The curious case of the fast feelers: a possible malfunction in a timing mechanism for perceived happening

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Abstract

There have been numerous reports of people experiencing events as speeded up or slowed down; for example other people are perceived moving as if in fast forward mode. This paper proposed a possible explanation for that. One part of the explanation is an information structure on the sub-second scale that represents recent perceptual history with events located and connected in time by means of time marker information. The other part is a calibration mechanism for updating the time marker information. It is proposed that a perturbation to the calibration mechanism may result in time markers being updated significantly more or less frequently than normal, resulting in apparent speeding or slowing, respectively, of events. Things are perceived, not as happening more quickly than normal, which is impossible, but as having happened more quickly than normal, because of the incorrect time marker information in the historical register.

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1. Speeded happening

Blom et al. (2021) published a survey of clinical case reports of distortions in the experience of time. They distinguished five categories of time distortion, of which one category (with two sub-types) is of particular interest here: apparent speeding up or slowing down of things happening. Typical reports mention perception of people as moving or speaking abnormally quickly or slowly. Three examples will serve to illustrate reports of speeded happening. All quotations in this paragraph and the next are from Blom et al. (2021, supplementary material, Table S1). From Hoff and Pötzl (1934), a stroke patient reported "quick-motion phenomenon (seeing physicians in the hospital move as quickly as 'in a movie that goes too fast'". From Häfner (1953), a patient with a fractured skull reported "seeing people move about extremely fast and having the sensation that he himself is moving fast, too". From Levi and Miller (1990), "seeing things speed up, as if he were 'watching a motion picture at fast speed'" (after use of drugs). Two examples of slowed happening will be given. From Takaoka et al. (2001); "'Everything is moving as if in a slow-motion picture'" (described as "Alice in Wonderland syndrome in toluene-based brain dysfunction"). From Flach and Palisa (1935): "feeling himself moving slowly, and seeing people in [his] surroundings move even slower" (during attackes of oculomotor nerve palsy). Blom et al. (2021) found 84 case reports of time distortion; 33 of those were reports of speeded motion or happening and 16 were reports of slow happening. The 33 reports of speeded happening were strikingly similar and suggest that, at least for most of them, the same basic mechanism might be involved.

Blom et al. (2021) were careful to distinguish between those reported experiences and "mundane fluctuations in the perception of time that everyone experiences now and then" (p.

2). An example would be the sense that time drags when one is bored. When experiencing such a mundane fluctuation, people do not perceive others as moving abnormally quickly or slowly. Speeding up or slowing down of things happening should also be dissociated from distortions in the experienced passage of time. Three examples can be given, again from Blom et al. (2021, supplementary material, Table S1). From Šerko (1913), "experiencing time to be rushing on". This was accompanied by "threefold overestimation of time duration" (mescaline intoxication). From Kloos (1938), a patient diagnosed with depressive disorder reported "Experiencing time to be going slower (when looking at a clock after completing a task)". From George and Bernard (2013), "having the sensation that time goes extremely slowly" (migraine and panic attacks with hallucinations). There is a clear and categorical distinction in the case reports between patients reporting speeding or slowing of things happening and patients reporting alteration to the passage of time: the former do not refer to the passage of time and the latter do not refer to speeding or slowing of events. That suggests that those two kinds of time distortion may be explained by different kinds of malfunction.

The case reports of speeded happening compiled by Blom et al. (2021) might be just the tip of the iceberg. Abe et al. (1989) ran a questionnaire study in which 1.4% of a large sample of schoolchildren reported having experienced a fast-motion illusion. It is not clear whether all of those reported were of the same kind as the case reports compiled by Blom et al. (2021), nor under what circumstances they occurred, but it does suggest that such experiences, although occasional, are not exceedingly rare. There is a website called "Fast Feeling" (https://www.reddit.com/r/fastfeeling/) where numerous reported experiences of time speeding up, usually lasting less than an hour, have been posted, although intermingled with experiences of other kinds. Voluntary posts to a website do not give any indication of prevalence in the general population but do indicate that such experiences are at least occasional in the non-clinical population.

This paper is concerned with experiences of speeding or slowing of things happening, not with fluctuations in judged duration or the passage of time per se. Speeded happening has a paradoxical aspect to it: if the perceived flow of events was really speeded up compared to objective time, the person would very soon be perceiving the future, which is not possible. In this paper it is proposed that the apparently paradoxical nature of perceptual speeding of events can be resolved with reference to perceptual memory. That is, things are not perceived as happening too quickly, they are perceived as having happened too quickly. There are two connected parts to the explanation: an information structure on the sub-second scale that locates items of information in recent history with time markers, and a calibration mechanism for the time markers.

2. The information structure: the perceptual timescape

Sperling (1960) first reported evidence for a sensory store on the sub-second scale. He presented brief static stimuli containing grids of digits and letters and cued participants to report the elements in one of the rows. By varying the latency of the cue relative to the stimulus he showed that the number of elements that could be reported greatly exceeded the capacity of short-term memory initially but declined rapidly to the limited capacity of short-term memory over some hundreds of milliseconds. The method of the study yielded the impression that the store was a static register of a fading image of the stimulus.

