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Time Perception

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Time perception is the name of the topic of research that deals with the perception of *temporal properties*. Listening to a piece of music, for instance, the experience one has turns centrally on whether two notes sound at the same time or in succession, the order in which different notes are played, and the duration of each note as well as of the gaps between them—these are just some elementary temporal properties. A large body of work has studied the mechanisms underpinning the perception of temporal properties, including their limitations, the errors they are subject to, and the factors causing such errors. However, researchers have also raised more fundamental explanatory questions—sometimes associated with the slogan that “there is no sense organ for time”—as to how it is possible for temporal properties to figure in experience at all. The particular theories of time perception that have been developed bear on broader issues such as the unity of consciousness, the boundary between perception and cognition, and the very nature of conscious experience.

History

The beginning of experimental psychology is often dated to a movement in Germany in the second half of the 19th century that included individuals such as Exner, Fechner, Helmholtz, Weber, and Wundt. An explicit aim of these researchers was to disprove pronouncements made by Immanuel Kant that psychology could never aspire to the rank of an exact science. Yet, they did share one preoccupation with Kant, and that was with the topic of *time*—the “form of inner sense” ([Kant, 1787](#)) that he had put at the heart of the very possibility of human experience and thought. Virtually every one of the pioneering works of psychology written during this early period dealt at some length with experiments seeking to explore aspects of time perception.

Alongside this flourishing empirical work, the psychology of time also saw important theoretical advances during this period. A central theoretical question concerned the very nature of perceptual experience itself: How is it possible for humans to be able to perceive temporal properties in the first place? One of the most consequential answers centered on the concept of the *specious present*, popularized by William [James \(1890\)](#). As typically understood, this concept refers to the idea that there is a short interval of time that is directly given in perceptual experience and that this is what makes it possible for one to perceive movement and change, for example. Similarly influential was another idea developed by Edmund [Husserl \(1991\)](#), who claimed that perceptual experience, alongside an awareness of what is strictly present, includes an awareness of what is just past and even an anticipation of what is about to happen. He called this a tripartite structure of *primal impression*, *retention*, and *protention* (see the section “Temporal experience”).

As noted by John [Wearden \(2016\)](#), the perception of time probably received more attention during this early period in the history of cognitive science than ever since. Moreover, many of the further landmarks since then hark back to this early tradition. This applies, for instance, to [Hirsh and Sherrick's \(1961\)](#) work, in the tradition of Exner, on the minimal temporal intervals by which two stimuli must be separated for

one to perceive them as nonsimultaneous (the *fusion threshold*) or to perceive the order in which they happen (the *order threshold*). Another example is work on temporal illusions in motion perception, originally studied by Wertheimer and revived by, for example, [Kolars and von Grünau \(1976\)](#). This deals with cases in which people report impressions of motion even though the displays they are presented with contain only stationary stimuli (see the section “Temporal illusions”). Particularly notable among novel developments in the field was the emergence of formal models of an “internal clock” ([Gibbon et al., 1984](#); [Treisman, 1963](#)), which have been agenda setting for the field of timing ever since (see the section “Timing”). Occasional ambitious efforts to provide a broad theoretical synthesis (e.g., [Fraisse, 1963](#); [Pöppel, 1988](#)) have proved somewhat less influential.

Today, research on time perception is once again flourishing, although it has yet to recapture the central place in the study of the mind it arguably had in its early years. Moreover, it has become very fragmented, with different lines of research tending to be investigated largely separately from each other. What is absent, in particular, is an agreed-upon framework for finding empirical measures that can speak to foundational concerns about the very sense, if any, in which time can be an object of conscious experience and the role temporal aspects of experience might play in consciousness itself.

Core concepts

Given the proliferation of different strands of work in the area, one concept clearly in need of further elucidation is that of *time perception* itself. There are in fact a number of different psychological phenomena that are being studied under this heading (see also [Pöppel, 1978](#)). They can helpfully be categorized along two dimensions, corresponding to more or less strict ways of construing the words “time” and “perception,” respectively.

