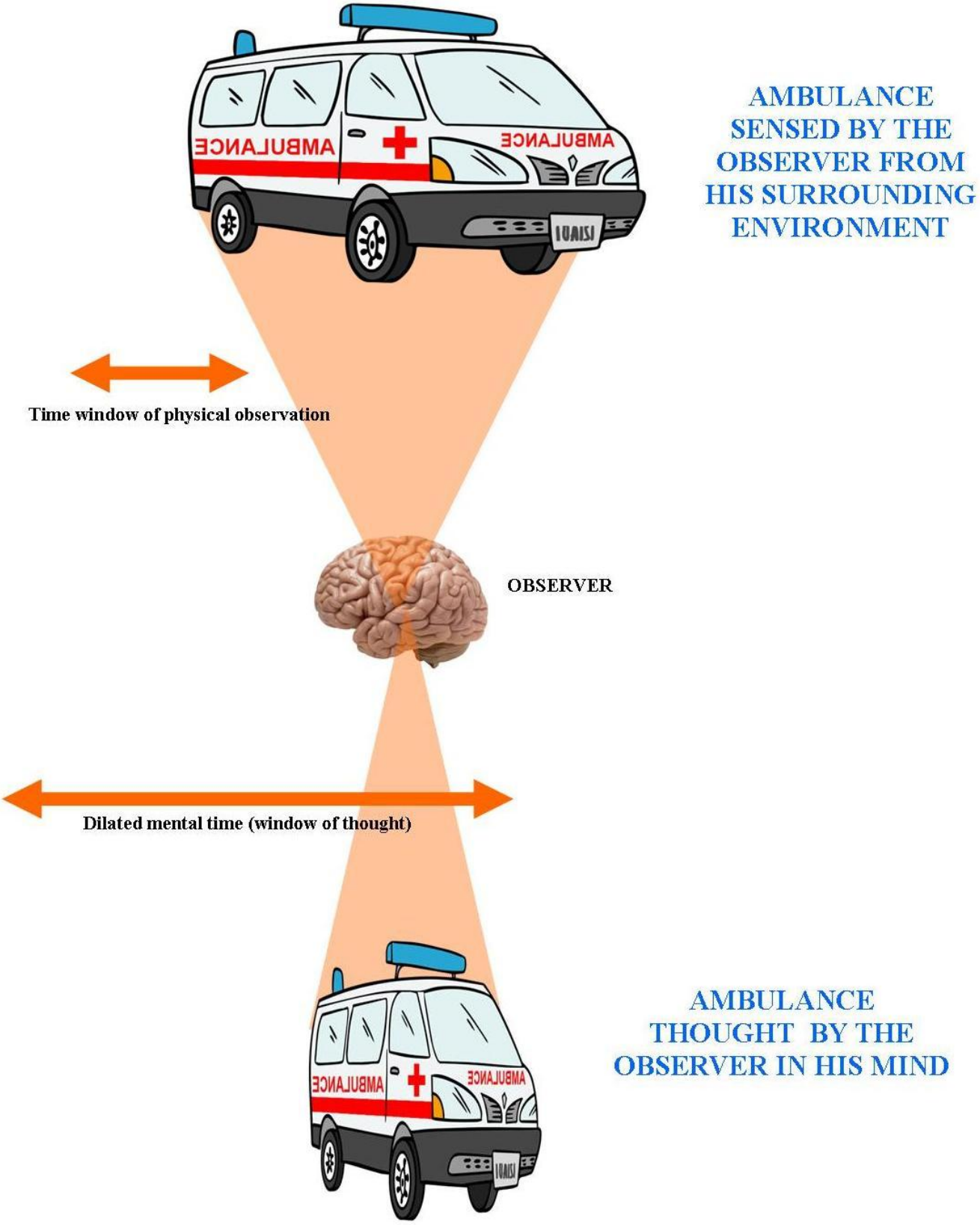
AMBULANCE
AMBULANCE
AMBULANCE SENSED BY THE OBSERVER FROM HIS SURROUNDING ENVIRONMENT
Time window of physical observation
OBSERVER
Dilated mental time (window of thought)
AMBULANCE
AMBULANCE
AMBULANCE THOUGHT BY THE OBSERVER IN HIS MIND