The store first identified by Sperling (1960) has been given various names, including iconic memory (Neisser, 1967), sensory register (Atkinson & Shiffrin, 1968), sensory memory (Öğmen & Herzog, 2016) and information persistence (Coltheart, 1980; Irwin & Yeomans, 1986). It has large capacity but information decays rapidly over ~300 milliseconds (ms), and with a maximum time span of ~1000 ms (Sligte et al., 2010; Sperling, 1960). It registers semantic and categorical information as well as surface visual information. It is therefore distinct from (i) visible persistence, which is a brief store of surface visual information not exceeding ~130 ms (Di Lollo, 1977; Di Lollo & Bischof, 1995; Loftus & Irwin, 1998), (ii) fragile very short-term memory which has a capacity intermediate between that of information persistence and working memory and in which information appears to persist for a few seconds with little decay (Landman et al., 2003; Sligte et al., 2008; Sligte et al., 2010; Vandenbroucke et al., 2015), and (iii) visual short-term or working memory, which retains information on a time scale of seconds, and in which information can be maintained by means of rehearsal (Baddeley & Hitch, 1974; Lewis-Peacock et al., 2018; Oberauer, 2019; Vogel and Awh, 2008). Further discussion of this can be found in White (2024).

Haber (1983) argued that the impression of a store of static, fading information was mistaken and that the sensory store was instead a store of information about continuity of change; that is, it registers change in perception over a short time scale. White (2021, 2024) developed a proposal for how continuity of change could be represented on the sub-second scale. The proposal was of an information structure that differentiates moments in time by means of time markers (White, 2023) and connects successive representations over time. The information structure is illustrated in Fig. 1. The figure shows a series of representations of a moving black square at different moments in its history and four kinds of information that connect the representations to form a coherent and orderly perceptual representation of that history.

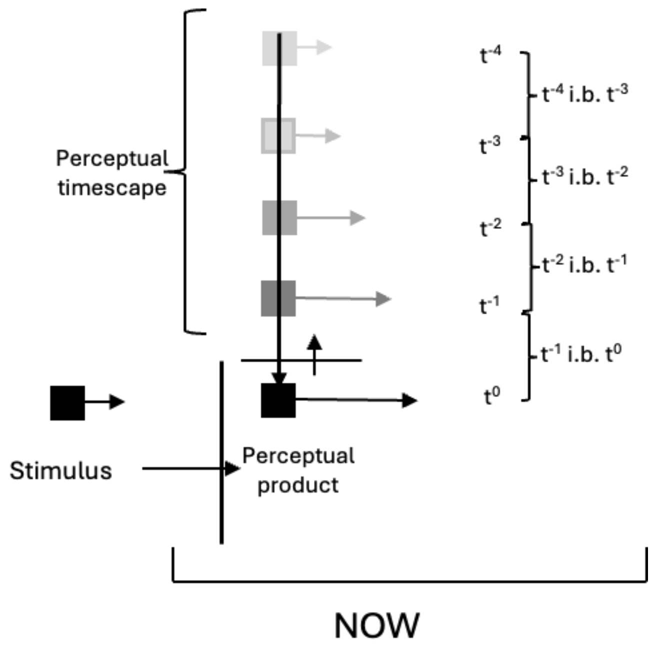

Figure 1. Schematic representation of the perceptual timescape. t^0 to t^4 are time distance markers. t^{-1} i.b. t^0 to t^{-4} i.b. t^{-3} are ordinal temporal markers. Arrows attached to each representation of the square represent rate of change information for velocity. The vertical arrow running through all representations of the square symbolises connective information. See main text for further explanation of these kinds of information. Changes in grey scale for the square symbolise decay of information in memory.

Two of those kinds of information are time markers. Time markers are semantically encoded components of perceptual representations. They are labels encoding features, not themselves visible (or audible or tactile, etc.) but part of the perceptual interpretation of the stimulus. In that respect they are akin to other nonvisual or amodal semantic features in perceptual information such as categorical identity (Wutz & Melcher, 2014) and spatial location (Lappe & Krekelberg, 1998) Time distance markers (t^0, t^1, etc.) are attached to each representation of the object and indicate how far in the past that representation is at a given moment. They are given abstract designations in the figure but in reality would have semantic indicators that are at least approximately calibrated to objective time. The figure shows only four time markers in the perceptual timescape (plus one for the perceived present, t^0) but in reality there would be many more. Ordinal temporal markers (t^{-1} i.b. t^0, t^{-2} i.b. t^{-1}, etc.) indicate ordinal relations between successive representations of the object: they convey that the representation of the object at time distance marker t^{-1} occurred immediately before (i.b.) the representation of the object at time distance marker t^{0}, and so on. (The convention "immediately after" could just as well have been used.) That links the successive representations as occurring in a temporal order in relation to each other.

The other two kinds of information concern the object itself. One kind is information about rate of change at a given moment (White, 2024). Every feature of an object at every time distance marker where that object is represented has rate of change information attached to it. If no change in that feature is occurring, rate of change information is still there and has a value of zero, meaning no change occurring at that moment. In Fig. 1, rate of change information is given for velocity in the form of horizontal arrows attached to each representation of the square. The length of the arrows symbolises speed. The figure shows the square as accelerating, so the most recent representation is the one with the highest speed (the longest arrow). The other kind of information, symbolised in Fig. 1 by a vertical arrow running through all the representations of the object, is connectives. Connectives bind successive representations of objects and features into a connected series. They say, in effect, that this object at this moment is a continuation of that object at the immediately previous moment. Connective information is necessary to bind the separate representations of the square into a representation of a single perceptual object persisting across all of them.