Taking “time” first, one might want to distinguish between experiences of

- time itself, or at least what appear to be properties of time itself, such as the rate at which it is passing
- temporal relations such as simultaneity, succession, and duration
- things that occupy time, such as momentary changes, states, and extended processes, and the ways they fill and/or unfold over time

Turning to “perception,” here it might be helpful to distinguish

- a narrow, sensory, notion of perception, as in the *visual* or *auditory* perception of a stimulus and its temporal properties
- a broader notion of perception, capturing intuitive feelings or impressions related to time that do not seem to be tied to any particular perceptual modality

- a very liberal notion of perception or awareness of time, which can also, at least in part, be a matter of memory, inference, or knowledge of temporal facts

An issue in the background of many of the topics to be discussed below is which of the relevant readings of the terms “time” and “perception” are in fact at stake, as there is an obvious potential for confusion if they are not kept sufficiently separate from one another. Similarly, it is important to distinguish between a number of different aspects of time that researchers have engaged with.

Timing

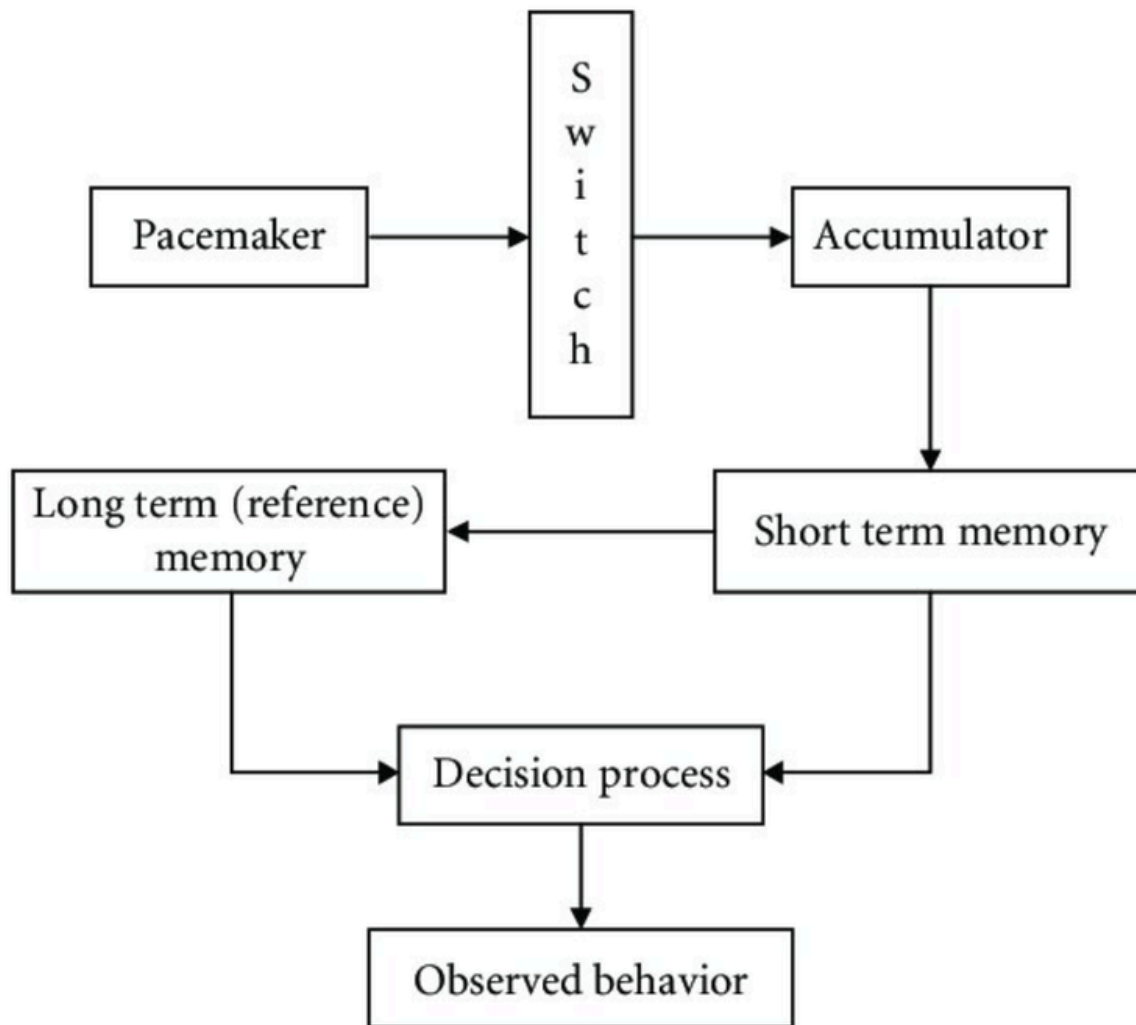
The word *timing* typically refers to the perception of metrical temporal properties. Paradigmatic examples are the perception of the length of the interval between one stimulus and another or between the onset and the offset of a stimulus. A key distinction is that between *prospective* (forward-looking) timing and *retrospective* (backward-looking) timing. The distinction is perhaps easiest to explain in terms of two associated types of experimental protocol. In a prospective timing study, participants are explicitly told from the start that their task will be to make a temporal judgment about an event that is to follow, such as the length of the interval for which a visual stimulus is displayed. A retrospective timing study, too, may involve the presentation of a visual stimulus, but participants are not told in advance that the length for which the stimulus is displayed is relevant to the study. Only once the stimulus has been displayed are they then given the further instruction to judge, for example, how long the stimulus lasted.