QUANTIFYING MENTAL IDEAS THROUGH SPECIAL RELATIVITY AND BEKENSTEIN-HAWKING FORMULAS

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When perceived by the human mind, an object might encompass a diverse amount of available information, according to different observers. Starting from this simple observation and extending it to the Einstein's four-dimensional spacetime and to Bekenstein and Hawking equations, we show how, in terms of special relativity, information is not a stationary and fixed quantity as currently believed, but rather depends on the observer's standpoint. We elucidate how the subjective phenomenon of time (perceived by our mind as static) might give rise to changes in informational entropy between the real and the imagined object. We describe a way to correlate and quantify the information of the sensed object embedded in the environment and of the corresponding internal thought about it (subjective percept). In particular, we show how changes in our mental time windows are able to squeeze the information content of the subjective percepts, compared with their matching environmental, real objects. Further, we elucidate how this novel framework could be able to confirm or reject a recently raised hypothesis, which suggests that the brain activity takes place in functional dimensions higher than the four-dimensional spacetime environment.

INTRODUCTION

In our daily phenomenal experience, we have our conscious states' contents as occurring "now" and "here" (Droege, 2009; Fingelkurts and Fingelkurts, 2014). In line with this observation, it has been suggested that conscious awareness necessarily demands mental content being held "fixed", "frozen" within a discrete but continuous progressive present moment that stands for a phenomenal unity (James,1890; Lynds,2003; Revonsuo, 2003, Fingelkurts and Fingelkurts, 2014). Estimates of the mean duration of the specious present's frame suggest that it varies from~100 ms to several seconds, depending on circumstances (Pöppel,1988). In this paper, we try to extend the subjective perception of time to an objective reference frame of mechanisms outside the phenomenal realm. We will discuss the relationships between two different observer's standpoints: a) the standpoint of an observer while he/she watches an object embedded in his/hers external environment, and b) the standpoint of an observer while he/she thinks about the same object, thus having the subjective thought presenting the object. In order to correlate the subjective mental time with the objective reality surrounding us, we need to introduce the information theory.

Information is a measurable physical quantity that is currently believed to be the most general paradigm able to asses physical and biological systems (Bekenstein, 2003; Zenil, 2012). The idea that the physical world is made up of the fundamental physical quantity called information dates back to F.W. Kantor (1977). By then, different information-related perspectives have been developed, from a proposed link among information theory, statistical thermodynamics and quantum mechanics (Jaynes 1957; Lloyd 2000; Marzuoli and Rasetti, 2005, Fuentes-Guridi et al., 2005), to connections with Bekenstein-Hawking Entropy (Weizsäcker 2006, Görnitz 1988). Indeed, information sits so strongly at the core of physics, that the slogan "it from bit" has been launched (Wheeler, 1990).

For the purpose of this paper we ask: are we allowed to use physical information, in order to assess mental ideas? Taking into account the formalisms of Bekenstein's and Hawking's entropies, thermodynamics, information theory and

Einstein's special relativity, we will try to answer to the following questions: how much information does an observed object (say, an ambulance that you watch in the street) encompass? Is such informational content an invariant quantity? Is it feasible to quantify also the information content of the "concept" of ambulance that my brain is able to think about? Can we assess the information encompassed in a thought, or in the mental process of imagining the same ambulance? Here we show how, by joining concepts from far-flung branches of science, a novel and suitable framework can be drawn, able to throw a bridge between the information encompassed in the environmental objects and the information endowed in their corresponding mental presentations. We will show also how this novel approach could be used in order to confirm or reject a recently raised claim, e.g., that the brain activity lies in functional dimensions higher than the four-dimensional spacetime environment surrounding us (Tozzi and Peters, 2016a, 2016b; Peters et al., 2017a).

