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The Illusions of Time Passage: Why Time Passage Is Real

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Abstract: The passage of time pertains to the dynamic happening of anticipated future events merging into a present actuality and subsequently becoming the past. Philosophers and scientists alike often endorse the view that the passage of time is an illusion. Here we instead account for the phenomenology of time passage as a real psycho-biological phenomenon. We argue that the experience of time passage has a real and measurable basis as it arises from an internal generative model for anticipating upcoming events. The experience of passage is not merely a representation by a passive recipient of sensory stimulation but is generated by predictive processes of the brain and proactive sensorimotor activity of the whole body. Although some philosophical approaches to time consider some psycho-biological evidence, the biological basis of the passage of time has not been examined in detail from a thorough scientific perspective. This paper proposes to remedy this omission.

Keywords: flow; passage of time; predictive processing; A-series; B-series

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1. Introduction: Debates on the Illusion of Time Passage

The view that the passage of time is an illusion is popular among physicists and philosophers. For the most part, philosophers have followed physicists in their denial of passage, often invoking aspects of the mathematical formalization of space-time in general relativity, and a few of them actually appealing to biology and cognitive science to account for the puzzling illusion of time passage, in addition to the key insights from physics [1,2] (see the philosophical and psychological essays on "The Illusions of Time" in [3]). In particular, the emphasis has been in explaining the passage of time as illusory, rather than on accounting for the phenomenology of passage as a real biological phenomenon. Philosophers have thus gone very much against folk intuitions, with the justification that science demands abandoning the commonsensical notion that time passes. As Zimmerman [4] points out, this is not necessarily the standard approach in metaphysics or epistemology, areas in which commonsense provides a substantial degree of epistemic justification (e.g., the existence of chairs and tables).

In philosophy of time, we are well beyond the age of intuition and subjective introspection. Our intuitive and perceptual access to time is through its continuous passage and the asymmetry between present, past, and future: Events pass in time from the future to the present to the past. As the debate on the nature of time shows, there are multiple ways of explaining this phenomenon of passage. Developments in physics, for instance Einstein's theories of special and general relativity, show that the nature of time is much more intricate and counterintuitive than what is revealed through our awareness of time. The metaphysics of time is entirely independent from contingencies regarding our subjective experiences. Yet, the passage of time guides not only our mental life but a variety of phenomena, including biological processes. Biology is essentially concerned with time not only through the theory of evolution but on smaller time scales through organismal rhythms (periodicity) and critical transition times which are extended over time in the organization of life processes (synchronicity) [5].

The contrast between the tenseless relations of the equations of physics and the tensed flow of our temporal realities has been classified according to distinctions introduced by McTaggart [6]. A lot has been clarified since this classification, and the commitments of the so called A and B theories are now much more nuanced and empirically informed. While the division between A and B approaches remains, the debate on the nature of time now concerns a considerable number of scientific issues. Our contribution is to emphasize the importance of findings in psychology and neuroscience for this debate.

1.1. Challenges to the View That Time Passage Is an Illusion

We ground our discussion on a criticism of the concept of the flow of time by Huw Price [7], because it is particularly useful to specify what is meant by flow and also to identify the main challenges confronting the view that the passage of time is illusory. After presenting various objections to different conceptions of temporal flow, Price writes:

> I conclude that all three of the paths that seemed variously co-mingled in philosophical accounts of the flow of time—a distinguished present, an objective temporal direction, and a flux-like character, distinctive of time—are theoretical dead ends. In most cases, it is difficult to see what coherent sense can be made of these notions, let alone how they could be supported by evidence or argument. [7] (p. 304)

Price defines the flow of time in terms of the three independent paths/views mentioned above. First, that the present moment is objectively distinguished; second, that time has an objective direction from past to future; and third, that there is something dynamic or "flow-like" about time. His main objection to each of the three paths is that they are incoherent—one cannot tell with any precision what these views would mean. Thus, according to him, the idea that time flows is worse than being false, since one cannot falsify what is incoherent.

However, even if one takes this refutation of the passage of time as conclusive (a non-trivial concession to the effect that the arrow of time, which is essential to counterfactual dependence, is metaphysically non-fundamental), there is important work to be done with respect to the notion of flow, according to Price. He mentions two issues in particular, which he considers as crucial for our understanding of time and which together "should be setting the agenda for future research in philosophy of time" [7] (p. 305). These issues are the project of explaining how the flow of time is a secondary quality, and the goal of addressing Eddington's challenge with respect to the asymmetric evolution of events [7,8] [1]. The first challenge, Price describes in terms of explaining the flow of time as a secondary quality "resident solely in the sensitive body," citing Galileo. Price says that he has nothing to contribute to this project, except that he surmises that the notion of flow is deeply linked to that of an (also illusory) enduring self [7] (pp. 305–306). While we do not argue for the reality of passage on the basis of a metaphysical self, we discuss how the self and time are intricately related, as we show below. On our account of the flow of time, if flow is conceived as a secondary property, then it is objectively dependent on neuro-biological processes that manifest the essential arrow of time required for life to be possible.

The second challenge is more intriguing, and Price gives much more importance to it. In essence, Eddington's challenge is that the advocate of a block universe with no objective passage of time (a version of the B theory) should explain why contra- evolutionary theory is as plausible as an evolutionary theory, dependent on an asymmetric arrow for galaxy formation and the possibility of life. This is no small challenge, and Price addresses it by pointing out that the flow or passage of time is a local phenomenon, depending on the specific entropy gradient of our region of space, rather than a cosmic and basic feature of space-time. This qualification, according to Price, has implications for cosmology, the nature of modal properties and relations (including counterfactual dependence) and microphysics. These problems are so fundamental that they might entail completely new models of physics, particularly concerning how to understand the very notion of what is a "state" of a physical system, and how to understand the interactions between elementary particles,

potentially opening the door to future-to-past effects. Verifying these time-symmetric models will be required to fully meet Eddington's challenge [7] (p. 309).

