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ATTENTION TO THE PASSAGE OF TIME

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> *Time travels in diverse paces with diverse persons. I'll tell you who time ambles withal, who time trots withal, who time gallops withal, and who he stands still withal.*
>
> (Shakespeare, *As You Like It*, III, ii)

1. Overview

The idea of an intimate connection between attention and time is a traditional one, long embraced by scientists and philosophers, and firmly enshrined in folk wisdom.[1] In explaining variations in our experience of duration, contemporary cognitive scientists commonly make appeal not just to attention, but specifically to the concept of *attention to the passage of time*.[2] Time, we are told, trots when we attend to its passage, and gallops when we are distracted from it. A wealth of data is explained in these terms. Yet the central metaphor of attending to the passage of time provokes uneasiness. As the psychologist Richard Block demands, 'What . . . does it mean to attend to time itself?' (1990, 22) This paper proposes an answer to that question.

I proceed as follows. In the next section (§2), I set-out the standard story concerning attention to time found in the empirical literature, and the evidence that supports it. In the following two sections I consider and reject two natural interpretations of attention to time. In §3, I consider interpreting attention to time in terms of attention to perceptible change. I argue that such an interpretation cannot be right, since attention to perceptible change has almost the opposite effect on perceived duration to that explained in terms of attention to time. In §4, I consider interpreting attention to time as a form of selective perceptual attention to stimulus duration, analogous to other forms of feature-based attention, e.g., to colour, orientation, or movement. I argue that this interpretation is also unsustainable, since it cannot explain the finding that combining a timing task with a perceptual or motor task only interferes with the performance of the timing task, whereas combining a timing task with a cognitive (e.g., mental arithmetic) task shows bidirectional interference (Brown 1997; Brown 2010).

Both rejected interpretations share the assumption that time should be thought of as analogous to other perceptible stimulus features (an idea enshrined in Michon's 'equivalence postulate'). Both interpretations thus assume that attention to time should be treated as analogous to other forms of perceptual attention. The failure of both interpretations casts doubt on that assumption. In §5, I suggest an alternative way of understanding attention to time as a form of *internal* attention (Chun et al. 2011). In turn, I suggest that internal attention should be identified with mental activity within our non-perceptual stream of consciousness: conscious thinking in the broadest sense of the term. I propose that attention to time, so understood, increases perceived duration because the quantity of such conscious mental activity provides for us a key measure of perceived duration. In §6, I show how we can account for the data from dual-task paradigms given this interpretation of attention to time. Finally, in §7, I consider in more detail the nature of the hypothesised relationship between conscious mental activity and our awareness of the passage of time.

2. Attention to Time: the Standard Story

It is commonly held amongst contemporary theorists of time perception that time perception in influenced by *attention to time* — attention which is competed for by non-temporal processing. Thus, Dutke describes the hypothesis 'that directing attention to the "course of time" increase[s] the subjective duration of temporal intervals, whereas distracting attention from time decrease[s] subjective duration' as the 'most successful hypothesis about the cognitive factors that influence duration judgments' (2005, 1404).[3] Many make an even stronger claim: time perception—here meaning specifically *duration* perception—*requires* attention to time.[4]

The evidence which underlies the appeal to attention in relation to duration perception comes principally from an abundance of paradigms which exhibit a dual-task interference effect, said to be 'the most robust, well-replicated finding in the time perception literature' (Brown 2010, 111).[5] In essence the effect is that, relative to a single-task (i.e. timing only) condition, duration judgments made under dual-task (i.e. timing plus non-timing task) conditions are *shorter* and/or *more variable and less accurate*. Additionally: when the difficulty of the concurrent (non-timing) task increases, the strength of the interference effect typically increases (e.g., Zakay, Nitzan, and Glicksohn 1983; Brown 1985; Brown 1997); when subjects are instructed to pay more or less attention to the timing task, they produce relatively longer or shorter duration estimates (e.g., Macar et al. 1994, discussed below); and, finally, when subjects receive training on either the timing or non-timing task, the interference effect reduces (e.g., Brown and Bennett 2002).