Because prospective timing is taken to involve attending to the duration of an event while it is taking place, the difference between it and retrospective timing is also sometimes framed as one between *experienced duration* and *remembered duration* ([Block, 1990](#)). However, both prospective and retrospective timing arguably involve some form of memory, as participants make their actual judgments only after the relevant stimuli have been perceived. The key difference is that retrospective timing judgments are typically held to be based on an inference from information that is not temporal per se. For instance, participants may instead estimate how long an interval lasted based on the overall amount of change they remember happening during that interval. What underpins duration judgments in prospective timing tasks, by contrast, is often theorized to be the output of a mechanism specifically dedicated to measuring duration itself: an internal clock.

The idea of an *internal clock* is that of a cognitive mechanism that has the dedicated function of producing outputs that systematically track elapsed time. The parts out of which such a clock might be composed and the role played by each of those parts have been discussed most extensively within the context of scalar expectancy theory ([Gibbon et al., 1984](#)). The theory describes a timing system (see [Figure 1](#)), which has at its heart a pacemaker-accumulator device—the internal clock, narrowly understood. As the description indicates, this consists of a *pacemaker*, producing a stream of what are often conceived of as “pulses,” which is connected via a switch to an *accumulator*, that is, something that can collect the pulses produced by the pacemaker. At the beginning of a to-be-timed interval, the switch opens to allow the

pulses produced by the pacemaker to collect in the accumulator. As a result, the number of pulses collected in the accumulator increases in line with the interval.

The contents of the accumulator thus provide a kind of measure of the length of the interval. Judging the length of a given interval, however, typically also requires the ability to compare it with others (e.g., whether it is longer or shorter than another interval that was presented previously). Scalar expectancy theory therefore envisages the pacemaker-accumulator clock to be part of a larger timing system also including, for instance, working memory. Working memory is taken to be able to access the contents of the accumulator, which can then be put to two purposes. They can either be transferred into a long-term memory store so as to serve as a *reference interval* for further intervals to be measured against. Or a decision process can compare the contents of working memory with a relevant, already-stored reference interval. This is how a timing judgment is generated.

**Figure 1**

The elements of the timing mechanism postulated by scalar expectancy theory. Reproduced from **Wearden (2016)** with author's permission.

Scalar expectancy theory is probably the most prominent clock-based model of timing, but several alternatives or variants have been developed. Some of these differ, for instance, in the nature of the time-sensitive process that counts as the central time giver. It has also been suggested that different types of such processes might underpin the timing of durations of different lengths (e.g., the sub- vs. supra-second range). Furthermore, some accounts of prospective timing make no appeal to the idea of a dedicated clock-like neural mechanism in the first place. So-called intrinsic models suggest that when a stimulus is perceived or held in working memory, the very neurons this involves also exhibit dynamic features (i.e., features to do with how their activity unfolds over time) that serve to encode the duration of the stimulus ([Ivry & Schlerf, 2008](#)). Indeed, there are also approaches on which people's own background awareness of processes going on in their bodies—such as their heartbeat—is taken to underpin awareness of time ([Craig, 2009](#)).