These are intricate issues that will require radical new developments in physics and cosmology, far beyond the scope of this paper. But there is an aspect of Eddington's challenge that we hope to meet here. Even if one concedes that the flow of time is a feature of our local entropy gradient, the evolution entailed by time's passage can be objectively understood as a fundamental aspect of space-time in such regions [9]. The key is to understand this issue as one concerning scale and complexity, as we argue below. Thus, while we remain neutral with respect to the ultimate verdict regarding the truth of either the A or B theory, we aim at offering an account of objective time-passage that could be further explained by either of these theories. In essence, events in the A theory continuously change their position over time, from the future to the present to the past. The present is thereby privileged because it is the time of actuality. In the B series this dynamics is missing because events have a fixed temporal order within the time series, a conception that is not unlike a ruler for measuring space. If the A theory is true, the account of time passage will complete the theory of time emerging from the objective passage of time in physics, with evidence from neuroscience and psychology. If the B theory is victorious, then our account of passage could complete their solution to Eddington's challenge. Thus, the passage of time will be either a fundamental aspect of the structure of space-time (the A theory) or a real secondary property of specific regions of space-time (the B theory).[2]

To further clarify this issue, there are two qualifications regarding our proposal. The first is that the biological basis of time perception can serve as the foundation for the real passage of time at the scale we live in. This is a critical qualification. Similar to space, our experiences of time as passing in one dimension have a real basis at a specific scale, even if at the cosmological or microscopic level more dimensions of space might be needed (or even if, in general, space is an emergent phenomenon—the way passage might be). This is a narrow, metaphysically qualified claim that is still compatible with the ultimate truth of the B-theory, which cannot be confirmed until the findings presented by Price are decisively established. The second point concerns this potential resolution of the debate about the nature of time, which is best characterized as an aspect of our view concerning epistemic humility, given the information we have available. We don't know the final theory of everything in physics, and we believe it is premature to assume the truth of the B-theory in all debates about time simply on the basis of equations and a priori considerations. This kind of neutrality is compatible, however, with explanations of how the passage of time can be, in some sense, real on the basis of biological phenomena. This is despite the lack of a final verified theory of B-time at all temporal scales, which will require the major revisions of physics described above. More needs to be said about how exactly the biological basis of passage relates to detection mechanisms in time perception, but that is a topic for a separate paper.

We propose, then, to understand this issue as one of scale. Secondary properties at our life-conducing entropy gradient are still objective and in that sense passage and time's evolution through asymmetric change is real. That is all we need to motivate our claim that biology is the right place to look for this real passage of time, and that the evidence from neuroscience and psychology is central to both projects described by Price: accounting for flow as a secondary quality and addressing Eddington's challenge. What we propose is to identify flow with the mesoscale conducive to life, independently from issues concerning metaphysical selves or introspections about the self.

In our daily activities things change, and we experience such changes through our awareness of the passage of time at our mesoscale, i.e., events in the present moment continuously slip into the past, which is fixed, while the future, which is open, we seek to control [9]. This happens on the basis of the complexity of evolutionary asymmetries at our biological scale, but also at the cosmic scale of observable events, as emphasized by Eddington. This basic notion of passage that Eddington so clearly captured in his challenge is the one we rely on. Such a scale provides a bridging principle between the

large timescales of cosmology on the one hand, and life and the human mind on the other. Even on a B-theoretic account, the secondary properties characteristic of the passage of time are of enormous metaphysical significance. For instance, the arrow of time underlies the basic notions of modality, such as possibility and counterfactual-dependence, as Price notes. The arrow of time has a solid foundation in biological and psychological processes that are associated with our awareness, rather than merely on our concepts or introspections concerning time. While biology has been explored by some philosophers of time, the evidence has not been examined in detail, especially with respect to the passage of time as based on neurobiological processes.

Despite the importance of the experience of the passage of time in our daily lives, various lines of resistance to the notion of passage have been offered recently, including objections to the psychological phenomenon that time seems to pass, or the idea that there is a phenomenology of the passage of time. Callender [1] (pp. 228–231) for instance, argues at length against the notions of flow and the experience of passage. Deng [10] objects to the view that there is an illusion of passage, not on the traditional grounds that such a psychological phenomenon has no basis in reality, but rather on the basis that there is no such psychological phenomenon: there is no phenomenology of passage. Miller [11] rejects the phenomenology of passage by appealing to linguistic biases. A more congenial view of the veridicality of the experience of passage by Balcells [12] argues that the phenomenology of passage is explainable within the structure of a block universe, through an analogy with motion, thereby questioning the strong reading of the phenomenology of passage as reflecting a real asymmetry in time.

Moreover, in a recent paper Miller [13] introduces distinctions that further complexify the way that findings may support the A-theory and its notion of passage. She distinguishes between a robust and a non-robust sense of passage, and shows how robust views of passage are committed to implausible claims about our sensorial capacities and what they can actually represent. Crucially, there are ways of understanding veridical views about the contents of our perception of time that are not illusionist and yet do not appeal to the passage of time—they are "passage-less" views. These distinctions depend on an in depth analysis and comparison of the contents of perception, including the perception of color, which go beyond the scope of this paper and deserve independent treatment. In particular, our intuitions concerning the contents of our perceptual capacities may differ significantly from the way we conceive of time's passage once the focus is on biological mechanisms. Working out the details of distinctions such as Miller's in this context is a project worth pursuing in future research.