Those four kinds of information bind together distinct representations of the object in its perceptual history with each moment of that history located in time and linked in order. That comprises a coherent, orderly set of information that depicts a persisting object and changes in it over a brief historical period. That is how happening is perceived (White, 2021). Happening cannot be perceived at a single moment. A very short exposure photograph of an object in motion shows only a static image of the object in time and there is no way to know from that image how the object is moving (or indeed changing or not changing in any other respect). Most importantly, the entire historical representation in the perceptual timescape exists at a single moment in time, symbolised by the word "NOW" at the bottom of the figure. We do not and cannot perceive change from one moment to the next. We perceive change at a single moment, by virtue of a representation of the object's history that exists at that moment. The present moment as perceived can incorporate rate of change information, so that there can be, for example, information about the object's velocity at that moment. But that is not sufficient for perception of motion (or any other kind of happening). For that, the informationally connected and temporally structured historical representation is necessary.

3. The calibration mechanism

3.1 Synfire rings

White (2024) summarised several lines of evidence indicating that the temporal resolution in the perceptual timescape could be as little as 20 ms. The time markers in the perceptual timescape should also be accurately calibrated with the objective passage of time. To fulfill the function of the perceptual timescape as an information-rich register of the recent past, the time markers would have to be generated, monitored and controlled by a calibration mechanism capable of accuracy on a very short time scale. Such a mechanism would have two connected functions: changing the value on each time distance marker and calibrating the value changes so that they remain closely correlated with the objective passage of time.

Numerous timing mechanisms have been proposed (Buonomano & Merzenich, 1995; Gorea, 2011; Grondin, 2010; Mauk & Buonomano, 2004; Merchant et al., 2013; Paton & Buonomano, 2018; Rao et al., 2001; Rolls & Mills, 2019; Sugar & Moser, 2019), but all of them are interval timing mechanisms and most of them are concerned with timing on supra-second time scales, requiring the involvement of working memory (Rao et al., 2001). Neither feature is appropriate for the calibration mechanism for the perceptual timescape. Interval timing is concerned with judgment of duration. Such a mechanism would not generate or calibrate the time markers in the perceptual timescape; it could only generate a judgment of how long some event or interval lasted for. Also, mechanisms for timing on supra-second scales are unlikely to be sufficiently accurate to support temporal resolution and calibration of information on a time scale of ~20 ms.

White (2024) argued that only one kind of timing mechanism currently in the literature can support the required functions of time marker adjustment, fine temporal differentiation, perpetual operation (at least when awake), and precise calibration to objective time. That is the synfire ring (Cabessa & Tchaptchet, 2020; Diesmann et al., 1999; Levy et al., 2001; Miller & Jin, 2013; Zheng & Triesch, 2014), which was developed from the original proposal of a synfire chain (Abeles, 1982). A synfire chain is a feedforward neural circuit with excitatory connections between layers. Neurons in a given layer tend to fire synchronously and firing propagates through the layers in a synchronised manner. A synfire ring is a closed loop of neurons with the same properties. Recent authors tend to use the term "neural sequences" instead of "synfire chains". There is abundant evidence for neural sequences occurring in relation to ongoing actions such as wheel-running in rats and birdsong (Buonomano et al., 2023; Mackevicius et al., 2023; Pastalkova et al., 2008; Zhou et al., 2020). However the functional role of the neural sequences is not clear and could encompass action planning (Pastalkova et al., 2008) and episodic memory (Buonomano et al., 2023). Also, neural sequences have a limited time span, measured in seconds. The attraction of synfire rings is that the closed loop of excitatory connections means that they can continue to operate for indefinite amounts of time. For that reason, they are a better candidate for a calibration mechanism for an information structure that is maintained constantly in the waking state. The term "synfire" means synchronously firing (Abeles, 1982) and, as will be seen, synchronous firing is a property of neurons within a group in synfire rings. So, with due acknowledgement that "synfire rings" might turn out not to be the best name for these neural systems, their applicability in the present context will now be discussed.

A simple model of a synfire ring is shown in Fig. 2. In real synfire rings there would be many more members in each group, and probably more groups in the structure. Fig. 2 shows the organisational principles, not the likely quantities of components. Neurons within a group tend to fire synchronously; each neuron in the next group receives synchronous input from the neurons in the first group, as a result of which they are very likely to fire, and in like manner synchronised group activity proceeds around the loop. When a group of neurons is made to fire by excitatory input from a previous group, there is an inhibitory connection back to the neurons in the previous group (not shown in Fig. 2).

