events, not enough time passes between their occurrences for there to exist a cause-effect relationship crossing the spatial distance between the events at the speed of light or slower. Generally, the events are considered not to have a cause-effect or past-future relation. This can be observed in ordinary conscious experience. Conscious events which occur simultaneously, but in different spatial positions (space-like separation of events), do not have a cause-effect or past-future relationship. They do, however, have a spatial relationship and make up part of the context of the events.

**Organization of Conscious Experience**

Space-time intervals account for the organization of conscious experience. Space-time intervals in effect link (associate) conscious events to form a coherent four-dimensional conscious experience (i.e., a coherent four-dimensional observation of conscious events). Space-time intervals explain why conscious experience appears to us the way it does, i.e., they explain the subjectivity of conscious experience. Ultimately, conscious experience may be described as an orientation in space and time (an awareness of the existing situation with reference to space, time, and identity), an understanding of the position of the observer in space and time. As will be seen, this is important for human cognition and the implementation of intentional goal-directed actions.

**The Neural Correlate of Human Conscious Experience and Cognition**

A fundamental feature of conscious experience is the spatial organization of events. “Place cells” have been discovered in the hippocampus (O’Keefe, 1976; O’Keefe & Dostrovsky, 1971). Place cells fire at particular places in a spatially-structured environment. They fire so reliably, one can tell where an animal is in an environment by which place cells are firing. A place cell fires when an animal passes through a specific small region of space called the place field. Place fields are considered allocentric rather than egocentric because they are defined with respect to the outside world, rather than the body. By orientation based on the environment, place cells can work effectively as neural maps of the environment (Jeffery et al., 2003). The hippocampus essentially encodes a neural representation of surrounding space—a neural representation of the layout of the environment. The discovery of place cells led to a series of investigations that culminated in a book entitled “The Hippocampus as a Cognitive Map” which argued that the hippocampal neural network instantiates cognitive maps for spatial memory function (O’Keefe & Nadel, 1978). This motivated hundreds of experimental studies aimed at clarifying the role of the hippocampus in spatial memory and spatial navigation (Maurer et al., 2005; Moser & Moser, 1998). Considerable data indicate the hippocampus is critical to episodic memory in humans (Rolls, 2013; Sieb, 2015; Steinworth et al., 2005). Episodic memory is memory of personal past experiences of a particular time and place with reference to the person as a participant-observer (Munoz-Lopez et al., 2010; Schacter et al., 2011; Sieb, 2015). Conscious recall is required to demonstrate episodic memory (Munez-Lopez et al., 2010; Tulving, 1983; Ullman, 2004). A fundamental feature of episodic memory is the spatial representation of events composing a unique experience. An allocentric representation of the environment is encoded in the hippocampus and stored as episodic memory and hippocampal place cells play a crucial role in
the establishment and maintenance of this representation (Serino & Riva, 2014; Sieb, 2015). Place cells then are part of a complex circuit that informs memory and awareness (Jeffery, 2007; Jeffery et al., 2003). Another fundamental feature of episodic memory is the temporal organization of serial events that compose a unique experience (MacDonald et al., 2011). The hippocampus is essential to encoding unique sequences of events as well as disambiguating sequences that share common events. Studies on humans have shown that the hippocampus is critical to remembering the flow of events in distinct experiences and, in doing so, bridges temporal gaps between non-contiguous events. “There is a robust hippocampal representation of sequence memories, highlighted by time cells, that encode successive moments during empty temporal gaps between key events, while also encoding location and ongoing behavior” (MacDonald et al., 2011, Abstract). The hippocampal representation of time is quite similar to its representation of space (MacDonald et al., 2011): a large proportion of neurons are engaged in both; time cells fire at discrete moments during “empty” periods in a temporally-organized memory, much as place cells fire at discrete locations, devoid of specific stimuli; time cells signal the nature and timing of salient events, just as place cells signal the nature and spatial location of salient events; time cells disambiguate overlapping sequence memories, just as place cells disambiguate overlapping routes; and time cells partially “ret ime” when key temporal parameters are altered, just as place cells partially “re map” when critical spatial cues are altered. These findings suggest that hippocampal neuronal ensembles segment temporally-organized memories much as they segment spatial memories. MacDonald and coworkers (2011, Abstract) conclude that “place cells and time cells reflect fundamental mechanisms by which hippocampal neural networks parse any spatiotemporal context into quantal units of where and when important events occur and bridge, and thereby organize elements, in a conceptual organization of events.” Eichenbaum (2014, Abstract) concludes that “the firing properties of time cells parallel the properties of place cells and provide an additional dimension that is integrated with the spatial dimensions.” Both investigators conclude: that hippocampal neurons differentially encode key events in space and time (space-time) and compose unique spatially and temporally-organized representations of specific experiences. The representation of time and space in the hippocampus is a fundamental mechanism for organizing the elements of experience.