Temporal integration

Timing, as just described, can be grouped together with the somewhat more basic capacities for *temporal discrimination* (whether or not two stimuli are synchronous) and *temporal order perception* (which of two stimuli came earlier vs. later). Each of them is a matter of perceiving a relevant class of temporal properties. A somewhat different aspect of the psychology of time is sometimes discussed under the name *temporal integration*. This relates to the idea that the perceptual system deals with the continuous flow of events by processing it in units of a certain length. That is to say, they are units into which the perceptual system divides time up for processing.

Units of temporal integration have been postulated at several different scales. At the shortest end, a *functional moment* of around 30 to 60 ms has been proposed. This is longer than the minimum interval required for discriminating and perceiving the order of two successive stimuli. Nevertheless, it has been argued that temporal and spatial features within this interval are bound together into a basic perceptual whole—a single event ([VanRullen & Koch, 2003](#))—that is not experienced as being decomposable into temporal parts. Functional moments have been described as something akin to elementary temporal building blocks, out of which longer stretches of perceptual awareness are composed (for discussion, see [van Wassenhove, 2009](#)).

Claims about temporal integration over longer intervals have centered in particular on the idea of a *subjective present* of around 2 to 3 seconds. Here, one broad theoretical motivation has been the attempt to explain a sense in which the contents of perception can be experienced as “happening now” but at the same time as being *dynamic*, that is, involving a succession of events ([Wittmann, 2011](#); see the section “Experience and the present”). The range of 2 to 3 seconds has been suggested to constitute an upper bound to the capacity to successive experience events “together” in the relevant way.

Some of the arguments for these units of temporal integration have turned on the idea that roughly the same duration stands out across a number of different empirical measures (see, e.g., [Pöppel & Bao, 2014](#) for review). For instance, durations of 30 to 60 ms—as associated with the idea of a functional moment—look to be of some significance both in physiological studies of the activities of single cells and neural groups but also when people’s reaction times are measured. Findings that have been cited as evidence for the 2 to 3 second subjective present include, amongst others, the following: the rate at which one can switch between the two ways of perceiving a bistable stimulus such as a Necker cube (see [Figure 2](#)); studies showing that people are relatively accurate when asked to reproduce intervals within a 2- to 3-second range, with accuracy declining above that; the way people subjectively accentuate metronome beats to group them; and even commonalities across cultures in the length of lines of poetry.

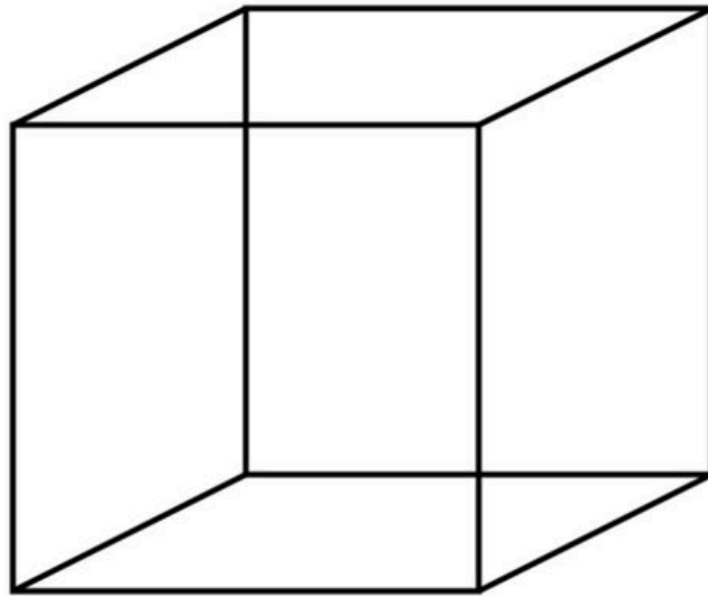


Figure 2

An example of a Necker cube. The drawing can be seen in two ways (it is “bistable”), with the facing surface including either the leftmost edge or the rightmost edge. There appears to be a limit to how fast one can switch between the two ways of seeing the cube, which has been taken as evidence of a subjective present of 2 to 3 seconds.