MATERIALS AND METHODS

Assessing the information of an object embedded in our surrounding environment. At start, we need to assess the physical amount of invariant information encompassed in an environmental object, e.g., our example of ambulance. Here the Bekenstein inequality comes into play. Let k be Boltzmann's constant, R the radius of a sphere that encompasses a given system (in this case, we generalize the ambulance's shape, describing it in terms of an abstract sphere-like surface), E the total mass energy, $\hbar$ the reduced Planck constant and c the speed of light. The Bekenstein bound is an upper limit on the thermodynamic entropy S (or, according to Shannon 1948, the information I) endowed in a finite region of space equipped with a finite amount of energy. In other words, the Bekenstein bound stands for the maximum amount of information required to describe our ambulance. The universal form of the bound is the following (Bekenstein, 1973 and 1974):

$$S \leq \frac{2\pi RkE}{\hbar c} = \frac{2\pi Rk(hf)}{\hbar c} = \frac{2\pi Rk\left(\frac{hc}{\lambda}\right)}{\hbar c},$$

where f is the wave frequency of the particulate photon energy E and h is the Planck constant.

In Hawking's terms (Hawking, 2005), we can state that:

$S = AkC^2 / 4\hbar G$

Where A is the spherical object's area, k is the Bolztmann constant, C is the light speed and G is the gravitational constant. Note that the Hawking formula is easier to assess and quantify, because just S and A are variable quantities, while the other terms stand for constants.

The Bekenstein and Hawking formulas were initially used to demonstrate that the entropy encompassed in a black hole is proportional to the area of its event horizon (Hawking, 2005), *i.e.*, to the two-dimensional border of a sphere-like object enclosing it. Indeed, the maximal entropy scales with the radius squared, and not cubed as might be expected. Parenthetically, this led also to the theory of the world as hologram ('t Hooft 1993; Susskind 1994). In our case, this means that the amount of ambulance's entropy is endowed in its visible surface, therefore being easily quantifiable. This is also in touch with Gibson's ecological theory of perception (Gibson, 1979, 1986; Gibson and Pick, 2000), according to which an individual shifting in its environment perceives just the surfaces and the shadows of the objects approaching him.

Summarizing, according to physical claims, and in particular to the Bekenstein bound, the information encompassed in our ambulance is a fully describable, measurable quantity endowed in its observable surface. The entropy, and therefore the information encompassed in the object we observe, is proportional to its (approximately) two-dimensional sphere-like border. Therefore, an observer collects from the environment a distinct pattern and accurate amount of information related to it, in this case coming from the ambulance he is looking at. We have now to tackle the other, crucial issue: if the information content from the ambulance surface is constant, how does our brain process such inputs? Is it possible to quantify the amount of information encompassed in the subjective image/thought and concept of the ambulance reminded or imagined by our brain?

A link with Einstein's special relativity. In order to try to answer to the latter central question, we need to project ourselves into the field of the special relativity (Einstein, 1905). By the standpoint of an observer in uniform translatory motion relative to the object, when its speed increases, it seems to modify. In particular, in an inertial frame, when the object approaches the light speed, its time slows down, compared with the time detected by the observer at rest.
The Einstein's formula of time dilation at increasing speeds is the following:

$\Delta t = t_0 / \sqrt{1 - v^2/c^2}$

where Δt stands for the time interval between two events, and t_0 for the minimum duration of the time length.

Another detectable change predicted by Einstein equation occurs: modifications in object length along one of its spatial dimensions. Indeed, when a body approaches the light speed, one of its length shortens, according to the formula:

$L = L_0\sqrt{1 - v^2/c^2}$

where L stands for the length of a moving body and L_0 for the maximum length of a body at rest. In Einstein's words, the length of a regulus (in this case, our object) is not invariant, because its dimension X shortens together with increases in its speed.

Therefore, in the inertial frame of special relativity, one of the three spatial dimensions changes, depending both on the observer's standpoint and the observed object's speed. In terms of object length, this means that, if the inertial observer changes his relative position and speed compared with the object, he detects changes in the length, and therefore in the surface, of the observed object.

Δt and L are correlated through the formula:

$$\frac{\Delta t}{\Delta t0} = \frac{L0}{L}$$

This means that, in a *gedankenexperiment*, a spherical object at rest, say a black hole, appears more or less squeezed by the standpoint of two hypothetical observers, one at rest, and another traveling at the speed light. Therefore, according to the different observer's motion and speed, the black hole's spherical surface is more or less deformed. In special relativity, the Minkowski norm of 4-vectors makes sense; such quantities (such as the object length in our case), constructed out of non-invariant quantities, can be shown to exist.
It can be demonstrated that such apparently non-invariant quantities display different information content. Indeed, by joining the two issues of Einstein's special relativity and black hole thermodynamics, we are allowed to make the following statement: according to the different observer's standpoints, the information encompassed in the object changes at relativistic speeds, e.g., close to the speed of light. Therefore, when the observer moves in an inertial system, the information he detects about the analyzed black hole modifies. This means that, in an inertial system, the object's information content must change when the observer's speed varies, because also the object's surface, correlated with thermodynamic and information entropy, modifies. When an observer analyzes a black hole, he detects different amounts of information, according to his relative speed. Indeed, for the Beckenstein and Hawking theorems, the entropy of the black hole, and therefore its encompassed information, is proportional to its surface. This means that the entropy endowed in an object is not an invariant, static, stationary and fixed physical quantity as currently believed, but fully depends on the observer. Consequently, the amount of information encompassed in an object depends on the observer's speed. The faster the observer, the more information he gains about the object at rest being analyzed.

Assessing the information endowed in a thought, through the mental time. The above-mentioned Einstein's framework stands, of course, for "relativistic" inertial frames, e.g., when the objects or the observers move close to the speed of light. Is it possible to use the same scheme in order to elucidate, assess and quantify also mental operations, that take place at nonrelativistic, much lower speeds? In other words, is it possible to describe the changes in information experienced by our mind, compared with the stationary physical information embedded in the objects we observe? Brain operations, of course, cannot reach the light speed, therefore the parameter speed must be kept invariant and fixed. However, there is a parameter in Einstein equations that deeply modifies during our brain activity: *time*. Indeed, our mind is able to subjectively dilate the time as a progressive present moment (see for a review Fingelkurts and Fingelkurts, 2014). Therefore, in order to build a relativistic theory of human mind functions, we have to leave apart the case of an inertial frame in which the observer (or the object) moves at speed of light, because this is not feasible neither in our brain, nor in our biological niches. We do not need to take into account what happens at light speed, rather what happens when time dilates in an inertial mental frame. By the standpoint of special relativity, a massive time dilation resembles the case in which an inertial observer at rest watches an object moving close to the light speed. In our case, based on time lengths, the observer watches an object which physical features (in particular, the length on one of its dimensions) modify. In other words, in the dilated time achievable by our conscious mind, an object's perception modifies.

RESULTS

By using simple calculations, our theoretical approach allows us to formulate empirically testable previsions related to brain function. We provide an example, in order to elucidate how to build the proper experimental setting. Take a cube at rest, 1-meter sided. In this case, L_0 stands for 1 meter. The cube is sensed by us for one second, through direct observation. In this case, t_0 stands for 1 second. The cube's objective information content (expressed in bits) can be calculated, through the Bekenstein-Hakwing formulas. After the object has been removed from the visual sight of the subject, he/she continues to observe it mentally in a thought for, e.g., 3 seconds. Now the cube's length in the mind should be calculated. In other words, we need to calculate the object's deformation that occurs in the subject's mind, when his/her mental time is subjectively dilated. The calculation is the following. The time, form the observer's standpoint (in this case, the subject's standpoint), is t_0, while the cube length is L_0. Therefore, the Einstein equation for time dilation is:

$\Delta t = 1/\sqrt{1-0} = 1$ second

where t_0 stands for one second of direct observation of the cube at rest, and therefore with speed = 0. In this case, the time detected by the observer is unchanged, i.e., is one second.

Now we want to examine what happens to the cube length when the subject mentally sees the cube for three seconds.

Starting from the above-mentioned relationship:
$\frac{\Delta t}{\Delta t0} = \frac{L0}{L}$,

We achieve the following results:
$\frac{3 \text{ seconds}}{1 \text{ second}} = \frac{1\, meter}{x}$,

Where x stands for the unknown value of the L of the cube that the subject imagined for three seconds. Solving by x, we easily find that the required length is 0.3333. Therefore, in the case of 3 seconds of thought, the cube detected by the subject's mind has the following side measures: 1 x 1 x 0.333.

The **Figure** grossly describes what happens when our mental time dilates. In sum, our theory predicts that, when a person thinks for three seconds to a one-meter-sided cube, he/she would mentally detect a decrease of one of its sides until the value of 0.3 meters. The imagined object displays a surface lower than the real observed one, therefore encompasses a lower amount of entropy. This means that the amount of information of the cube's subjective image/though is modified, compared with the objective values detected from the real cube's surface.