In 2014, John O’Keefe, May-Britt Moser, and Edvard Moser were awarded the Nobel Prize in Physiology or Medicine for the discovery of “grid cells”, cells that constitute a “positioning system” in the brain. A grid cell is a type of neuron found in the brains of many species that allows them to “understand” their position in space (Doeller et al., 2010; Hafting et al., 2005; Figure 3. A hexagonal lattice. The dots are firing fields of a grid cell.
Sieb, 2016a, 2016b). Grid cells have been identified in rats, bats, monkeys, and humans. A grid cell fires when a freely-moving animal traverses a set of small regions (firing fields) roughly equal in size and arranged in a periodic triangular array that covers the entire available environment (Hafting et al., 2005). Firing fields are equally spaced apart, such that the distance from one firing field to all six adjacent firing fields is approximately the same (Figure 3). Firing fields are positioned such that the six neighboring fields are located at approximately 60 degree increments (firing fields are organized into a hexagonal lattice). Doeller and coworkers (2010) provided the first evidence for grid-cell-like representations in humans that implicates a network of regions supporting spatial cognition and autobiographical (episodic) memory. This network consisted of the entorhinal/hippocampal/subicular, posterior and medial parietal, lateral temporal, and medial prefrontal cortical areas. The signal was greatest in the right entorhinal cortex. Doeller and coworkers (2010, Abstract) concluded that “grid cells provide a strikingly periodic representation which is suggestive of very specific computational mechanisms.”

The hippocampus has reciprocal connections with the entorhinal cortex and many other brain areas (Serino & Riva, 2014). Besides output to the entorhinal cortex, additional output goes to other cortical areas, including the prefrontal cortex (PFC) and the posterior parietal cortex (PPC). A key function of PPC is the implementation of visuospatial attention and of spatial processing in general (Wendelken, 2015). The intraparietal sulcus (IPS), which separates the inferior and superior parietal lobes (IPL, SPL), has been shown to contribute to the maintenance of spatial location information and the IPL is a locus of spatial-relational processing. Lara and Wallis (2015) found that the strongest activity of the overwhelming majority of PFC neurons reflects the spatial location of stimuli and the passage of time. PPC and PFC have been implicated in time-experiencing (Wendelken, 2015): the cerebellum, right PPC, right PFC, fronto-striatal circuits, and insular cortex for duration perception; the inferior frontal and superior temporal lobes, hippocampus, medial PFC, medial parietal and posterior cingulate cortex for past–future distinction and mental time travel; the PFC, IPC, superior colliculus, and insular cortex for synchronous and asynchronous event distinction; and the posterior sylvian regions, PPC, and tempo-parietal networks for temporal order judgment. Wendelken (2015) observed stronger PPC activation for processing inequalities, than for processing equalities, and argued that this was due to representation of the more specific inequality relationships in PPC. This is interesting because space-like and time-like space-time intervals are inequalities. Wendelken (2015) found that current evidence is most consistent with accounts that involve estimation and probabilistic computation for the PPC and PFC. This is just what would be expected if the PPC and PFC processed space-time interval inequalities. PPC is a primary area involved in mathematical (numerical) cognition. In addition to these parietal regions, regions of the frontal lobe are also active in calculation tasks. In monkeys, neurons have been found in the frontal cortex and IPL that respond to numbers (Wendelken, 2015). There is evidence that numerical cognition is intimately related to spatial cognition (Wendelken, 2015). Regions of the parietal cortex show shared activation for both spatial and numerical processing, and as mentioned above, for temporal processing. These various lines of research suggest a strong, but flexible, connection between numerical, spatial, and temporal cognition in PPC and PFC. Wendelken (2015) found that the extraction of mental relations from the hippocampus by the PPC and PFC initiates an important process of relational integration. These studies support the contention that the PPC and PFC may preferentially extract space-time interval inequality information from the hippocampus in a process of relational integration of spatiotemporal function.
Perception is the identification, organization, and interpretation of sensory information in order to represent and understand the environment (Schacter et al., 2011); an awareness of the elements of the environment through physical sensation; physical sensation interpreted in the light of experience. Perception is shaped by learning, memory, expectation, and attention (Bernstein, 2010; Gregory, 1987), processes which the hippocampus, PPC (including the IPC), and PFC are engaged in (Sieb, 2013, 2015). Perception also has features which may be conditioned by the hippocampus, PPC, and PFC: constancy (the ability to recognize the same event from widely varying sensory inputs-Atkinson et al., 1990; Bernstein, 2010), grouping (humans naturally perceive events as organized sets of qualia-Goldstein, 2009; Gray, 2006; Wolfe et al., 2008), contrast (experienced properties can be affected by the qualities of context-Corsini, 2002; Kushner, 2008; Popper, 2010), experience (with experience, organisms can make finer perceptual distinctions and learn new kinds of categorization-Sumner, 2009), motivation (Coon & Mitterer, 2008; Sieb, 2013; Weiten, 2010), and expectation (a predisposition to perceive things in a certain way-Coon & Mitterer, 2008; Sieb, 2013; Weiten, 2010). Perception appears to be conditioned by the hippocampus-PPC-PFC (Sieb, 2013, 2016a, 2016b). Since conscious experience has such an intimate connection with perception, the hippocampus-PPC-PFC probably is also involved in the creation of conscious experiences.