A convergence of quite different measures on similar values is one piece of evidence for a common underlying mechanism being in play. However, the usefulness of constructs such as the functional moment and the subjective present plausibly also turn on whether they can meaningfully be connected to research in other areas (such as the field of temporal experience discussed in the next section). Another important question is how exactly views that postulate discrete temporal units in perceptual processing can be reconciled with the seeming continuity of conscious experience (see, e.g., [White, 2018](#)).

Temporal experience

The term *temporal experience*, although typically not formally recognized as a piece of technical vocabulary, has come to designate a third, somewhat separate, field of research ([Dainton, 2023](#); [Phillips, 2017](#)). The central issue discussed under this heading might be put as follows: when one perceives, say, an object moving or changing, one has a perceptual experience of something that occurs in time. However, the experience itself is also something that occurs in time, and there are two quite different forms it might take. Is it a process that itself goes on over time? Or is it a state that one is in at a moment in time? Sometimes the question is also framed as one about the relationship in time between the mental act of perceiving, on the one hand, and its content, on the other, on the assumption that the content can include such things as an object moving or changing.

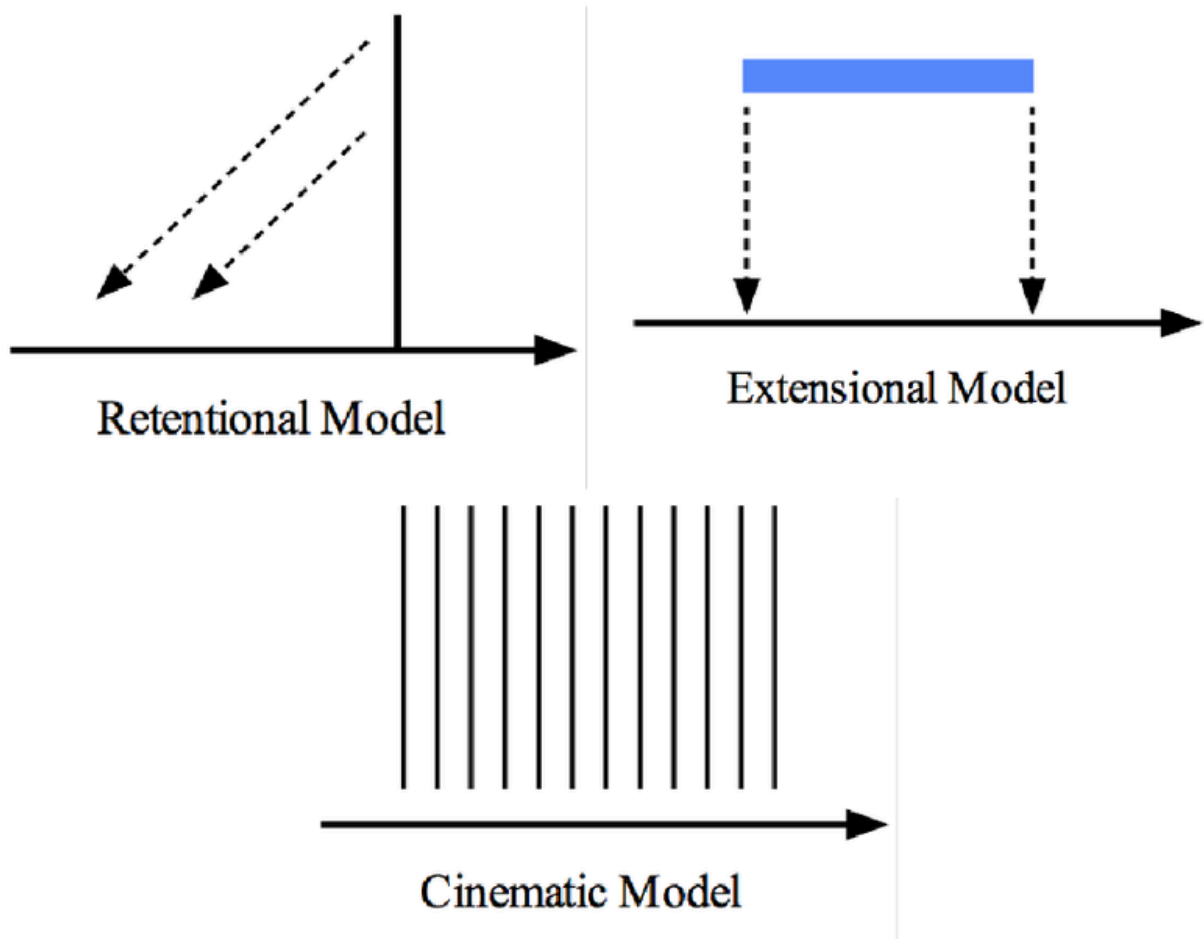


Figure 3

The three main conceptions of temporal consciousness. Reproduced from **Dainton (2023)** with author's permission.