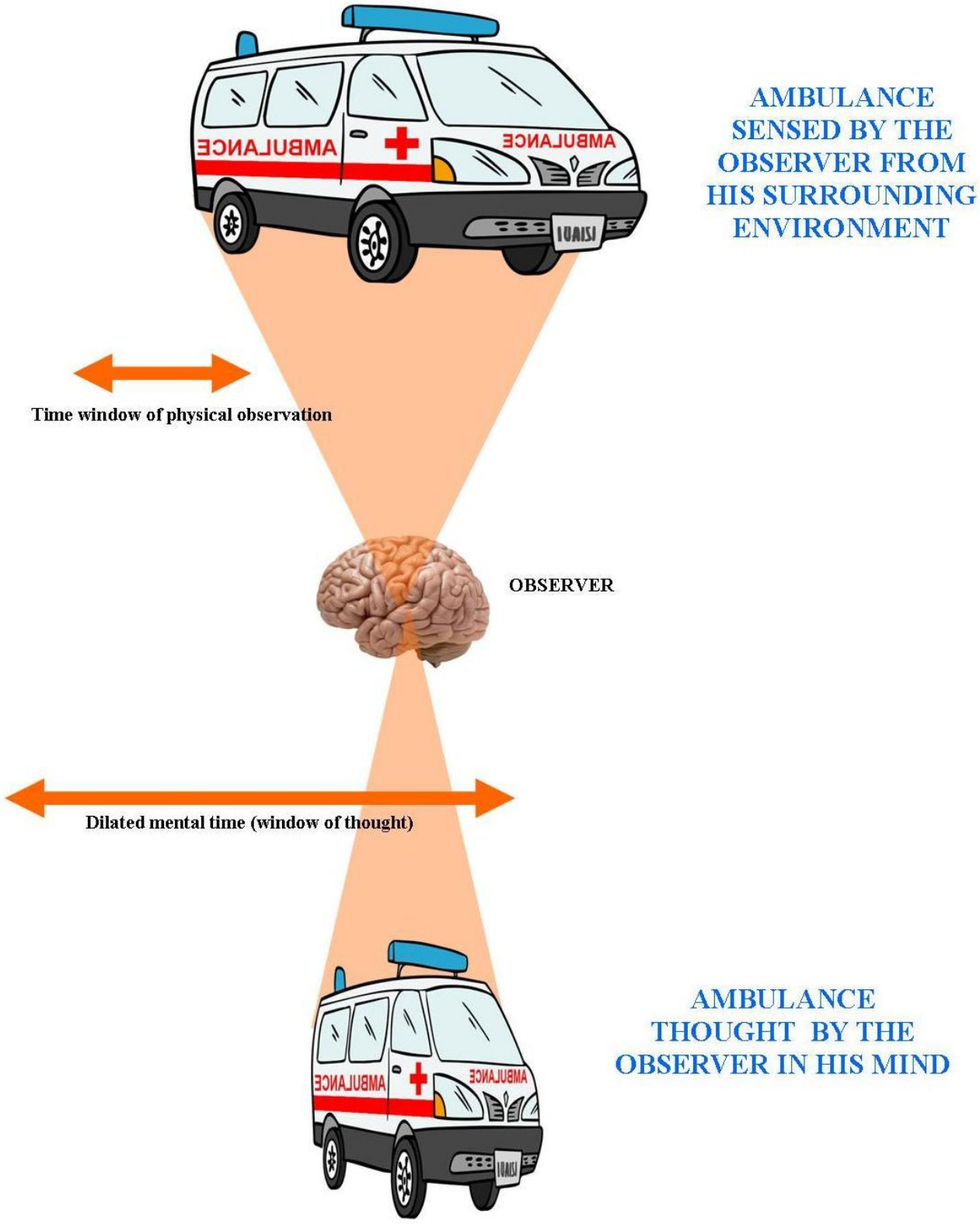

Figure. The brain is able to detect, through his sensory channels, the naive information coming from an object embedded in the environment (**upper Figure**). However, when the brain slows his mental time, the object (in this case, the thought of the object) is squeezed. Therefore, an imagined or reminded object encompasses, according with the Bekenstein and Hakwing theorems, a lower amount of entropy and information (**lower Figure**).