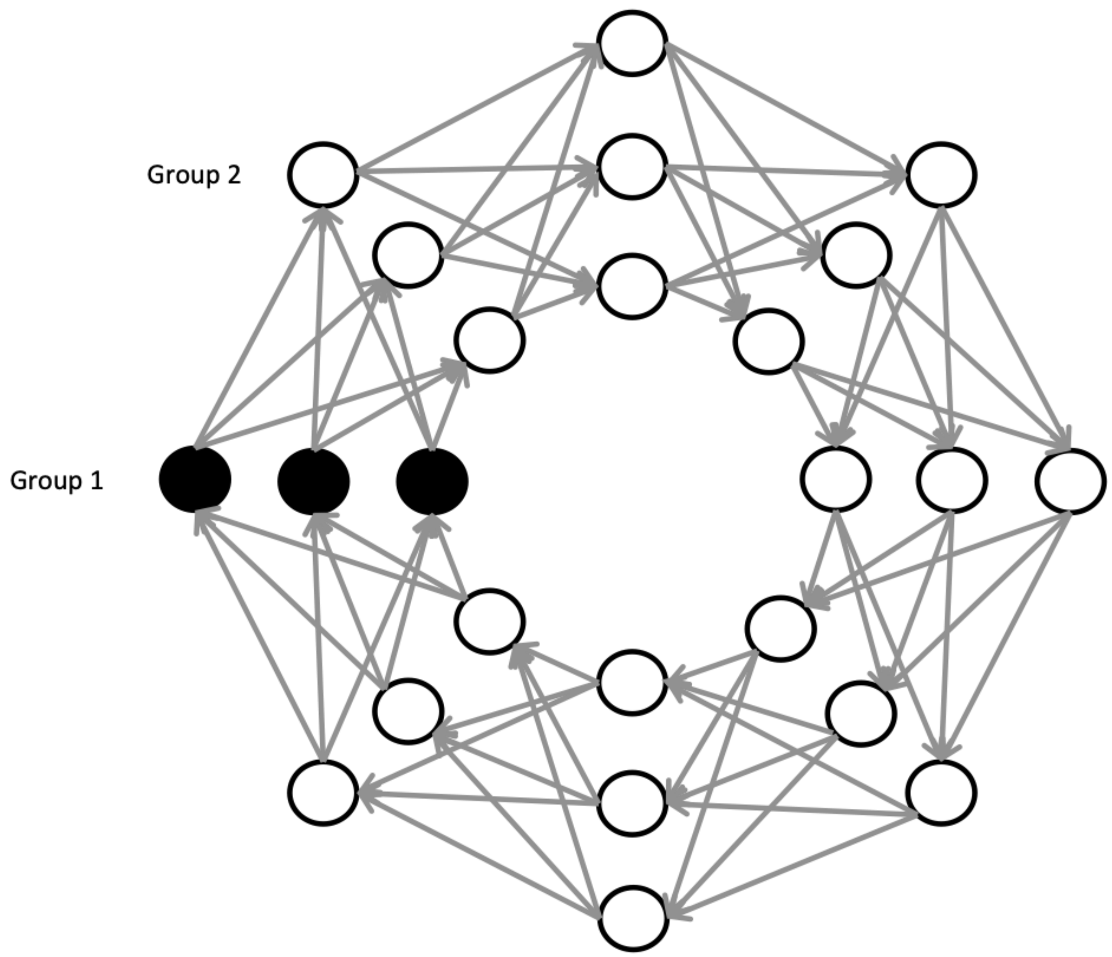

Figure 2. Schematic and simplified depiction of a synfire ring. Circles represent individual neurons and arrows represent connections between them. Black circles are the initial group to fire. Redrawn from fig. 5 in Cabessa and Tchaptchet (2020).

With that arrangement, feedforward excitatory activity can be perpetuated around the loop indefinitely. The main limiting factor is that a given neuron cannot fire again while it is in its refractory period, so the time taken for activity to circulate around the loop must be greater than the refractory period of the neurons in it. The refractory period is about 1 ms and the upper limit of a neuron's firing rate is about 500 to 800 impulses per second (Goldstein, 2014). Thus, the lower limit on a single cycle of activity around a loop would be about 2 ms. That would be more than sufficient to support temporal discrimination of 20 ms in the perceptual timescape. Temporal resolution could be improved by increasing the number of groups in a ring, and by having arrangements of rings that operate at the same rate but offset from each other by some small amount of time, or having connections to further processing that have different transmission latencies. So fine temporal resolution is, in principle, not a problem for networks of synfire rings.

Given some neurobiologically plausible assumptions, computational modelling has shown that synfire chains in general, and synfire rings in particular, have some noteworthy and relevant properties. Where a target neuron receives input from multiple synchronously firing neurons, its spike response can be more temporally precise than the input (Diesmann et al., 1999). Thus, if all neurons in a group receive synchronous input from all neurons in the previous group, instead of losing temporal precision, groups of neurons tend to become more precisely synchronised in their activity, presumably up to some asymptotic level. The mere perpetuation of activity around a synfire ring therefore maintains temporal precision and synchrony in the firing patterns (Cabessa & Tchaptchet, 2020; Diesmann et al., 1999).

The model developed by Deismann et al. (1999) showed an attractor state in a two-dimensional space defined by activity (number of spikes in a volley) and temporal dispersion of the spikes. An attractor state is a particular configuration of activity to which a system is drawn; that is, a wide range of values on the variables in the state space result in the same kind of activity, which therefore forms a stable configuration that is resistant to perturbation. In the model developed by Diesmann et al. (1999), the attractor state was located at about 90 spikes with a temporal dispersion of < 1 ms; thus, it is possible for synfire chains and rings to settle into a stable, self-sustaining state of activity with temporal precision of less than 1 ms. Other models built on different assumptions and models of neurons also show stable attractor states with similar temporal resolution (Cabessa & Tchaptchet, 2020). Robustness comes, in part, from redundancy: groups with larger numbers of members are more robust to failure of firing in individual cells (Cabessa & Tchaptchet, 2020). Other properties of synfire rings are reviewed in White (2024); for present purposes, fine temporal discrimination, robustness, and precision in firing patterns are the properties that matter most. Those properties make synfire rings suitable for calibration of time marking information in the perceptual timescape. Obeid et al. (2020) said of synfire chains and, by implication, synfire rings, that they "can be used to produce precisely timed intervals defined by the time elapsed between when activity arrives at a given pool and when it arrives at a subsequent pool" (p. 1). Thus, synfire rings, by a combination of precise and regular intervals between firing times of successive groups in the ring, robust and self-sustaining activity, and temporal resolution on the order of 1 ms, exhibit behaviour that can be used for time marker adjustment on any sub-second time scale down to about 1 ms.