Here are two examples of the effect. Macar et al. (1994) presented subjects with visual and auditory stimuli of varying intensities and durations (between 250–3000msec across experiments) under five different attentional sharing instructions: duration only (control), maximum duration/minimum intensity, half/half, maximum intensity/minimum duration, and intensity only (control). The more attention subjects were instructed to pay to intensity, the more likely they were to classify the stimulus as having a 'short' as opposed to 'long' duration. The authors interpret this as a direct result of the decrease in attention to time when attention to intensity is prioritised. More generally, the authors conclude that 'the amount of attention allocated to time is a key factor of a temporal performance. The allocation of attention to time determines the accuracy of timing as well as the subjective length of the internal duration' (1994, 684).

In a rather different paradigm, Hicks et al. (1976) compared estimates of a 42s period during which subjects dealt cards according to one of the three rules: into a single pile (0-bit condition), by colour (1-bit condition), or by suit (2-bit condition). Subjects, who knew in advance they would be asked to estimate the time they had spent sorting the cards, estimated on average that they had been counting for 53s in the 0-bit condition, 43s in the 1-bit condition, and 31s in the 2-bit condition. In other words, the increase in task difficulty led to a dramatic reduction in subjects' sense of elapsed time (in the 2-bit condition 42s 'felt' like only 31s). Again Hicks et al. interpret the findings in terms of the idea that 'the prospective judgment of time requires attention to time' (ibid., 725). The harder the task is made, the less the subject can attend to time, and the shorter her sense of elapsed duration becomes.

As this last remark indicates, Hicks et al. do not seem merely to be expressing the view that duration perception is affected by attention to time, but rather the view that attention to time is *necessary* for duration to be perceived at all. Macar et al. suggest much the same, holding that 'it is not only possible but also necessary to pay attention to time-in-passing to perform a timing task correctly' (1994, 683). Comparable results and interpretations are found across a very wide range of paradigms and timescales.[6]

Attention to time is typically modelled within a widely adopted (if highly controversial) internal-clock model of time perception. This model posits an internal-clock or pacemaker whose function is to generate 'pulses'.[7] Perceived duration is then understood as a monotonic function of the number of pulses collected in an accumulator/counter during the course of a given period or event.[8] The number of stored pulses is obviously affected by two factors: the *initiation and termination* of pulse collection, and the pulse *rate*. In order to accommodate the dual-task data noted above, it is proposed that the number of accumulated time units is affected by *attention to time*. This effect can be modelled in a variety of ways. One popular model due to Zakay and Block (1996, §4) introduces an 'attentional gate' between the pacemaker and accumulator. According to Zakay and Block, '[a]s an organism allocates more attention to time, the gate opens wider or more frequently' (1996, 154), thereby allowing