We cannot provide detailed responses to all these interesting and nuanced views. Our focus is their core assumption that physics entails that succession is the only relation that matters to provide a metaphysical explanation of time perception. More precisely, these criticisms against the phenomenology of passage construe it in terms of beliefs, static stimuli, and succession. Since we are favoring both the psychological and real aspects of passage, we must clarify what other psychological processes are relevant besides beliefs and order relations of stimuli, determined by clocks and simultaneity windows. Here we offer two insights. First, we expand the notion of "stimuli" to physiological regulation and body awareness, which occurs constantly and independently of events, their temporal ordering, or their sensorial rate of succession [14]. Second, the asymmetry of time can be grounded on this biologically regulated input, rather than on a given sequence of events. This is very relevant to the objections against passage. Consider again Eddington's challenge. The challenge is not whether events can be put into a succession that grounds some phenomenological process. The challenge is to explain why a specific sequence of events moves from prior states that explanatorily relate to posterior states in a way that information from the past differs from the future. A biological basis for this dynamic seems more plausible than one based on sensorial yet static stimuli.

Regardless of how the phenomenology of passage is described, a biological basis for the reality of passage can be offered as a crucial macroscopic ground for the experience

of passage and flow [9]. This need not include "moving" from one event to another in an otherwise static and B-theoretical sequence. Rather, it involves a vital component that serves as the basis for the difference between past and future at the macro level, based on a unique kind of information processing. The present account also provides a biological basis for a temporal indexical, as the now relates to the biological sum of macroscopically salient signals integrated at a time continuously passing from present to the past and projecting into the future. Thus, the proposed account provides the foundation for the experiences of time "speeding up" or "slowing down," which is characteristic of the phenomenology of enjoyment and boredom.

However, we are not, as mentioned, challenging the ultimate veracity of the B-theory in the realm of physics. What we are arguing for is that relevant scientific evidence from the biological sciences must also be considered in the debate about passage. In our opinion, too much abstraction concerning the ultimate nature of the equations of physics has dominated this debate. Similar to the literature on space and macroscopic objects, our accounts need more than the bare structure of physics and its fundamental equations. Given the uniqueness of time as a dimension with critical psychological repercussions for perception and rationality, the natural place to look is biology and neuroscience. Like space, time occurs at different scales, and the reality of passage occurs at the particular scale at which macroscopic objects become aspects of our biological reality. Scale matters to this debate. Crucially, we are not basing our argument on a priori considerations. Unlike defenses of the phenomenology of passage based on intuitions about temporal parts, we base our argument on scientific findings.

1.2. Roots of Time Passage in Biology

Having clarified this, if one takes a more comprehensive approach to the relevant scientific findings and includes evidence on the complex biological basis required for the phenomenology of passage, it seems very difficult to simply dismiss the passage of time as an illusion. Clearly, if one subscribes to the general recommendation that science must inform philosophical views, biological findings should not be ignored. Philosophical models of time consciousness encompass the phenomenal and conceptual-descriptive level; psychological and neurophysiological models inform us about the underlying processing mechanisms [15]. To the extent that the complexity of biological systems is not illusory, the passage of time is not illusory—at the very least not in the traditional sense of the word, namely, experiencing and perceiving the passage of time is not an erroneous or unreliable form of perception.

This claim requires clarity on what is meant by "illusion," "perception," and "passage." This paper presents two challenges to the illusion-based theoretical approach of the passage of time. First, although authors use the word "illusion," the passage of time is unlike any known illusion (or hallucination) in cognitive science or psychology. The word "delusion" is not better. Thus, the proponent of illusionism owes an explanation of the kind of illusion at stake. We argue that given the homeostatic and biologically based phenomenology of passage, no notion of illusion is plausible. We complement this criticism of illusionism with a clarification of the term "perception" arguing that illusionism also depends on a sui generis and outdated notion of perception.

Second, if passage is simply demoted as metaphysically irrelevant, there is a problem concerning the very real causal interconnections between the phenomenology of passage and biological processing. This challenge from causation suggests that there is no account of the illusion of passage—even an ad hoc or sui generis one—that is satisfactory from the perspective of neuroscience or biology. Since the passage of time depends on a network of causal influences, one cannot demote the phenomenology of passage as wholly unrelated to reality. We explain how this account is compatible with what physics says about space-time by appealing to different contexts of explanation, in particular, the context of living organisms and their extremely specific biochemical constitution.

One kind of illusionism is a denial of the phenomenology of passage—time does not even really seem to pass (similar to the view that Miller et al. [16] call "cognitive error theories"). Although this view receives support from recent articles, e.g., [10,11], including one from experimental philosophy [17], and the empirical fact that the intuition of time passage is not shared by every person when asked [18], we believe that claims about passage should not limit themselves to our intuitions or judgments about the phenomenon of passage, although it necessarily is the starting point of inquiry.

A less radical kind of illusionism is epistemic (a view that can be called "phenomenal illusionism"). Some versions of this account suggest a type of simultaneity-based mechanism, or an informational cumulative side-effect to explain why although time is static it seems to us that it passes. They are "epistemic" because our belief that time passes is ultimately false, despite being provisionally justified by the illusory phenomenology of passage. The exact characterizations of both the phenomenology of passage and the nature of our folk intuitions with respect to the passage of time in extant B-theories are beyond the scope of this paper.