Reasoning (the capacity to reach novel conclusions on the basis of existing premises) is among the most complex of cognitive processes (Wendelken, 2015). Bilateral PPC activation was found during relational reasoning and left PPC activation during propositional reasoning. Within PPC, reasoning is most strongly associated with activation of middle to posterior IPL, and to a lesser extent, with neighboring regions of SPL. Left PPC demonstrated greater involvement than right PPC. Selectivity for higher-order visuospatial reasoning, but not semantic reasoning, was found in right PPC. There were notable similarities between reasoning activations and activations associated with visuospatial processing and attention, particularly on the right, and between reasoning and phonological processing, particularly on the left. The mid-IPL appears to be unique for relational reasoning. Wendelken observed stronger PPC activation for reasoning with inequalities, than for reasoning with equalities and that current evidence points away from logical rule-following as a primary mechanism for reasoning and is more consistent with accounts that involve estimation and probabilistic computation. He found that it was clearly indicated that the pattern of activation in PPC associated with reasoning is most closely related to that for mathematical cognition. Wendelken (2015) found that rostrolateral PFC extracts mental relations from the hippocampus and is specialized for second-order relational reasoning. He found that current results are consistent with the possibility that rostrolateral PFC may share this duty with a sub-region of mid-IPL. Although direct anatomical connections between rostrolateral PFC and mid-IPL have not been reported, it is noteworthy that these two regions demonstrate strong functional connectivity during task execution and even at rest (Sieb, 2013, 2016a, 2016b). These studies support the contention that space-time interval inequality relations are extracted from the hippocampus by the PPC and PFC for reasoning, a complex cognitive process.