Synfire rings, therefore, operate at a rate that could support temporal resolution in the region of 1 ms. As discussed above, the minimum temporal resolution of time markers in the perceptual timescape is probably around 20 ms. Even if some variation in those values is possible, it is unlikely that signals from a synfire ring mechanism and adjustment of time marker information would just happen to occur at the same rate: they are independent systems so that would be a coincidence. That being so, there would need to be a mechanism that would take signals from the synfire ring mechanism as input and output a signal to change the values on the time distance markers at a rate that is calibrated to the minimum temporal resolution of the perceptual timescape. No such mechanism has been developed yet but the basic functional requirement for such a mechanism can be outlined. That is just that input from the synfire ring mechanism results in some sort of progressive accumulation which eventually reaches a point where a neural signal is triggered and transmitted to the time distance markers, resetting their value.

Perhaps the closest approach to those functional requirements in the timing mechanism literature is a neural population that functions as an integrate-and-fire mechanism (Gerstner & Kistler, 2002; Simen, Balci, deSouza, Cohen, & Holmes, 2011; Tuckwell, 1988; Wackermann & Ehm, 2006). Such a population would take as inputs spike trains, and it can be supposed that the outputs from a synfire ring mechanism could fill that role. The population responds with recurrent and increasing excitation or ramping activity to a threshold level that activates a trigger which is functionally a bistable switch. Such mechanisms are commonly modelled as leaky (Wackermann & Ehm 2006) but can be non-leaky or perfect temporal integrators (Simen et al., 2011). The models of that kind that have been proposed operate on the supra-second scale and have been developed as models of interval timing. However, the bistable switch could be used for multiple purposes, and it is reasonable to suppose that the triggering of a signal that adjusts the time distance markers could be one. For that there would be a requirement that the input-driven ramping could be accomplished on a time scale of 20 ms. This has never been investigated but does not appear to be beyond the realms of possibility. It is noteworthy that the firing rate of neurons, specifically the number of spikes in a temporal window, can robustly encode information and can be read out or transmitted on a time scale of 20 ms (Rolls & Treves, 2011; Tovee & Rolls, 1995). This was one of the reasons for proposing a temporal resolution of ~20 ms in the perceptual timescape (White, 2024), and it allows for the possibility of updating of time markers on that time scale. So an integrate-and-fire mechanism that operates on that time scale is not impossible, and could serve to mediate between the output of the synfire ring mechanism and the adjustment of the time markers.

3.2 Variance

Proper functioning of time marker adjustment in the perceptual timescape requires a high degree of accuracy in the system that maintains it. There are a number of sources of variance in the performance of the system. The first is the precision of timing of the output from the synfire ring mechanism. Variance due to that will be minimal because the mere perpetuation of activity around a synfire ring maintains temporal precision and synchrony in the firing patterns (Cabessa & Tchaptchet, 2020; Diesmann et al., 1999). Second, neural transmission times from the synfire ring mechanism to the integrate-and-fire mechanism, or whatever other triggering mechanism is there, are subject to variance, or random error. It is likely that the mechanism has evolved to have low variance in relation to the time scale of operation of the synfire ring. And if multiple signals from the synfire ring are necessary to activate the bistable switch that changes the values on the time markers, then individual random error will be to some extent ironed out over the signals as a set. There is also a source of variance in neural transmission times from the bistable switch to the time markers, but again that is likely to be small in relation to the temporal resolution of the perceptual timescape. A temporal resolution of 20 ms in perceptual information means that random error significantly less than that will make no practical difference because it is below the capacity of the perceptual system to detect. Overall, then, the various sources of random error in the system should have little if any functional consequence under normal circumstances. Variance in the time at which values on time distance markers change will be minimised by the fact that a single signal resets all of them, so, for any given reset, the only source of variance is in neural transmission times from the bistable switch to the time markers. As a general principle, the system needs to be both accurate and robust because of the fundamental importance of perceptual information about things happening, so it has probably evolved to be that way.

In an early pacemaker-counter model of interval judgment, Treisman (1963) hypothesised that an arousal centre could influence the rate at which pulses were produced by the pacemaker. This was in order to account for evidence that interval judgment is affected by arousal (Allman et al., 2014; Merchant et al., 2013). It is functionally important that perceived happening be closely calibrated to the objective passage of time. The disruptive effects of speeded perception experienced by the patients catalogued by Blom et al. (2021) are adequate testimony to that. So it is very unlikely that the system would allow that factors such as attention and arousal (see Grondin, 2010, and Matthews & Meck, 2016, for surveys of several such factors) could impact on the functioning of the temporal calibration mechanism.