[Figure 3](#) illustrates the main types of answers to these questions in the literature. Perhaps the most straightforward way of introducing them is to take what may be considered the most radical one first. Defenders of the *cinematic* or *snapshot model* of experience in fact hold that succession and change over time cannot literally be perceived (for some qualification, see the section “Experience and the present”). On the cinematic model, perceptual consciousness is made up of a succession of momentary experiential states, much like a movie is made up of a succession of still images. Even if they are perhaps not, strictly speaking, instantaneous, what is experienced in each is a state of affairs lacking any distinguishable temporal properties. It is only through the workings of memory, rather than perception, that people become aware, for example, of succession or change.

The two main alternatives to this cinematic model of experience can both be seen to invoke a version of the idea of the *specious present* (see the section “History”). That is, they share the idea that, instead of just presenting us with a snapshot of how things are at a moment in time, perceptual experience always ranges over a small interval. Within this interval, temporal properties such as succession or movement

can be directly perceived, much as one can directly perceive the spatial properties of, or spatial relations between, objects if they fall within one's field of vision. Theorists therefore also sometimes speak of experience featuring a temporal field, in analogy to the (spatial) visual field. Where the *retentional* and *extensional model* differ from one another is in how exactly they spell out this idea.

The *retentional model* shares with the cinematic model the view that experience occupies time in the manner of a state one is in at a time. In order to explain how it can nevertheless range over an interval of time, the retentional model conceives of this experiential state as one that encompasses an awareness not only of what is the case at the time it occupies but also of a portion of what has been the case just before. This backward-looking element of *retention* is thus conceived of as something that is integral to perception itself, in contrast to memory, which constitutes a standalone mental state.

The *extensional model* of temporal experience, by contrast, conceives of perceptual experience as something that itself unfolds over time ([Hoerl, 2013](#)). On the extensional model, there is no backward-looking element needed for perception to range over an interval of time. Instead, one can perceive, say, an object moving because the interval through which the movement of the object unfolds is matched by the interval through which one's experience unfolds. One's experience of the movement is constituted by that unfolding experience (see the section "Experience and the present").

Questions, controversies, and new developments

There is no shortage of unresolved questions when it comes to research on time perception. Indeed, perhaps because time is such a pervasive and yet intangible element of mental life, foundational questions remain about what exactly it is that such research should be looking for in the first place.

Finding time in the brain

Progress in cognitive science can often be measured by advances made in discovering candidates for locating mental functions in the brain. By that standard, research on time perception might be said to lag behind work in other areas. The question, "To what cerebral process is the sense of time due?" already posed by [James \(1890, p. 594\)](#) remains very much a live one. Despite the existence of well-developed formal models of mechanisms involved in timing (see the section "Timing"), what there is by way of evidence for their concrete existence still mainly comes from the fit between the predictions of the relevant models and observed timing performance. There has been some excitement, for example, about the discovery in animals of what have been dubbed *time cells* in the hippocampus ([Eichenbaum, 2014](#)) as well as other cells elsewhere in the brain whose activity seems to correlate with temporal features (see, e.g., [Tsao et al., 2018](#)), but there is considerable debate about the interpretation of the relevant findings (and indeed the appropriateness, e.g., of the label "time cells") as well as the range of behaviors they might be capable of explaining.

One general challenge faced by attempts to identify mechanisms responsible for time perception in the brain is the bewildering array of factors that impact time perception. Indeed, it is hard to find a

psychological variable that does not affect time perception. To name but a few, attention, perceptual modality, emotions, or stimulus intensity all modulate timing judgments, as do drugs, body temperature, agency, or beliefs about a causal connection between the to-be-timed events. Particularly profound effects on time perception have been reported in psychopathology and meditation.