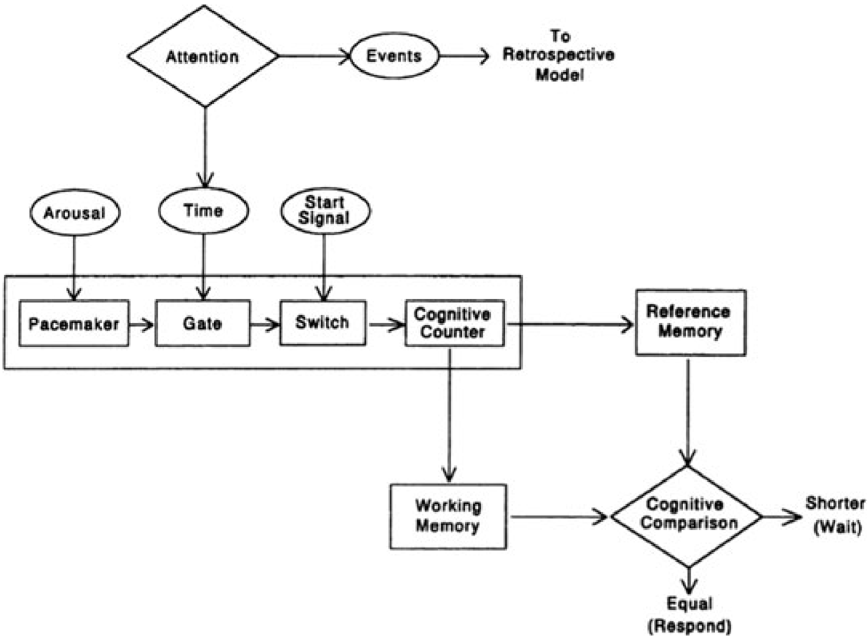

Figure 1. The attentional-gate model of prospective time perception. From Zakay and Block 1997, 14. Copyright © 1997 American Psychological Society. Reprinted by permission of SAGE Publications.

more pulses to reach the accumulator. They later suggest that attending to time is not merely facilitative of pulse transmission but 'necessary, for pulses to be transmitted to the cognitive counter' (ibid., 155).[9] This model can then be represented as in Figure 1 which shows the pacemaker and counter system embedded within a larger memory and decision system. Here, in effect, a gate controlled by attention to time has been grafted on to a more traditional pacemaker-counter system.

Much the same picture is sometimes expressed in terms of the idea that 'attention is needed to *activate* an internal timer that will accumulate units' such that 'pulses may be lost when attention is not focused on the elapsing time' (Macar et al. 2002, 244; my emphasis). But, however exactly one models the effect, the basic idea remains the same: increasing attention to time causes more pulses to be accumulated over a given period (Wittmann et al. 2010, 7). And on many such models the absence of attention simply leads to a failure to accumulate pulses at all: duration perception requires attention to time.[10]

Despite the consensus over the *involvement* of attention to time in duration perception, the *concept* of attention to time is liable to provoke unease. It is not uncommon for psychologists to recognize that further clarification is needed. For instance, Sawyer, Meyers, and Huser, although generally supportive of an attentional model, express concern that such models 'fall short of furnishing a clear explanation of the experimental results' and ask for greater clarification of 'the notion that subjects can devote attention to temporal processing' (1994, 656). Likewise, Dutke, again operating within an attentional framework, closes a paper by noting the need 'to further specify the cognitive processes addressed by the metaphor of *directing attention to time*' (2005, 1412; emphasis in original). This dissatisfaction goes back at least to Block (1979, 193; see also Block 1990, 21–2), who complains that previous explanations invoking attention to time are 'vacuous' and 'unacceptably vague', asking, 'What . . . does it mean to attend to time itself?'[11]

Block's first response to his own question is to take 'attention to time to mean attention to temporal information' (Zakay and Block 1996, 152). However, this simply begs the question as to what is meant by 'temporal information'. Both Block and Zakay offer a number of different suggestions in this relation, and I will return to these in the course of the discussion below. However, I want to start by considering two very natural suggestions as to how we should understand the concept of attention to time (and so of temporal information), and show why they are inadequate as they stand. In the next section, I consider understanding attention to time as attention to perceptible change. In the subsequent section, I consider whether attention to time can be thought of as a kind of feature-based attention to stimulus duration. Having shown that neither interpretation is sustainable, I build on some suggestive but initially puzzling remarks of Block and Zakay's to argue that attention to time should not be thought of as a form of perceptual attention at all. Instead, I propose that attention to time, at least in the relevant experimental contexts, is a form of *internal* attention. Internal attention, I claim, should be identified with non-perceptual conscious activity: conscious thinking in its broadest sense. What explains the involvement of internal attention so construed in duration perception is the fact that for us a crucial measure of perceived duration is the quantity of concurrent non-perceptual activity which occurs during the interval to be timed.

3. Attention to Time as Attention to Change

Philosophers and psychologists alike have traditionally felt uncomfortable at the idea that we might literally be said to perceive time or its passage. Kant, for example, repeatedly proclaims throughout the *Analytic of Principles* that 'time cannot be perceived by itself' (2003, B233; see also A33/B49–50, B219, B225, B257, and A183). And later philosophers and psychologists have echoed this sentiment. Thus, Woodrow declares that 'time is not a thing that, like an apple, may be perceived' (1951, 1235); Gibson takes as his title the widely endorsed slogan that 'events are perceivable but time is not' (1975, 295; cf. Fraisse 1984, 2); and Block reminds us that 'time itself is not a stimulus' (1990, 9).