A particularly nuanced version of illusionism, on which we focus below, is Hohwy et al.'s [19] proposal for a probabilistic "best perceptual hypothesis" account of the passage of time. The basic idea is that even in the absence of stimuli the "hypothesis generator" is attuned to expectation and can still generate the illusion of passage. An immediate problem for this view is that the phenomenology of passage does not seem to be a phenomenology of uncertainty or likelihood. Truly, it is a phenomenology of the passage of time as in the dynamic change of an anticipated event becoming a present experience, and then a memory. A deeper problem, however, is that the epistemic generation of hypotheses need not have any connection to biological and homeostatic processing, which we believe is fundamental to explain the phenomenology of passage based on the arrow of time, characteristic of biological processes. A counterexample is found in contemporary machine learning algorithms. These algorithms constantly create new hypotheses but lack the kind of homeostasis dependent balance of signals involved in the phenomenology of passage. We explain these issues in more detail below.

The key point of these introductory remarks is that since the phenomenology of passage is based on our biology as a whole, the traditional distinctions between perception, illusion, and hallucination cannot apply. The phenomenology of passage does not depend on any specific sensorial stimulus and therefore, cannot be an illusion or hallucination in the traditional sense. But precisely because there is no specific stimulus, how is it that we can "accurately" perceive the passage of time? Our proposal is that it depends on the complexity of biological systems. The phenomenology of passage is not a feature of either the micro-world of quantum mechanics or of the cosmological world of general relativity. Rather, it is a feature of the meso-world, based on the dynamics of homeostatic biological systems which enable the maintenance of constant conditions in the organism despite being embedded within an interacting environment. Similar to Buonomano & Rovelli's conception [9], which explains the conscious experience of time on the basis of entropy alone, our approach grounds the experience of passage on a clearer meso-scale, namely that of complex biological systems.

Regarding the constant flow of elementary matter in physiology, it has been argued that living beings are more fundamentally processes than substantial things [20]. Physiological processes are describable as the constant flow and integration of component matter through and in an organism. As Longo [21] explicates: as a principle of agency in all living beings, even cellular activity necessitates forms of retention and protension, i.e., memory of previous paths in the anticipatory search for food. Agency of living beings entails the reactivation of traces from the past in the present context of novel proactive (future oriented) behavior.

The best way to make sense of the metaphysical character of the passage of time (or the fact that it is condition for the possibility of appearances without itself being the result of specific sensorial stimuli) is that it is rooted in the complexity of biological systems.

Passage is a real and constant feature of biological systems. It is independent from the probabilistic structure of quantum mechanics and the modality-specific sensorial stimuli that produce psychological illusions. Thus, while we grant that passage cannot be a global or universal phenomenon, it is an objective feature of local biological systems.

2. Psychological Views on Illusions

Explaining the passage of time as an illusion is the traditional way in which B-theorists account for the phenomenology of passage. For instance, J. J. C. Smart writes: "If the passage of time is an illusion it is a strange and intellectually worrying one. It would be good if we could not only give reasons for thinking that it is an illusion [...] but also if we could give some sort of explanation of how this illusion arises." [22] (p. 10) B-theorists need to characterize the phenomenology of passage as an illusion because it is an essential corollary to the metaphysical thesis that time does not pass. The experience of the passage of time, at least on a basic intuitive level, makes possible the experiences of motion (dynamically understood), change, boredom, and flow states (among many others which depend on the arrow of time).

According to the B theory, the illusion of passage, like any other illusion, can never fully justify our beliefs about the passage of time because these beliefs are systematically false—there is no reliable perceptual-phenomenal access to the nature of time. In the words of Albert Einstein: "For us believing physicists the distinction between past, present, and future only has the meaning of an illusion, though a persistent one." [23] (pp. 37–38). Contemporary metaphysicians who follow him on this issue have not really provided a satisfactory account of the illusion, at least not one that fully considers the neurobiological evidence in detail. While the epistemic claim concerning the illusion of passage is fairly clear, the perceptual thesis concerning the phenomenology of this illusion is significantly more problematic and controversial. Moreover, if we follow Einstein's insistence on the existence of a time for psychologists and a time for physicists [24] (p. 5), we should investigate subjective time from the perspective of the cognitive sciences [25,26]. Therefore, while our proposal cannot decide between the A and B theories, we believe that more precision is needed when claiming that passage is psychologically illusory.

In particular, illusions involve misperception or misrepresentation: necessarily, illusions involve the presence of stimuli that are systematically misperceived by subjects. Illusions, like hallucinations, require accuracy conditions in order to explain what is illusory or erroneous about a specific perceptual experience. How can something so robust and systematic as the passage and direction of time be explainable in terms of accuracy conditions that make it erroneous about specific aspects of the environment? What are these accuracy conditions? Considerations regarding equations, particle physics, or cosmological features of spacetime cannot help solve this issue. One could think, following a slogan of modern physics, that no aspect of our experience is crucial to understand the nature of the universe. But this statement hardly helps explain psychological illusions. Even color, which can be completely dispensed with in physics and potentially metaphysics, has accuracy conditions—we see certain colors under certain conditions, and in the wrong conditions we are under color illusions or hallucinations. The problem is that the conditions for the illusion of passage cannot be specified in this way—consider Eddington's challenge mentioned in the introduction.

This is an odd situation regarding our scientific understanding of time because the explanations of passage, whatever they are, cannot be understood in terms of any standard account of illusion (or even accurate perception of a stimulus). Like space, time can be scaled, and thus issues of scale and context must inform this debate. Unlike space, however, it is not clear what is the right scale and accuracy conditions for successful or erroneous experiences of passage—in the case of space it is clear that, regardless of what physics has to say, perceptual space is three-dimensional. Why cannot one say, analogously, that regardless of what physics says, there is a temporal scale at which the perception of time's passage is accurate? Our diagnosis of this oddity is based on this asymmetry. Similar to the

three dimensions of space, the passage of time is real if the right meso-scale and context is taken into account.