Yet conversely, despite this vulnerability of time perception to such a wide range of influences, there do not seem to be any factors capable of wiping out the very awareness of time altogether. Even occasional reports of “time appearing to stand still,” for example, in meditation, seem, on closer inspection, not to imply a literal loss of any sense of time as such ([Frischhut, 2024](#)). Time, it appears, is more than just one object of conscious awareness among others; the perception of time is instead a constitutive part of what it is to be conscious in the first place (see the section “Time and consciousness”).

Experience and the present

Demonstrations of the speed at which impulses are propagated within nerves (going back to Helmholtz) have made clear the time lag involved before external events enter consciousness. As such, they are often taken to unmask as illusory the everyday impression that perception puts one in direct contact with reality. However, by the same token, they draw attention to an important aspect of the *phenomenology of experience* (i.e., how experience appears from the first person point of view). Even if experience is illusory in this respect, it appears integral to one’s experiencing an event that the event is experienced as happening in the present. Call this *experiential presence*.

A key challenge for accounts of temporal experience is how to reconcile experiential presence with the possibility of perceiving instances of succession or change, which are things that go on over time. Consider, for instance, the retentionalist model of experience (see the section “Temporal experience”). As mentioned, the retentionalist seeks to explain how succession and change can figure in perception by invoking the idea that there is a form of awareness of just-past events—retention—built into perceptual experience alongside the awareness of what is present. Note that the proposal cannot just be that when one hears, say, two tones in succession, one still hears the just-past one when the present one sounds. For then one would hear a chord, not a succession. So, the retentionalist has to postulate a way in which the just-past tone figures in experience—that is, as past—that distinguishes it from the present one. However, that means that the explanation of how succession can be perceived comes at the price of giving up experiential presence.

It has been argued that, at least when it comes to movement perception, no conflict with experiential presence need arise because perceiving an object *as moving* need not imply perceiving it as occupying different places at different times. This claim has been central to the *dynamic snapshot model* of experience ([Prosser, 2016](#)). One inspiration for it comes from *motion aftereffects*. In the classic example—the waterfall illusion—one first looks at a uniformly moving stimulus for a prolonged period of time and then shifts one’s gaze to a stationary stimulus, with the effect being that the latter will be perceived to be moving. Crucially, it has been claimed that the impression of movement experienced in the illusion is different

from an impression of the stimulus changing location—that is, of a difference in time in the places it occupies. (A background here is the thought that separate brain mechanisms underlie the detection of motion and the registration of location changes; however, also see, e.g., [Nishida & Johnston, 1999](#).) Thus, the argument has been that experiencing a stimulus only as it is at the present moment in time need not rule out experiencing it as moving.

The view perhaps most closely associated with the idea of experiential presence, however, is the extensionalist model. It seems able to explain experiential presence in a simple way because it entails that there is something special about time. Experience does not otherwise itself exhibit the properties that figure in it (e.g., an experience of something green is not itself green), but for the extensionalist, there is a sense in which experience, as something that itself unfolds over time, shares the temporal properties it is an experience of ([Phillips, 2014](#)). Experiential presence can be explained as a byproduct of this; one is not aware of any difference between the temporal location of one's own experience of an event and the temporal location of the experienced event itself because the former serves to indicate the latter in in experience.

Temporal illusions

One line of empirical research that is often seen to be particularly relevant to theorizing about time perception is work on temporal illusions ([Arstila et al., 2019](#)), in particular *postdictive phenomena*. The term *postdiction* describes perceptual situations in which the occurrence of a stimulus seems to have an impact on what is perceived to happen in the interval preceding that stimulus. A basic example is *apparent motion* (illustrated in [Figure 4](#)) in which two stationary stimuli are presented in two different locations, A and B, in brief succession, but observers report an impression of one stimulus moving from A to B. The impression of movement would not occur without the second stimulus, yet it is an impression of movement occurring in the interval preceding it.



Figure 4

An animation illustrating a simple case of apparent motion, sometimes also referred to as the (color) “phi phenomenon.”

Two potential models of postdiction have been distinguished. To take the example of apparent motion, on the *Orwellian model*, both stationary stimuli are initially perceived, but the observer subsequently remembers one moving stimulus. The *Stalinesque model*, by contrast, postulates a delay that visual

processing is subject to; before either of the two stimuli reaches consciousness, the visual system therefore has time to edit them together to create the percept of one moving stimulus.