This traditional piece of negative wisdom is usually combined with the positive claim that we are nonetheless aware of time in virtue of our perception of change. As Shoemaker puts it, tracing the view back to book IV of Aristotle's

Physics: 'we measure time by observing changes' (1969, 366). In the same spirit, talk of our perceiving the 'passage of time' is modestly rendered in terms of our awareness of change. In James' phrase: 'awareness of change is the condition on which our perception of time's flow depends' (1890, 620). Likewise, Le Poidevin: 'We . . . see time passing in front of us, in the movement of a second hand around a clock, or the falling of sand through an hourglass, or indeed any motion or change at all' (2007, 76). In what follows I assume that any satisfactory account of attention to time ought to accord with these insights.

Given this, it is extremely tempting to think that attention to time or its passage should be understood in terms of attention to perceptible change. Fraisse takes this view, proposing that 'direct time judgments [are] founded immediately on the changes we experience' (1963, 234) and that 'attention to the lapse of time affects duration estimation only by changing the number of perceived changes' (Kojima and Matsuda 2000, 145). More recent glosses of attention to time or temporal information also place stimulus change centre stage. Thus, Block (citing Fraisse) writes that 'changes serve as referents, or cues, to use in experiencing, remembering, and judging time' (1990, 9). And when Brown holds that [a]ttention to time involves a heightening consciousness of temporal cues', stimulus changes are his first example (2008, 114).[12]

Natural as this view is, attention to time cannot be identified with attention to perceived change. To see this first consider a recent paper on the effect of music on perceived duration (Droit-Volet et al. 2010). Using a temporal bisection task, during which 'participants are instructed to pay attention to time' (ibid., 227), Droit-Volet and colleagues establish that the duration of a melody is perceived to be shorter than a non-melodic stimulus of the same objective duration. This finding is interpreted in terms of the idea that music is able to 'divert attention away from the passage of time' (ibid., 226), in line with the attentional-gate model discussed above.

Imagine being a participant in this experiment who is instructed to pay attention to time. As is standard in such experiments, you are explicitly told not to count (ibid., 227), and all watches and clocks are removed. So what do you do? As proposed above, it is natural to interpret the instruction as an instruction to attend to perceivable change. If you are to attend to change, what should you attend to? Surely the most obvious candidate is the music itself. After all, 'the notion "musical change" is a tautology. Music *is* change' (Kouwenhoven 2001, 54). Similarly, as Brown puts it, 'Western music consists of an organized set of pitch changes, rhythmical patterns, phrase structures and accents, and temporal hierarchies' (2008, 116).[13] Yet if attending to music is the most natural way of attending to the passage of time, how can music 'divert attention *away* from the passage of time', as Droit-Volet and colleagues propose? Assuming that attention to time should be understood as a form of perceptual attention to change, the idea that attention to music somehow competes with attention to time is hard to make sense of. Attending to music seems a paradigmatic way of attending to time on the present understanding.[14]

Droit-Volet et al. conclude that their 'results show that time flies in the presence of music because it distracts our attention away from the processing of time, probably due to music's rich structure or the pleasure produced by listening to it' (2010, 231). These additional and very different ideas do little to ease our puzzlement. First, as we have just seen, it is hard to understand why music's rich structure should distract us from attending to time, insofar as that structure is a *temporal* structure of pitch changes, rhythmical patterns, phrase structures, etc. Second, we might think that the pleasure we get from listening to music should increase our desire to listen. It is only if we already have assumed that listening to music is opposed to attending to time, that our pleasure in listening might help account for why music distracts us from attending to time.