The perceptual timescape is hypothesised to operate for multiple sensory modalities, notably vision, audition, touch, and proprioception (White, 2024). This raises the issue of cross-modal synchrony and sources of error in that. If there is a single calibration and adjustment mechanism for all modalities, then there is a possible source of non-random error in the form of differences in neural transmission times between modalities. In perceptual processing, there are many factors that affect synchrony between the senses. These were reviewed by Vroomen and Keetels (2010) and they include differences in neural transmission times and how they might be compensated for. Two pertinent points emerge from their review. One is that there is a degree of insensitivity to cross-modal asynchrony. The classic demonstration of this was the study by Dixon and Spitz (1981) who found that thresholds for audiovisual asynchrony detection were often more than 100 ms. The other is that there is evidence for synchronisation mechanisms that, to some degree, resolve asynchronies between the senses (e.g. Stetson et al., 2006). This raises the possibility that there are mechanisms that actively synchronise time marker information across modalities. Synchronisation occurs in perceptual processing. That means that synchrony is inherent in the products of perceptual processing and is therefore inherited by the perceptual timescape as information is transferred into it from perceptual processing. In any case, given the evidence that cross-modal perceptual asynchronies of 100 ms or more are often not noticed, the possibility of asynchrony on a time scale less than that of the temporal resolution of the perceptual timescape is unlikely to have any practical implication.

4. Perturbation in the calibration mechanism: a possible explanation for fast feeling

In the present account, perceived happening is an information structure in which items of perceptual information are located in recent history by means of time markers, specifically time distance markers and markers of temporal ordinality. At each successive moment the time distance marker for any given piece of perceptual information changes to reflect its passage further into the past. Changes in time distance markers are controlled by the calibration mechanism described above, with calibration signals issued at intervals corresponding to the minimum temporal resolution of the perceptual timescape.

Now suppose that the process of changing time distance markers loses calibration. Suppose, for example, that the time markers on all features and objects move on half as fast as the objective time distance. Thus, when a feature is objectively 400 ms in the past, it is time marked as 200 ms in the past. What would normally be time marked as t^{-200ms}, t^{-400ms}, t^{-600ms}... would instead be time marked as t^{-100ms}, t^{-200ms}, t^{-300ms}... That would suffice to give the perceptual impression that everything was going twice as fast as it should be. In other words, the impression that everything is happening twice as quickly as it should is in fact an impression that everything has happened twice as quickly as it should: the apparently speeded happening is a feature of the historical record in the perceptual timescape, not of the perceived present as it goes by. Our perceptual experience is a construct existing at a single moment in time, and that construct is representing things as having moved on twice as quickly as they should be because of the faulty calibration.

An important point about this is that perceptual processing itself is not affected. Perceptual processing has the same latency as usual and products of perceptual processing emerge with the same temporal differentiation as usual. The calibration problem affects information in the perceptual timescape, not the moment-by-moment informational products of perceptual processing. Cross-modal synchronisation in perceptual processing also proceeds as normal. At the point of entry to the perceptual timescape, cross-modal synchrony is as it usually is. If one modality is affected and not another, then cross-modal asynchrony will gradually increase as information passes through the perceptual timescape, but that will not be noticed unless there is some explicit cross-modal comparison operating on older information. Apparent speeding is a feature of the register of the past, not of information emerging from perceptual processing.

There are two possible causes of loss of calibration in time marker adjustment. One concerns the synfire ring model. Robustness in the firing pattern over an indefinite period of time is a feature of the neurophysiologically plausible synfire chain and synfire ring models that have been proposed. For example, in the model developed by Diesmann et al. (1999), for a wide range of values of spike amplitudes and temporal dispersions of the spikes, there is an attractor state to which neural activity is drawn; this shows, in effect, that the firing pattern is stable and robust despite quite wide variation in values of the variables that define the state space. But there are values of those variables under which the network does not enter, or departs from, the attractor state. It may be supposed that, under normal conditions, such values rarely occur. However it is a plausible hypothesis that values of those sorts can occur under some kinds of insult to the brain, whether due to stroke, tumour, lesion, psychoactive drugs, or other possible causes listed by Blom et al. (2021), and perhaps a transitory change of state in the same system can account for some of the non-clinical reports. Exactly how this happens is not understood because of the lack of research on the phenomenon. But an insult to the brain would function as a perturbation sufficient to knock the network out of the attractor state. When that happens, it is not unusual for a complex system to settle into a different stable equilibrium, in effect a different attractor state.[1] No alternative attractor states occur in the Diesmann et al. (1999) model and it may be that a model with more dimensions of variability might be required to find them. But it can at least be hypothesised that the network can settle into a different stable condition. In that case, the new stable condition might be sufficiently different for output signals to be generated at a different rate, and the inaccurate time marking in the perceptual timescape would result from that. The new attractor state would also tend to be stable, and the altered condition might persist. As the patient's brain recovers from the insult, values of relevant variables might normalise to some degree and eventually the network would flip back to the normal attractor state, with the effect that the time distortion no longer occurs, as was reported in some of the case histories reviewed by Blom et al. (2021). Something similar may happen on a shorter time scale in non-clinical instances of the phenomenon.