Intuitive as the distinction between the two models may seem, it has been argued that there is in fact no concrete difference between them because the contrast between misremembering and misperceiving breaks down at the relevant timescales. This has been part of a wider argument against a picture of consciousness as akin to a “stage” on which stimuli appear, implying that a sharp dividing line can be drawn between preconscious and postconscious processing ([Dennett & Kinsbourne, 1992](#) call this the *Cartesian theater*). In other parts of the literature, however, the question as to whether the Orwellian or the Stalinesque model is right is still seen as very much a live issue ([Rao et al., 2001](#)), one that has implications, for example, for the kinds of questions at stake in the debate between different models of temporal experience ([Grush, 2005](#)).

Yet another response has been to question both the Orwellian and the Stalinesque model of apparent motion on the grounds that they do not seem to get the nature of the illusory experience right ([Hoerl, 2015](#)). Here, it might help to look again at [Figure 4](#) and concentrate on what seems to be observed. There is no doubt an impression of movement. However, this does not obviously involve any apparent visual awareness of something traversing locations in the space between A and B—for instance, it seems obvious that nothing ever occupies the midpoint between A and B. Thus, whatever the explanation for the impression of movement, it is doubtful that it lies in the brain “making up” a moving stimulus, as both the Orwellian and Stalinesque model seem to assume.

Broader connections

Time and consciousness

Although perhaps not always articulated explicitly, the Kantian idea of a deep connection between time and consciousness can still be seen behind many researchers’ interest in the topic of time perception. Yet, much of the actual work deals with consciousness of time only in the fairly minimal sense of studying how subjective judgments of durations do or do not diverge from clock time. The possibility of genuine future progress in the field may well turn on the extent to which researchers are able to make connections between this research and broader questions, for example, about what is involved in being conscious of an interval of time in the first place (see also [Kent & Wittmann, 2021](#)).

However, obstacles to progress can be seen to come from the side of consciousness studies, too. There is a history of writing about consciousness in which conscious perceptual experience is conceptualized as the awareness of *qualities*—witness the way an experience of “redness” often serves as the paradigm of a conscious experience. This can, in turn, make it look as though it should be possible to give an account of consciousness (at least to a first approximation) that simply abstracts from its temporal dimension. Indeed, in the literature on consciousness, the temporal character of consciousness is typically treated as a specialist subarea of research. Arguably, however, conscious experience is never just experience of

qualities; it is experience of things either changing their qualities or staying unchanged over time. The way in which experience constantly “goes on” over time seems essential to its conscious character. Yet, the need to provide an explanation for this central feature of consciousness is seldom acknowledged—the so-called “hard problem” of consciousness instead being assumed to lie somewhere else entirely.

Experience and the folk concept of time

A successful program of research in other parts of cognitive science has been concerned with investigating the nature of *folk* or *intuitive theories* about particular domains, such as physics, biology, or the mind [see [Intuitive Theories](#)]. The idea of an *intuitive theory of time* ([Shardlow & Lee, 2026](#)) has only recently begun to be investigated empirically. In fact, however, there is a long tradition of work in philosophy discussing certain commonsense ideas that seem to be uniquely associated with time, such as that of a passage or flow of time (see also [Thönes & Stocker, 2019](#)). In this context, it is frequently claimed that these beliefs reflect how time appears in perception.

How exactly the appeal to perception might be understood here is itself an important question (see the section “Core concepts”), especially given frequent claims that there is “no sense organ for time” (see [Singhal, 2021](#) for discussion). One potentially interesting recent development is the growing recognition that there is an important aspect of time perception not captured by traditional timing studies. When people are asked to make *passage of time judgments* ([Wearden, 2015](#))—about how fast or slow time is felt to pass during a given interval—their responses are often not mirrored in their prospective or retrospective timing estimates of the length of the interval. This is still a relatively underexplored area of time perception, and the focus so far has been mainly on its quasimetrical aspects (i.e., passage specifically as something to which a rate might be applied). However, further work on passage of time judgments, and on their psychological underpinnings, might perhaps be able to provide one window on what is behind the elusive idea of the passage or flow of time.

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