But here again we confront the problem of the lack of any specific stimulus or set of accuracy conditions for the passage of time. Space can be scaled to the cosmological Plank scale, but it is much easier to establish that the relevant perceptual space is three-dimensional and close to Euclidean. Many spatial illusions, such as the famous Müller-Lyer illusion or ambiguous images about impossible objects, such as the Necker Cube, can be explained in terms of properties of perceptual three-dimensional space. These spatial illusions are generated because the adaptive processing strategies, which under normal conditions enable us to represent the world adequately, under artificially designed circumstances lead us astray. Spatial illusions exhibit the "inference problem" as formulated by von Helmholtz [27], see below: Our perceptual system has to construct the most probable interpretations out of a priori incomplete, noisy, and to varying degrees ambiguous sensory information [28]. In visual perception we are actually missing one spatial dimension because the 3D world is projected onto the 2D retina. The perceptual system therefore has to apply learned rules and concepts in order to reconstruct the third dimension. In some artificial situations this strategy reaches its limits, e.g., when our perceptual system becomes unstable during observation of the ambiguous Necker cube [29]. In this interpretation the resulting visual illusions and phenomena do not show deficits of the perceptual system, they rather demonstrate the well-developed strategies that allow us to see a stable and reliable world in normal, non-artificial situations [30]. Our proposal is to treat the experience of passage similarly, as a kind of biologically evolved understanding that time passes, just the way in which we learn that space has depth early in our infancy.

Does a similar effect interpreted as spatial illusion exist for time, i.e., for duration and time passage? What about the impression that an hour spent in one situation might feel much longer (time passing more slowly) than an hour spent in a different situation? Illusions by definition are obvious misrepresentations of reality, such as in the aforementioned spatial illusions: There is a difference between appearance and reality. As Power [31] argues, there is nothing wrong with feeling that an hour is subjectively long (time passes slowly) when I wait for something to happen and that in contrast it is subjectively short (time passes quickly) when I am entertained. On short time scales of the millisecond and second range subjective duration is malleable as well. Similar to the Müller-Lyer illusion, where spatial length is affected by differently oriented lines, perceived duration is affected by other events in temporal proximity and this effect depends on how each event is attended [32] [3]. Accordingly, one could argue that the feelings of malleable duration and time passage are not misrepresentations but depend upon adaptive attention and memory processes.

Nevertheless, one could go a step further and argue that the felt duration of an event which lasted one hour in clock time (or 1 s)—an objective and socially accepted measure—was 30 min (half a second). In this case, would one speak of an illusion of time? Similar, when I hike for exactly one kilometer and I say that I had the impression that the walking distance appeared to be 500 m, would that be an illusion in reference to objective space? In a strict sense someone could probably argue that the temporal experience of 30 min duration (when it was an hour) and the 500 m of distance covered (when it was 1 km) are illusions since there was a difference between subjective appearance and objective reality. One could still argue against this interpretation of an illusion if one assumes that adaptive attention and memory processes led to a considerable underestimation of time and space.

While a comparison is possible between subjective duration (as indicated in units of clock time) and physical clock time, and thus a misrepresentation is objectively measurable, no such comparison is possible between a subjective and objective passage of time. We might feel that an hour passed considerably faster (when I was chatting with my friend) than the hour before (when I was waiting for the friend). What should we refer to regarding a comparison with objective passage? The impression of time passing is an experience not to be categorized as an illusion. The feeling of passage cannot be reduced to a specific

sensory event or object. It is subjectively real as it relates to a complex set of happenings, but to appreciate how this is the case requires locating the phenomenon at the right scale.

How to resolve the issue of time passage? The present proposal is to address this problem with an updated and scientifically informed account of time perception that is firmly rooted in our biology. We shall argue that what determines the proper scale of the passage of time is determined by biological processes that influence conscious time perception in particular. The experience of the passage of time is a phenomenally conscious experience, and that is our focus here. Ultimately, we argue that just like three-dimensional space is neither psychologically nor metaphysically illusory, the passage of time is both psychologically rooted in our biology and metaphysically relevant because of its causal structure.

3. Theoretical Concepts and Experimental Evidence on Time Passage

Following earlier conceptualizations of unconscious inferences by Helmholtz (*unbewusste Schlüsse* [27], p. 430) and the reafference principle [33], a recent popular theory in neuroscience describes perception as a predictive, goal-oriented process directed toward the very near future [34]. Perception is not a passive sensory process. Rather, it relies on an active "predictive coding" mechanism. Based on prior experience the brain constantly makes predictions about what might happen. The goal is to minimize surprise, defined as the difference between prediction (what might happen) and actual sensory input (what then actually happens). This difference amounts to a "prediction error". Surprise means that the organism has to adapt its behavior which in turn increases energy consumption. The organism aims to minimize the prediction error in order to reduce energy consumption. Accordingly, perception is conceptualized as the amount of prediction error. Phenomenal waking consciousness relies on constant short-term predictions of a world that is not directly accessible to us but is internally created and represented as a construction of the brain. We do not necessarily adhere to this radical form of internalism, in which conscious experiences are fundamentally brain-generated simulations (for a critique of this radical neuro-representationalism, if not solipsism, see [35]). Representationalism easily ends in skepticism concerning the real world: "How can we ever know that what is internally accessible actually corresponds to something external" [35] (p. 57). The obvious question then is: How do we know about the real mechanisms of the brain if "the brain" is just a neural construction or simulation. Anticipatory processes and inference problems of experience are also discussed in enactive/embodied approaches of the mind [36,37]. Conscious perception is not so much generated by representational processes in the head but by sensorimotor activity of the whole body which proactively navigates the world and is dynamically coupled with the environment [38–40].