Long-term memories can be divided into declarative and non-declarative memories (Pause et al., 2013). Declarative (explicit) memories are conscious, can be voluntarily accessed, and can be verbalized. Non-declarative memories are not conscious and the contents cannot be verbalized. Declarative memories can be further subdivided into semantic and episodic memories (Pause et
Semantic memories refer to facts and rules and basic knowledge about the world. Context is therefore not important in their retrieval. Episodic memories, in contrast, have a context. They refer to single events or personal experiences that also contain information about the spatial and temporal context of these events. The concept of episodic memory was developed by Endel Tulving in the early 70s (Tulving, 1983). Tulving defined episodic memory as a memory system specialized to store specific idiosyncratic experiences in terms of what happened and where and when it happened. Episodic memory therefore is based on the encoding of three core types of information: what, where, and when (Mizumori, 2013; Pause et al., 2013; Yassa & Reagh, 2013). Episodic memory deficits are observed after medial temporal lobe injury, which includes important memory structures such as the hippocampus and amygdala, but also after lesions to the frontal cortex and diencephalic structures, such as the mediodorsal thalamus and the mammillary bodies (Pause et al., 2013). Episodic memory impairments have been demonstrated in the course of healthy aging, the acute phase following mild traumatic brain injury, and in a variety of neuropsychiatric diseases (Pause et al., 2013). Furthermore, it seems that episodic memory deficits usually precede more global cognitive impairments associated with neurodegenerative diseases (Pause et al., 2013). Therefore, one can view episodic memory functioning as a highly sensitive indicator of incipient brain pathology which manifests well before the full dimension of the disease becomes evident at the psychological and behavioral level. Both the PPC and PFC contribute to episodic memory. Parietal activation is most commonly associated with the endorsement of stimuli as having been previously encountered (Nelson et al., 2013; Wagner et al., 2005), though associations with memory encoding (Uncapher & Wagner, 2009) and memory confidence (Johnson et al., 2013) have also been noted. The PFC (particularly in the left hemisphere) is involved in the formation of new episodic memories. Patients with damage to the PFC can learn new information, but tend to do so in a disordered fashion (Janowski et al., 1989). The PFC may be essential for remembering the contextual details of episodic memory, help organize information for more efficient storage, or underlie semantic strategies which enhance encoding (Gabriele & Kao, 2007; Gabriele et al., 1998). Hence the PPC and PFC are intimately involved in complex cognitive functioning (perception, reasoning, episodic memory, mathematical cognition, spatial and temporal cognition) and space-time interval inequalities extracted from the hippocampus may play a key role in this processing.

Causality

Causal inference is a fundamental component of cognition and perception, binding together conceptual categories, imposing structures on perceived events, and guiding decision-making (Cummins, 2014). Causality is distinct from mere contingency or covariation (Cummins, 2014). In causality, one event has the power to bring about another event. In covariation and contingency, two events are simply statistically dependent on one another. Neuro-imaging studies show that the brain distinguishes causal events from non-causal events (Cummins, 2014). There are significantly higher relative levels of activation in the right middle frontal gyrus and the right IPL for causal relative to non-causal events. Causal judgments, beyond associative judgments, generated distinct activation in left dorsolateral PFC and right precuneus (part of the SPL), substantiating the particular involvement of these areas in assessments of causality. Perceptual causality can be distinguished from inferential causality (Cummins, 2014). Inferential causality activates the medial frontal cortex, with particular left hemispheric
involvement. Perceptual causality activates the right parietal lobe suggesting that the right parietal lobe is involved in the processing of the spatial attributes of causality. The PPC and PFC therefore appear to be involved in the assessment of causality. Since they also appear to be involved in the processing of space-time interval inequalities extracted from the hippocampus, assessments of causality could arise in conjunction with the processing of space-time interval inequalities by the PPC and PFC. This supports the contention that space-time interval inequalities are represented in the hippocampus and extracted by the PPC and PFC for cognitive function.