Puzzlement is far from confined to the musical case. Many other tasks which are held to distract attention from time clearly involve an increase in attention to perceptible change. For example, Brown (1997) focuses on the effects of the non-temporal task of 'pursuit rotor tracking', a task which involves a subject manually following a continuously moving visual target. Here attention to a target that is continuously *changing* its position shortens perceived time. Likewise, many studies have used flight (Bortolussi, Kantowitz, and Hart 1986) or driving simulators as their primary task. For example, Baldauf, Burgard, and Wittmann (2009) manipulate primary task difficulty by shifting from a 'straight road' driving simulation with no curves or obstacles to a 'city drive' simulation in which 'there were many events demanding caution and appropriate reactions by the driver' including a person in a parked car suddenly opening their door, a child with a ball jumping out from behind a parked car, the need briefly to wait for a traffic light to turn green, and a pedestrian crossing the road (ibid., 3). They also use an 'oncoming traffic' simulation in which the driver has to negotiate a winding road against a dense stream of oncoming cars passing at varying speeds. On the face of it these increases in primary task demand appear to involve an *increase* in 'temporal cues', viz. environmental changes. They contain more changes, and a greater number of successive events with a richer temporal structure. Thus again, assuming that attention to time is a form of perceptual attention to change, it is puzzling that longer productions in the demanding primary tasks should be explained by proposing 'that under higher workload conditions a subject is distracted more from attending to time' and so the 'production of a certain time interval then takes longer because hypothesized time counts (or pulses) that represent that duration take longer to accumulate' (ibid., 6). Higher workload conditions are conditions where more changes are present and demanding of attention, so it is obscure how such conditions distract attention away from time on the present hypothesis.

Just as in these cases change appears to have the opposite effect to that which we might expect, we similarly find a large number of cases in which the *absence* of change appears to *increase* attention to time. Consider a set of experiments designed to test the adage that a watched pot never boils (Block, George, and Reed 1980; Cahoon and Edmonds 1980). In Block, George, and

Reed's experiment, observers were instructed to attend to a beaker filled with liquid, as it stood on an electric burner for 270 seconds. During the last 30 seconds in some conditions, the pot began to boil, or the subject was asked a series of task-unrelated questions. Roughly speaking, under *prospective* conditions (see fn.4), boiling and questioning led to a shortening of experienced duration, a finding which the authors interpret in terms of the resultant distraction of attention from time. In contrast, under *retrospective* conditions, 'the presence of changes in task-related content (boiling), task-unrelated content (questioning) or both causes a lengthening of remembered duration compared to a condition in which there are no changes in content (no boiling and no questioning)' (1980, 91–2).

In making sense of this retrospective data here, the authors take it to be intuitive that the boiling and questioning conditions involve *more change* than the no-boiling and no-questioning conditions. After all, 'in the no-boiling condition, the liquid did not change in appearance' (ibid., 85). Similarly, what distinguishes the no-questioning condition is simply that there is no sudden change for the subject from simply watching the pot, to answering the experimentalist's questions. This is said to support a hypothesis on which *retrospective* estimates of time are based on the number of remembered changes during the period. However, once again, if attention to time involves attention to change, how can it make sense to suggest that salient changes (changes which are obviously noticed since remembered), *distract* us from attending to time? Yet this is just what is proposed to explain the effect of questioning under prospective conditions: '[the task] interruption causes attention to shift from the passage of time to the interrupting content, and experienced duration is shortened' (ibid., 91). We must surely wonder what attending to time could be such that a subject can be distracted from it by change, despite all there seemingly being to attend to in the undistracted case is a beaker of water failing to change in appearance. How can watching a pot be attending to time?[15]

It is clear then that attention to time cannot be understood simply in terms of attention to perceptible change. I now turn to another suggestion, namely that attention to time is a form of feature-based perceptual attention to stimulus duration.