CONCLUSIONS

Our claims suggest that an observer thinking of an object in a dilated mental time will detect a subjective mental deformation in one of object's sides. It might be argued that such phenomenon could not be noticed by the observer. One explanation could be that this is so simply be because people usually are used not to pay attention to this parameter (but see the next paragraphs for the alternative explanation). Further, our calculations predict that the longer one thinks about the object, the more the object squeezes, until it disappears from the consciousness. This might explain why our thoughts seem to fade away with seconds passing.

The way to operationalize our theory is the following: at first, we could calculate the objective amount of entropy (information) of an object embedded in our external environment. Then, we calculate (e.g., through fMRI or EEG) the amount of entropy that occurs in a subject's brain when he/she is thinking about (mentally visualizing) the same object for a given number of seconds. Our framework is able to predict exactly the expected amount of entropy.

The process can be also studied in the special cases in which the mental time is peculiarly dilated. For example, it is well known that certain psychoactive agents create subjective time distortions when administered. Particularly, opioids intake can lead to a prolongation of the subjectively perceived duration of thought. Neurophysiologically, as measured by EEG, this subjective experience is accompanied by an increased duration of operations produced by the neuronal assemblies with simultaneous decrease of synchronization between these operations (Fingelkurts et al., 2006). In touch with our framework, one may expect that the amount of entropy and information will be smaller under opioids administration than in an ordinary state, when the thoughts have normal duration.

Another experimental model that allows easy manipulation of the subjective experience of time is hypnosis. For example, a neutral hypnotic state does not need any suggestion, but allows a subject to experience an altered background state of consciousness radically different from the normal baseline one. In such state, that is characterized by "emptiness" or "absorption", the subjective sensation of time passing is modified, so that internal events are subjectively slowed (Fingelkurts et al., 2007). Neurophysiologically, this type of subjective experience is reflected in the extremely low level of the number and strength of synchronized operations produced by different local neuronal assemblies (as measured by EEG), thus leading to a limited possibility for any larger constellation of such neuronal assemblies to emerge (Fingelkurts et al., 2007). Again, one would predict that the amount of entropy and information should be smaller during such a neutral hypnosis state when compared with ordinary wakefulness state, when the thoughts have normal duration.

Another experimental model is sleep dreams. The nature of dreams in REM (rapid eyes movement) and non-REM sleep is different. During REM the dreams are complex, organized, temporally evolving, multimodal and often bizarre, while during non-REM the dreams are characterized by simple, static or isolated image(s) or though(s), usually of one modality. One would expect that neurophysiologically the non-REM static dreams should be accompanied by short-lived small neuronal assemblies and long-lived large neuronal assemblies, as well by the noticeable increase of synchrony combinations (but with a weak strength) between the operations produced by such neuronal assemblies (as measured by EEG). Empirical evidence fully confirms such hypothesis (see p. 34-35 in Fingelkurts and Fingelkurts, 2015). In this example, one would predict that the amount of entropy and information should be smaller in non-REM dreams, when compared with REM ones, or with wakefulness imagery.

An important objection needs to be taken into account. In the previous section, we have proposed to quantify the value of entropy detected by our mind when thinking about the object, and we concluded that our brain machinery uses for mental thoughts a lower amount of energy and information, compared with the real object's perception. If brain multidimensionality's claims were true (Tozzi and Peters, 2016b), we need to expect, during object's imagination and thinking, an INCREASE in information, rather than DECREASE. There is a possible solution for this controversy. According to the recently tested framework involving the Borsuk-Ulam theorem, every brain surface projects to two matching surfaces on one dimension higher (Peters et al., 2017b; Tozzi and Peters, 2017). This means that, when evaluating the information content of a thought, we need to assess it in terms of higher dimensions. Therefore, coming back to our example of the 1-meter sided cube, the information encompassed in the thought of this cube is not anymore correlated with the squezed object "surface", but with its squeezed "volume". If we, during the experiment suggested above, will detect an increase of mental object's information compared with the real object's one, and if such an increase would equal to the predicted one, we would be able validate the fascinating hypothesis of the multidimensional brain.

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