**Working Memory**

Working memory is the holding in mind of multiple pieces of information for a brief period of time and its manipulation. Working memory has been linked to attention, perception, conscious experience, learning, cognitive development, cognitive function, and memory (Lara & Wallis, 2015; Sieb, 2015, 2016a, 2016b). The concept of working memory describes a process of short-term storage of information to support ongoing or upcoming actions, and is considered a crucial component of the executive control of goal-directed behavior (Monsouri et al., 2015). The retention of task-relevant information in working memory is essential for complex behaviors which evolve in time, in order to maintain the perception and actions in a coherent and goal-directed framework. Working memory may accomplish this by maintaining a context. Working memory is crucial for the temporal and spatial organization of behavior, linking processes across delays. Working memory is considered an essential intermediate stage enabling further manipulation and integration of information involved in perceptual and mental functions (cognition). Functionally, working memory may be considered the provisional retention of perceptual information for prospective action, a type of focal attention whereby perception is reorganized and re-represented, becoming explicit, functional, and conscious (Sieb, 2004, 2015, 2016a, 2016b). The PFC, PPC, thalamus, and parts of the basal ganglia (caudate, globus pallidus) are crucial for working memory function (Sieb, 2013, 2015, 2016a, 2016b). There is an emerging consensus that most working memory tasks recruit a network of prefrontal and parietal cortical areas. An increasingly large number of investigations have found that the feedback connectivity between the PFC and PPC is required for working memory and conscious experience. Positive feedback appears to be involved (Sieb, 2004, 2011, 2013, 2015). Since the PPC and PFC appear to integrate space-time interval inequalities, space-time interval inequalities could play a substantial role in establishing and maintaining a context in working memory for the coherent organization of conscious experience, cognition, and behavior.

Neural activity in nearly every part of the hippocampal system is modulated by theta EEG oscillations. The entorhinal cortex is no exception. Like the hippocampus, it receives cholinergic and GABAergic input from the medial septal area, the central controller of theta. Grid cells, like hippocampal place cells, show strong theta modulation (Hafting et al., 2005). The theta rhythm reflects subthreshold membrane potentials which strongly modulate the spiking of hippocampal neurons and synchronise across the hippocampus in a travelling wave pattern (Lubenov & Siapas, 2009). Frontal-midline (fm) theta oscillations are of particular interest in regard to higher cognitive functions (Enriquez-Geppert et al., 2014). Fm-theta oscillations are recorded over fronto-medial brain regions at frequencies between 4–8 Hz and appear to be generated in the mid-cingulate cortex (MCC), a highly interconnected brain structure, that is part of the superordinate cognitive control network. The MCC (part of the prefrontal cortex—Sieb, 2013) is known to be crucially involved in executive functioning, which enables goal-directed
behavior. Enhanced cognitive processing is accompanied with increases of fm-theta, specifically in tasks involving working memory and executive functions. In addition, fm-theta activity has been related to efficient working memory maintenance and increases of fm-theta activity during task processing have been shown to predict successful behavioral performance and conflict monitoring. In addition to local synchronization, oscillatory activity of distant neural structures can synchronize (Enriquez-Geppert et al., 2014; Lara & Wallis, 2015). Because brain areas are bi-directionally coupled, the connections between brain areas form feedback loops. Oscillatory activity generally arises from feedback connections that result in the synchronization of firing patterns; positive feedback loops tend to cause oscillatory activity in which frequency is inversely related to the delay time. Oscillations from multiple cortical areas can become synchronized to form a large-scale oscillating network. Neural oscillations may coordinate neuronal spiking between and within brain circuits and coherent large-scale brain activity may form dynamic links between brain areas required for the integration of distributed information. Neural oscillations may provide a linkage of neural activity with behavior and thought. Different neural oscillations may appear concurrently and interact in a hierarchical way in order to implement perception and cognition. Synchronization and neural oscillation have been linked to many cognitive functions such as information transfer, perception, motor control, and memory. Neural oscillations have been linked to cognitive states, such as awareness and consciousness (Enriquez-Geppert et al., 2014). Hence theta oscillation appears to be correlated with the operation of working memory and the information transfer involved in perception, learning, memory, other cognitive processing, motor control, and conscious experience. Space-time interval inequality relations may be distributed and integrated throughout the wide spread theta-oscillating entorhinal cortex-hippocampal-PPC-PFC network to condition coherent processing. Relativistic space time intervals in effect compose and direct our conscious life.

CONCLUSION

In humans, knowing the world occurs through spatiotemporal experiences and interpretations. We observe (experience) the world through conscious experience. All knowledge comes to us through conscious experience. Conscious experience is an orientation in space, time, and identity; an understanding of the position of the observer in space and time. This is essential for cognition and the creation of intentional goal-directed adaptive actions. There is an intimate coherence between conscious experience, cognition, and behavior; relevant behavior appears to arise directly from conscious experience. This coherence arises because conscious experience, cognition, and behavior occur within a common context. Psychological research is the scientific study and analysis of the human mind and its functions, especially those affecting behavior in a given context. Hence setting up and maintaining an appropriate context that adequately represents the experience or behavior in question is of crucial importance in psychological research.