Given the likelihood of massive redundancy in the synfire ring mechanism, in particular the likelihood of multiple synfire rings, an insult that would knock all of them into a different attractor state at once seems unlikely. It is not impossible, particularly if the synfire rings that are functionally connected to the perceptual timescape are localised in the brain. An alternative possibility, however, would involve a perturbation to the time marker adjustment mechanism. In the present account there would be successive inputs from the synfire ring mechanism to some kind of neuronal network that can support some form of accumulation until a critical level is reached and a neural impulse is transmitted to the time distance markers; an integrate-and-fire mechanism was discussed as a candidate for that. Thus, a perturbation could alter the functional properties of the network such that more or fewer inputs from the synfire ring would be needed to initiate the neural impulse to the time markers. To support apparent speeding of things happening, the number of inputs required from the synfire ring mechanism would have to be greater, so that more time passes between each successive signal to the time distance markers. In the integrate-and-fire mechanism, it would take a significantly higher level of activity in the neural population to turn the switch. As in the previous possibility, it is likely that this change represents a shift to a different attractor state that is resistant to perturbation. As the system recovers from the insult, so a point might come at which the mechanism reverted to its normal attractor state and things would once again be perceived as happening at normal speed.

The explanation proposed here applies specifically to perceived speeding and slowing of events: it is a distortion to the register of perceived happening on the sub-second scale, in the perceptual timescape (White, 2024). Distortions in the experienced passage of time, as in the examples given at the start of this paper, would have to be explained in some other way because (a) the time scale of such distortions goes beyond the time scale of the perceptual timescape so that working memory and, in some cases, long term memory must be involved, and (b) the patients in question specifically do not report distortion in perceived happening, only in judged duration. Some sort of malfunction in an interval judgment mechanism, such as a pacemaker-accumulator model operating on the supra-second scale, might be capable of accounting for distortions of that kind.

This is no more than a framework of an explanation. The details of the neurophysiological processes involved must await further research, both with patients who report time distortions and on the presence and functions of timing mechanisms in the human brain. But, as far as it goes, it is a plausible explanatory framework, and no other hypothesis has yet been proposed to account for distortions of perceived time. Indeed, however they may be explained, time distortions are the clearest evidence that time and events are not perceived directly or with actual temporal extension. The only possible vehicle for such distortions is an information structure that differentiates moments in recent history and that exists at one moment, and then the distortion results from a calibration failure in the time marking.

5. Slowing of time in life-threatening incidents

There have been many reports that, during an emergency situation where one's life is in danger, such as an accident, time seems to slow down. The extent of the slowing, as subjectively experienced, is extraordinary: Noyes and Kletti (1972) claimed as much as 100-fold in some cases. Even if such figures are exaggerated, they still indicate a quite different phenomenon from the very slight slowing of time reported in some experimental investigations (e.g. Stetson et al., 2007).

Arstila (2012) made a strong case that perceptual and cognitive processing really speed up in accidents, referring to widespread effects in the brain of a rapid release of the neurotransmitter norepinephrine governed by the locus coeruleus norepinephrine system. Arstila argued that this general speeding up of processing would not in itself generate a sense of time slowing down because there was a need for a standard against which to compare the experienced rate. Arstila argued that the standard was provided by memories of experiences under normal circumstances, where the number of thoughts per unit time, for example, was veridically fewer.

In fact there is no need for a standard for comparison: the rate at which events unfold is given by the time marker information in the perceptual timescape. Perceptual processing must be proceeding at its usual rate because it is tied to the time rate of information entering the senses. Perceptual information cannot pass through the perceived present faster than that: in that case the paradox would arise again and the future would be perceived before it happened. Timing of recent perceptual history is given by the time marker information in the perceptual timescape; timing of internal mental activity is given in the same way. The distortion must again be a distortion in perceptual memory: people do not perceive time moving more slowly, they perceive time as having moved more slowly. Thus, if internal mental activity speeds up, that will be automatically registered in the perceptual timescape and there will be more internal mental events across a given span of time markers than usual.

Fast thinking	Normal thinking	Time distance
Thought 1	Thought 1	t^{-9}
Thought 2		t^{-8}
Thought 3	Thought 2	t^{-7}
Thought 4		t^{-6}
Thought 5	Thought 3	t^{-5}
Thought 6		t^{-4}
Thought 7	Thought 4	t^{-3}
Thought 8		t^{-2}
Thought 9	Thought 5	t^{-1}
Thought 10		t^{0}

Figure 3. Schematic depiction of information in the perceptual timescape across a range of time markers with internal mental events proceeding at their usual rate (column headed "normal thinking") and an alternative in which internal mental events are proceeding twice as fast as normal (column headed "fast thinking"). Other features of the perceptual timescape are not shown for the sake of clarity in the essential information. Each column represents a single moment in time: an experienced history, not an actual one.

That is illustrated in Fig. 3, which is a minimal representation of a moment in time with the information structure of the perceptual timescape. To keep things simple, only time distance information is shown. Two alternative information structures are shown, one with internal mental events proceeding at their normal rate ("normal thinking") and one with internal mental events proceeding twice as fast as normal ("fast thinking"). It is easy to see in the figure that twice as many internal mental events occur across the time markers shown for fast thinking as for normal thinking. That is, internal mental events will be experienced as having happened twice as fast as normal. No comparison is required; the time marker information suffices to generate the impression of speeded mental events.

That does not mean that no comparison with other things occurs. Indeed, reports of temporally distorted experiences sometimes include explicit comparisons. Two of the patients quoted in the introduction here referred to movies running at fast speed as a way of describing their experiences. But they would not be able to make such comparisons if their perception was not speeded, and that is a phenomenon that does not depend on comparisons for its occurrence. The comparison is simply a way of conveying the quality of the experience to someone else. The same applies to the apparent slowing of time in emergencies. The experience of time slowing is a function of the compressed representation of recent events in the perceptual timescape. That compressed representation can be compared with normal events, but the occurrence of the experience is not dependent on that comparison.