Independent of these philosophical views, empirical research in cognitive neuroscience has shown how temporal structures that occur in the environment necessitate adequate predictions by the organism, i.e., proactive attention and movement preparation for upcoming events [41]. When we want to catch or hit a ball the arrival time has to be anticipated beforehand in order to move the arms and legs right on time [42]. Our experience has an anticipatory character; it is proactive towards future events. Social communication is about predicting the behaviors of other people as dynamical non-verbal and verbal inter-bodily exchanges which are measurable as synchrony patterns between two individuals [43–45]. Processes take time and this temporal unfolding of a movement from a beginning to an end involves a trajectory which relies on the body's configuration within the environment; perception as understood within such a sensorimotor framework implies that the experienced present is temporally extended [36,40,46]. Anticipatory timing of movement for upcoming events functions most accurately, precisely, and effortlessly within a window of a few seconds [47,48]. Since all biological process take time and we assume that embodied brain processes underlie the acts and contents of conscious awareness [4], an experienced interval of time must have an extension within which perception and action unfold [49]. We can only detect movement and change—as we argue, also flow and passage—when

perception covers a sufficiently extended time span in which changes happen. Accordingly, the two aspects of (1) awareness of change and time passage and (2) the present moment, the window of the Now, are not separable [50].

This conceptualization of time passage and presence of course goes back to Edmund Husserl [51]. According to him the temporal property of experience is an integrated whole of what has just happened (retention), a primal impression (German: Urimpression), and anticipation of what is about to happen (protention). The experienced present carries an event's history and possible future as implicit temporal structure of consciousness [52]. The awareness of ongoing experience with this tripartite structure enables self-reflective consciousness [53,54]: We become aware of ourselves through memory of what happened to me and anticipations of what might happen to me. Through this temporal structure of consciousness the realization of a self emerges. Time and self are manifestations of the same underlying process. Important for our investigation, subjective experience is intrinsically dynamic. I feel an itch on my arm and I anticipate that I will scratch the spot on my skin. Then I feel the relief while scratching. Eventually the scratching is a past event and I see a red spot on my skin as a result of my scratch. The temporal dynamics of passage concerning the itching feeling and the scratching may have lasted two seconds.

Phenomenological analysis would not describe this situation as an itch at t_1, then the scratching at t_2, and finally the post-scratch feeling at t_3. A phenomenological analysis is not about the temporal ordering of independent events. Say, the above scratching experience and behavior would have lasted 2 s and we subdivide this interval in steps of 1 ms (t_1, t_2, t_3, . . . , t_{2000}). Would the itch after my scratching between t_{523} and t_{1529} go away at t_{1363}? The dynamics of the experience is not captured at all by mapping the experience of unfolding events to a B-theoretical time line. A high-resolution camera with a frame rate of 1000 Hz could of course capture the movements of the finger on the skin. But how to integrate this motion within my experience? Regarding subjective temporal resolution, it is perceptually impossible to tell apart the temporal order of four unrelated stimuli when they appear with inter-onset intervals below 300 ms [55]. From a methodological point of view, the measurement of reports concerning the times of intentions and movements in the range of seconds are based on inferences and are therefore considered unreliable, if not invalid [56]. Experience is essentially an interwoven perceptual whole with a future (protention), immediate impression, and past (retention) component. In referring to the A-theoretical conceptualization, experience has extensional boundaries pertaining to a moving present with a future (me about to scratch the spot on the skin) dynamically merging into immediacy (the dynamic and temporally extended scratch itself) and a very recent past (still feeling the previous scratch). In our understanding this dynamically extended experience means that there is passage of time rooted in our biology and its relation to our immediate environment.

An answer as to why many philosophers have neglected the possibility of time passage in experience might lie in an overemphasis on passive perceptual processes (the observer as recipient of stimulus input) and not considering the proactive sensorimotor basis of human consciousness and its causal complexity. In accordance with taxonomies from psychology and the neuroscience referring to temporal experiences of simultaneity, succession, temporal order, and duration [57], philosophers have claimed that temporal phenomenology involves only these impressions of time and not time passage or flow (for a discussion: [10,11]): We would actually not perceive the passing of time, the passage of time would be an illusion. The temporal experiences of simultaneity, succession, temporal order, and duration are indeed sensorial. There are physical properties of auditory or visual stimuli which can be described as duration (a 1-ms click; a 300-ms sinus tone) and in their temporal relations (the two sounds have an inter-stimulus interval of 200 ms). Psychophysical experiments can objectively measure thresholds of detectability concerning the perception of temporal order and duration. For example, an interval between two short events of around 40 ms are needed for young healthy subjects before they are able to tell which of the two stimuli came

first (the temporal-order threshold; [58]). The temporal sensory thresholds are determined in relation to objective parameter variations (the psychophysical approach initiated by Gustav Theodor Fechner). When reporting the impression of 'passage of time' we do not point to any specific stimulus.

Here we want to emphasize the proactive dimension of perception which, as we argue, is essential for an understanding of the temporal dynamics in experience, for the passage of time. In the context of a predictive conceptualization of perception, Hohwy and colleagues [19] argue that the sense of passage and flow arises from an internal generative model for anticipating upcoming events. Based on an assumed Bayesian inference model, the organism would constantly produce novel hypotheses about a possible future. This would explain "why we feel we are continually being pushed forwards on a rolling crest rather than being left in the wake of time" [19] (p. 30). This is in our opinion the feeling of time passage and flow within a moving window of an extended present moment. This would explain why, even when there is no change in the environment, perception nevertheless can change in bistable or ambiguous figures [59]. One perspective of the Necker cube or the Rubin's vase is seen for a few seconds before it switches to the alternative perspective. As one prior hypothesis (seeing the Necker cube from above) wanes, the alternative hypothesis is strengthened (seeing the Necker cube from below) until a switch in perception happens [19]. The phenomenology of flow is generated following these continuous proactive updates concerning the environment.