Conscious experience, cognition, and behavior are built from three core sources of information: what, where, and when. Psychological research is also built from the same three core sources of information: what, where, and when. Hence psychological research is aptly suited for the study of human conscious experience, cognition, and behavior. Where and when information form a context for the what, i.e., a setting by which the what can be fully assessed and understood. It is a common context which ties conscious experience, cognition, and behavior together, so that
behavior appears to arise directly from conscious experience. Hence the where and when information utilized in psychological research must set up and maintain an appropriate context for what in any research study. Through a common context, a coherent transition from conscious experience to cognition to behavior occurs and the behavior appears to emerge directly and immediately from conscious experience.

Conscious experience may be described as a four-dimensional space-time continuum. Einstein’s special theory of relativity is the most successful model of a four-dimensional space-time continuum. Since conscious experience is a four-dimensional space-time continuum, the special theory of relativity is a viable model for human conscious experience. In fact, a neural correlate for human conscious experience has been found in the brain, which is modeled by Einstein’s special theory of relativity. Einstein’s special theory of relativity was derived from human conscious experiences (Einstein’s imagination, diagrams, and thought experiments). Hence it is not surprising that special relativity models human conscious experience. Hippocampal place cells and time cells encode what, where, and when information for spatiotemporal function (conscious experience, spatial memory, episodic memory, cognition, behavior) as the subject moves around the environment. Entorhinal cortex grid cells provide a representational grid (analogous to the four-dimensional frames of reference of special relativity) in the hippocampus for the computation of space-time interval relationships from the spatial and temporal information. These relationships are extracted from the hippocampus by the prefrontal cortex and posterior parietal cortex for the organization of coherent conscious experiences, cognition, and behavior.

Space-time intervals are the fundamental units computed in the human brain that are involved in the organization of all coherent conscious experiences, episodic memories, cognition, and behaviors. A space-time interval is the separation between two events in four-dimensional space-time. It is given by the formulation: \( s^2 = \Delta r^2 - c^2 \Delta t^2 \) or \( s^2 = \Delta r^2 - \Delta t^2 \), if \( c=1 \). Space-time interval is the difference between the space coordinates of two events - the difference between the time coordinates of the two events. Based on this formulation and the light cone, three types of space-time interval are possible, each contributing a different aspect to conscious experience, cognition, and behavior. Light-like space-time intervals separate events occurring at light speed. Such occurs when observing light-emitting or light-reflecting objects or events. Experience of the defining qualities or properties (qualia) of objects or events (the what) may occur via light-like space-time intervals. Space-like space-time interval separation of events explains a major component of conscious experience (conscious events experienced at the same time, but in different spatial locations). Space-like space-time interval separation may contribute to the context of conscious experience, cognition, behavior, and psychological research.

Time-like space-time interval separation explains the other major component of conscious experience (conscious events experienced at the same location in space, but at different times). Time-like space-time interval separation also contributes to the context of conscious experience, cognition, behavior, and psychological research. In addition, time-like space-time interval separation establishes cause-effect and past-future relationships. Space-time intervals therefore explain the organization of human conscious experience, cognition, behavior, and psychological research. They explain why conscious experience appears to us the way it does (its subjectivity);
the coherence of conscious experience, cognition, behavior, and psychological research; and the agency of conscious experience, cognition, behavior, and psychological research. This shows that conscious experience is not some mysterious phenomenon that cannot be explained scientifically, but is a natural phenomenon produced through classical relativistic physics. Subjectivity arises as a natural consequence of the physical processing of space-time intervals. Hence the hard problem of consciousness is solved (how something subjective like conscious experience arises in something physical like the brain).

The relativistic concept of conscious experience explains how psychological research works. Particular what, where, and when information which represents a particular psychological construct is collected, measured, and manipulated to generate coherent results and conclusions. What information is represented in a particular context (provided by the where and when information) to give coherent results and conclusions about the construct in question. Particular attention then to the collection and interpretation of the what, where, and when information must be implemented during psychological research to ensure that the best possible results and conclusions are reached. If any of the three types of information is missing, incorrect, distorted, false, or unreliable, then the results and conclusions may be deficient. Cognizance of the relativistic concept of conscious experience may thereby improve the efficacy of psychological research.