6. Conclusion

This paper presents a scientific conjecture. It is a testable hypothesis, or set of hypotheses, that have the capacity to account for both the temporal calibration of the perceptual timescape and the strange experiences of speeded perception summarised in the review by Blom et al. (2021). It goes some way beyond what is currently known about the systems in question, but the aim is mainly to indicate that there is a matter of considerable importance there that has been neglected by perception researchers, and to put up a target for research to shoot at. The hypotheses may be wrong, but the issues they address are not trivial. There is a need for research to seek evidence for the perceptual timescape in the brain, though, as with identifying specific timing mechanisms, it would be difficult to obtain the kind of evidence that might confirm or disconfirm it. Identifying malfunctions in temporal calibration in patients who experience speeded perception might not be possible because the insults to the brain that were responsible for their condition might have multifarious effects, among which disruption to temporal calibration would be hard to distinguish. Finding a synfire ring in the brain is problematic enough: distinguishing a malfunction in one in a patient who might have many problems would be very challenging. But the search for identifiable timing and temporal calibration mechanisms is clearly important.

The functional importance of the perceptual timescape can perhaps best be appreciated by a thought-experiment in which everything about the brain is the same except that the perceptual timescape is not there. There would still be some forms of memory. Notably, there would be working memory, which is a post-perceptual store in which a limited amount of information abstracted from the products of perceptual processing can be held. Despite that, however, the loss of the perceptual timescape would mean the loss of almost all information about what is going on in the world. Perceptual processing would generate an informational representation of what is the case now, and that could plausibly include local motion information. If we imagine the example of watching a ball that has been thrown into the air, at any given moment we would have a percept of the ball at a single location, and possibly some information about its velocity at that moment. But that is all. For all practical purposes it would be equivalent to a short-exposure photograph. The critical difference is that a photograph, once taken, can continue to exist. A moment in perception does not continue to exist because it is immediately replaced by the next moment. So perception would comprise a series of disconnected individual moments with no history. There has been abundant research on the construction of a spatially coherent perceptual world, one in which there are objects with organised collections of features and scenes in which objects are located. But there has been little realisation that the temporal coherence of the perceptual world matters as much as spatial coherence does. The ball has to be represented not just at a moment in time but as having a history. That history gives us the perceptual impression of the ball as a persisting object moving through space; in the same way it gives us the perceptual impression of the furniture around us continuing to exist, of branches waving in a breeze, of a rapid sequence of notes in a piece of music, of the feel of a finger brushing along our arm; and everything else of that kind, on the sub-second time scale. That is why an informational representation that has temporal information and information about how sets of information at individual moments connect together is absolutely vital. The perceptual timescape is a hypothesis about the kind of information structure that would enable those sorts of experiences.

It has been argued here that fast feeling can be explained by a combination of two things. One is a representation of perceptual history on the sub-second scale in which time markers have the function of temporally locating and differentiating perceptual information; the effect of that is the perception of things as having happened, and that is as close to perceiving actual happening as the brain can get. The other is a calibration mechanism that generates the time marker information and maintains it in an attractor state that represents the passage of time with reasonable accuracy. Fast feeling occurs when some kind of perturbation knocks a component of the calibration mechanism out of its normal attractor state into a different and possible less stable attractor state that effectively changes the distribution of time distance markers across the perceptual information in the representation. That results in events being perceived as having occurred faster or slower than they actually did.

That paragraph described the essence of the proposal in as neutral terms as possible. Here it has been proposed that the first component, the representation of perceptual history, is the perceptual timescape (White, 2021, 2024), and the second component, the calibration mechanism, is the combination of a synfire ring mechanism that generates regular signals with high frequency and temporal precision, and something such as an integrate-and-fire mechanism that mediates between the signal rate of the synfire ring mechanism and the temporal resolution of the perceptual timescape. There is evidence that the sub-second scale perceptual store houses information about change over time, so that tracking of moving objects is possible (several studies showing this were cited in White, 2024), and that is at least consistent with the perceptual timescape proposal. There is also evidence for patterns of neural activity in brains consistent with what would be expected for synfire chains or neural sequences (reviewed in White, 2024 and see above), but only in non-human species, mainly birds. Clearly there is a need for further testing of the key elements of this proposal, but identifying particular timing mechanisms in the human brain, in particular, is very challenging and perhaps awaits further developments in research methods and technology.

Whether the particular proposals made here, the perceptual timescape and the synfire ring mechanism, are correct or not, something functionally equivalent to them must be the case. The basic truth about experiences of perception as speeded or slowed is that it cannot be an alteration of the rate at which information enters perceptual processing because that is determined by outside events. Such experiences must be of things as having happened too quickly or slowly, not as actually happening too quickly or slowly. That being the case, there has to be an informational register of recent history and the time distortions must reflect an inaccurate calibration of the perceptual information in that register. If it is not exactly what has been proposed here, it must be something functionally equivalent to that. It is to be hoped that the present proposal will motivate research to discover more about the kind of processing in the brain that makes these time distortions possible.

Footnote

This is known to happen in food webs, for example (Pimm, 1982).

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