A similar future oriented processing mechanism has been identified for visual sequence detection. The order of two visual stimuli can be consciously identified only beyond a certain threshold of around 40 ms between them. Below such an individual threshold the observer has no conscious experience of temporal order. Empirical evidence however shows that below the threshold and on an unconscious level temporal sequence is nevertheless processed, as implicitly detected on a behavioral level [60]. It has been proposed that this fine-scaled, serialized process structure would enable the unconscious coding of sequence and thus create the feeling of the continuous passage of time [61,62].

It is a matter of conceptual and empirical debate whether the experience of an extended present can be juxtaposed with a specific neurophysiological mechanism (e.g., spanning a few seconds) or whether many independent temporal mechanisms can be identified [63,64]. The predictive processing approach assumes hierarchical and multilayered timescales which can account for predictions and error minimizations with several temporal frequencies [40]. Similarly, the enactive-embodied approach [39,65] assumes at least three different temporal integration levels for explaining phenomenological and neurophysiological phenomena spanning the time range from milliseconds to several seconds [26,57,66,67]. Two levels of an extended present have been delineated which are important for our discussion. One in the range of a few seconds is related to temporal integration in perception and action, the experienced moment. The other is in the range of multiple seconds, mental presence, which enables the continuity of current experience through working-memory processes within which long-term memories can be activated.

These two levels complement an idea put forward by Riggs [68] that one should distinguish the 'passage of time' in two different ways.[5] For one, primary perception refers to the immediate impression of passage, an internal feeling that time passes. This is not unlike Hohwy's [19] characterization that we feel as though we are continually being pushed forward. This concept of passage fits also the idea of flow as experienced within an extended experienced moment as realized through neurophysiological integration mechanisms with a temporal width of a few seconds [57,65,69]. Secondary perception of 'passage of time' according to Riggs [68] spans a larger time scale involving memory function when one is aware that one has 'lived through' an interval of time, be it the last few minutes waiting for the bus or the years spent at the current job. This latter 'passage of time' fits the concept of mental presence where we perceive a continuity of what is currently happening and what has happened to us according to long-term memory, as actualized in working memory. The feeling of time passage concerning my life is enabled through the

activation of long-term memory traces within working memory, when we might complain about "how fast the last 10 years have passed" [70]. Callender [1] equally concludes that although there is no single sensory experience of time passage, the impression depends on a sensed enduring self which perceives itself as the 'leading edge' of a constantly unfolding story relying on a perpetual update dependent on episodic memory. A similar distinction between two modes of flow is made in the dual-processing approach by Gruber and colleagues [71,72] where a lower level is defined by the perception of events happening over time, the flow of events on a short time scale, and a higher level is constituted by a cognitive-narrative view of past, present, and future [6].

Empirical work using brain imaging technology has identified distinct neural integration levels, which relate to how long a just passed event proactively influences moment-to-moment neural activity related to continuous video and sound clips [73,74]. These temporal integration levels form a hierarchy of progressively longer temporal processing windows within working-memory. Lockwood [75] has argued that these temporal integration mechanisms might represent functional properties of the brain but they do not necessarily associate with the experienced present. Two recent conceptualizations link specific neural activation patterns to William James' [76] and Edmund Husserl's [51] notions of "stream of consciousness" and "inner time consciousness", respectively, which encompass the passage of time as experienced within an extended present. Georg Northoff [77,78] identifies slow cortical potentials as a mechanism which generates the sense of time passage within an extended present moment through the temporal integration of discrete, neurophysiologically coded time points. Such temporal integration of neural processes enables the awareness of passage of time which in turn can be used to initiate self-generated or event-related movements [79,80]. Using fMRI technology, Dan Lloyd [52,81] identifies the default mode network (DMN), related to midline structures of the brain, with its temporally fluctuating activity for encoding the flow of events over time, leading to felt temporality and the passage of time. The intrinsic dynamics of the world, the passage of events over time, are mirrored by the perception of fluctuations regarding the bodily self and the surrounding sensory space. The dynamical world affords complex organizing principles from the body and brain. The two conceptualizations by Northoff and Lloyd try to capture the neuro-dynamic representation in their respective neuro-phenomenological approaches.

4. Discussion

The empirical evidence reviewed above shows that the phenomenology of passage is grounded on biological processing. Like the phenomenology of embodied space, the phenomenology of the passage of time plays a crucial explanatory role in psychology, neuroscience, and biology. From a psychological perspective, the phenomenology of passage explains the basic features of the active and predictive view of perception that receives much empirical support. We complement this informational approach with more specifically biological and phenomenological considerations concerning embodiment, interoception, and homeostatic processes [14,82]. This addendum is critical because otherwise a strictly informational approach would lack the embodied and vital aspects of the experience of the passage of time. None of these interoceptive and homeostatic processes are illusory, either in the psychological (i.e., incorrect modality-based perception) or metaphysical (i.e., lacking reality) sense—with the caveats mentioned in the introduction.

From a neuroscientific perspective, the phenomenology of passage is far from illusory as well. In fact, the phenomenology of passage is essential for the explanation of the dynamic and integrative neural processes that generate the subjective experience of conscious awareness. When the impression of continuous passage of time in perception breaks down, as can happen in individual neurological cases, functionality is affected as well. For example, a patient with damage to posterior parts of her brain after an ischemic infarct could not detect continuous visual movement and change [83]. She could not properly pour coffee into a cup because she saw the fluid to be frozen. As a consequence she could not find the right moment to stop pouring the coffee because she was not able to perceive

the liquid in the cup rise. When talking about problems with traffic crossing a street she said: "When I'm looking at the car first, it seems far away. But then, when I want to cross the road, suddenly the car is very near." [83] (p. 315). This description suggests that the patient saw a series of stills which would mean that on a short time range the feeling of a smooth passage of time was disrupted.