The relativistic concept might also be utilized to explain some of the negative signs and symptoms of mental disorders. Apprehension, anxiety, and depression may arise if patients primarily use a space-like processing strategy in their cognition. The patient is bombarded by too much information at any one time or uses a global approach to analyze information, solve problems, make decisions, or make plans. If patients were to utilize a time-like processing strategy in their cognition, their apprehension, anxiety, and depression may be lessened, their cognition improved, and they may be able to improve their conditions. Time-like processing involves the processing of a limited amount of information at any one time and to make plans, decisions, or solve problems using a gradual sequential step-wise procedure (instead of trying to do it all at once). The time-like strategy also benefits learning and memory in the educational setting. In addition, the time-like approach appears to improve general cognition, learning, and memory in everyday life for anyone. This has a great effect in lessening stress, anxiety, and tension. It has worked for me.

**Basic Criteria for Psychological Research**

The above concept suggests some basic criteria for psychological research. The first criterion is that psychological research is best carried on in a laboratory setting. This allows for the precise description of the what, where, and when information; the precise manipulation of experimental variables; the correct timing of events; the precise location of events; and controls for the correctness of the results and conclusions. The second criterion is that the subjects should not receive any explicit instructions about what is being investigated, so as to prevent extraneous influences (preconceived ideas, expectation, etc.) from interfering with the results. The third criterion is that emotional arousal should be kept to a minimum (except of course for research on emotion) so as to keep the physiological, behavioral, and experiential effects of emotion from
interfering with the behavior being investigated. *The fourth criterion* is that psychological research should utilize a one trial procedure. Only the first trial of a study gives the best uncontaminated results. Repetitive trials using the same information may introduce additional interfering effects (habituation, adaptation, potentiation, learning, etc.) into the process or behavior being investigated. *The fifth criterion* is that the information to be induced, retained, measured, and retrieved must include what, where, and when information. Only what, where, and when information together provides a complete picture of the behavior or process being investigated. *The sixth criterion* is that the results should be unexpected. This allows an unbiased uncensored reliable reproducible investigation. *The seventh criterion* is that the working memory capacity of the subjects should be controlled for, or considered, when doing psychological research, since most psychological research utilizes the working memory of the subjects. Working memory sets up and maintains the context of the study and normally has a capacity of about 3 or 4 chunks of information at any one time. If the working memory capacity of the subjects is exceeded, or varies greatly among the subjects, during a research study, then the results and conclusions of the study may be incorrect or unreliable because of the context variations. *The eighth criterion* is that the what, where, and when information included in a study should be as complete, accurate, reliable, and relevant as possible to obtain the best possible results and conclusions. *The ninth criterion* is that the what, where, and when information utilized in a research study should define a specific coherent phenomenon and should lead to coherent results and conclusions about the phenomenon. *A tenth criterion* may be that all investigators should arrive at the same coherent results and conclusions from the what, where, and when information included in the study (a consensus is reached). If this is the case, it might be a sign that the results and conclusions are correct and follow naturally from the information included in the study. Any significant variation should lead to a re-examination of the what, where, and when information utilized and the results and conclusions reached. *An eleventh criterion* is that the results and conclusions of a study should be reproducible by the same or other investigators using the same what, where, and when information. If a study is not reproducible, there may be some errors in the what, where, and when information utilized, its interpretation, or in the results and conclusions reached. *A twelfth criterion* is that the space-time interval organization of the what should be carefully controlled. If the space-like or time-like separation of the what is too great or too small, the context of the what may be inappropriate and the results and conclusions reached incorrect. If the time-like separation of the what is too large, or too small, then cause-effect relationships may be lost or inappropriate, again leading too incorrect results and conclusions. The space-time interval organization of the what must therefore be properly controlled to maintain the integrity of the study. Controlled variations in the space-time interval organization of a study might also provide additional information about the behavior or process being studied.

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