Possibly, the impression of an uninterrupted flow of events is so important that neurophysiological mechanisms may have evolved to ensure the subjective impression of continuous passage. On average three saccades (ballistic eye movements) occur each second. During the saccade sensitivity of vision is strongly distorted, but this goes unnoticed by the observer. A mechanism to temporally extend the target's visual percept might fill in this perceptual "gap" during saccadic movement, thus enabling the experience of undistorted visual continuity [84]. People are also unaware that the eye blinks have a considerable duration of 200 to 250 ms and thus interrupt the stream of visual input considerably [85]. An active top-down mechanism might be instantiated so that the repeated eye blinks go unnoticed [86]. Why would the neural system actually have an active mechanism for letting the eye blinks go unnoticed? The duration of 200 to 250 ms is in fact quite long and functionally the top-down mechanism does not compensate for the loss of visual input. Arguably, this mechanism for letting eye blinks go unnoticed could be an indication that phenomenal consciousness is important for the observer [87].

Evidence from neuroscience, including functional neuroanatomy, confirms the key insight from phenomenology that the conscious experience of the passage of time is essentially related to the phenomenology of embodied space. For instance, synchronous neural activations in the visual cortex are correlated to the geometric and topographical structure of visual space [88]. The phenomenology of proprioceptive space, like the phenomenology of the passage of time, has a neural basis that integrates across modalities in the case of space (e.g., proprioception, vision, audition, etc.) and across modalities and biologically salient information related to emotions and feelings (e.g., interoception, the senses and the extended structure of retention and protention).

Finally, from a general scientific point of view, a theory of consciousness needs to address how the phenomenology of time relates to the manner in which phenomenal consciousness integrates information. On an introspective and subjective level, the experience of the passage of time structures the way we experience in general. At the physical level, scientific theories of consciousness have taken this kind of temporal information integration and proposed that it has a robust physical and causal structure. For example, according to the Integrated Information Theory (IIT) there are specific conceptual aspects, physical and functional properties, and causal networks that explain the unity and integrity of conscious awareness. In other words, IIT takes the phenomenology metaphysically seriously. This is behind IIT's slogan, "from phenomenology to physics" [89].

The previous point is not an endorsement of IIT, and we are neutral about which theory of consciousness is the best at this point. Our focus is on the causal basis for the spatiotemporal structure of a conscious subjective perspective. Informational bindings of experiences and sensorial contents in any typical conscious episode depend on the structure of the phenomenology of passage, described originally by Husserl. These information processes must have a metaphysical basis, even if this basis cannot be fully captured by fundamental particle physics or cosmology. It would actually be odd if the fundamental properties of subjective awareness could be explained by the most general of truths, namely those of physics—truths that describe physical systems in the most abstract and generic way.

For analogous reasons, some authors have actually argued that an explicit temporal integration of information as temporal passage or a process of resonance and binding of information provides a solution to the "exclusion principle" [90]. This is the problem of how to determine the boundaries of a conscious individual, which entails the exclusion of other conscious minds—it provides the metaphysical grounding for the exclusive first-person perspective. This is, presumably, a constraint on any view of consciousness and therefore, a constraint that requires a serious metaphysical endorsement of the passage of time, not

as illusion, but as an essential parameter of the first-person perspective—a real and not illusory parameter.

The present approach does not entail the A-theory, or any view of physical time that endorses a cosmological distinction between past, present, and future. A better, and more conciliatory, position between the extremes of non-passage and objective cosmic passage is possible and more desirable. Not only that, such an account has the support of extensive scientific findings in biology, neuroscience, and psychology.

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Notes

1 With Eddington's challenge we refer to Huw Price's discussion of flow. The reference Price gives is Eddington.

2 There are various versions of the B theory that characterize differently the notion of passage (see below), and there is a wide variety of views concerning the centrality of the present, one of the main claims of the A theory (e.g., the growing block theory, presentism, the spotlight view).

3 An intriguing time illusion which is similar to the spatial Müller-Lyer illusion has been posted by Twitter user Jagarikin (@jagarikin): https://twitter.com/jagarikin/status/1247325537371971584?s=20 (accessed on 15 October 2022). In this time illusion, two rectangles move at the same speed. Nevertheless, and at the same time the upper rectangle seems to move faster. We are thankful to Federico Alvarez Igarzábal for pointing out this time illusion. It is similar to the Müller-Lyer illusion since two stimuli are perceived next to each other.

4 Here, we are not discussing the distinction between acts and contents of consciousness which in the phenomenological literature are differently conceptualized within the cinematic, the retentional, and the extensional model of time consciousness. We are favouring the extensional model as we think that it captures the empirical evidence gathered in the cognitive neurosciences.

5 We think that the distinction made by Riggs is helpful for understanding the subjective passages of time. However, we do not follow his argument that these perceptions are illusions. We hold that the passage of time and the experience of flow are fundamental properties of conscious perception.

6 Gruber et al. make an interesting distinction between flow and passage of time. Flow refers to psychological aspects of time and passage of time concerns the evolving universe and concurrently created novel neurophysiological events. We do not follow all arguments of these authors concerning an illusion of passage and flow which according to them stems from completion processes covering up for the discreteness in perception, on the lower level, and from a false cognition of object persistence on the upper level.

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