4. Attention to Time as Attention to Stimulus Duration

Recall now the findings of Macar et al. (1994) above demonstrating that when subjects preferentially attend to the intensity of visual (or auditory) stimuli as opposed to their durations, they perceive their durations as shorter. In these experiments it is not very natural to think of allocating attention to time in terms of allocating attention to perceptible change. The visual stimuli do not themselves change. Rather, it is more natural to think that attending to time involves attending to a stimulus' duration *as such*. As Macar et al. suggest,

> [T]he terms *attention to time* or *temporal information* . . . are meant to stress the similarity between the mechanisms that are involved in temporal and in any other type of processing. They underline the fact that duration is one of the attributes of any stimulus, and, as such, is information and can plausibly be given either automatic or controlled attention. (1994, 674)[16]

In making sense of this idea, it is natural to appeal to what we already know about other forms of feature-based attention. We can deploy visual attention not just to locations and objects but also to particular feature-dimensions (at least: colour, orientation and motion), and specific features within these dimensions (e.g., blue, horizontal orientation, upwards motion). Such attention can operate throughout the visual field, and in principle independently of where spatial attention is deployed (for a review see Carrasco 2011, §6). The proposal above simply extends this model to duration. Coull is explicit: 'selectively attending to and estimating the passage of time itself' (2004, 224) involves 'selectively attending to temporal stimulus features . . . . if more attention is allocated to time rather than another stimulus feature (such as colour), estimation of duration is more accurate. This represents a process of temporal selective attention.' (ibid., 217) Conversely, 'The less we attend to the temporal properties of a stimulus, the more likely we are to misperceive its duration' (ibid., 222; see also Coull et al. 2004).[17]

It is clear from the data that subjects are able to adopt an 'attentional set' for time (cf. Correa and Nobre 2008). However, the more specific proposal that this set be thought of as a form of feature-based perceptual attention to stimulus duration is unsustainable. The problem emerges when we consider the full pattern of data concerning the interference effect, in particular data concerning the presence or absence of bidirectional interference depending on whether the competing, non-timing task is a perceptual/motor task, or an executive task. What emerges from such comparative studies (Brown 1997; Brown and Frieh 2000; Brown 2010) is that whilst manual tracking and visual search tasks interfere with a concurrent timing task, here the timing task has no (negative) effect on the tracking or search task.[18] In contrast, there is *bidirectional* interference with respect to executive tasks: these tasks interfere with timing, but timing also interferes with performance in these tasks.

This is hard to reconcile with the current proposal about attention to time (cf. Brown 1997, 1135). If attention to time is simply a form of perceptual attention to a stimulus attribute (viz. duration), we should expect it to compete with other forms of perceptual attention for a limited pool of shared resources. This competition is, after all, what is said to explain the effect of attention being distracted from time. But, if this were right, the pattern of interference in perceptual (e.g., visual search or intensity discrimination) and motor tasks ought to be bidirectional (cf. Brown 1997, 1120). Yet perceptual and motor tasks do not seem to be interfered with by timing. Consequently, we have reason to doubt that attention to time draws from the same attentional pool(s) as do motor and perceptual tasks. On the other hand, we do find bidirectional interference in relation to executive tasks (e.g., mental arithmetic, verbal reasoning, or memory updating). This supports Brown's view that 'time perception is closely related to the resources that supports these executive functions' (2010, 116). This contention is central to the positive proposal I develop below. For now I simply note that, if timing is an executive task, it is disanalogous to familiar feature-based perceptual attention.

In the time perception literature, it is common to assume that time be treated as analogous to other perceptible features, an attitude captured in Michon's 'equivalence postulate', the 'basic tenet of the psychophysics of time' that 'time behaves like any other psychological dimension such as brightness, loudness, itch, or sweetness' (Michon 1986, 62; see also Michon 1972; Michon 1985; and Michon and Jackson 1984), or as Brown glosses it, that 'time has the same status as any other stimulus attribute, such as size, loudness, or colour' (2008, 112). The pattern of bidirectional interference set-out above, together with the conclusion of our earlier discussion concerning attention and perceptible change, suggests that the equivalence postulate should be rejected.

Such a view is already implicit in the remarks of various authors.[19] For instance, consider this initially baffling passage from Zakay and Block, in which they describe the basic idea behind their attentional gate model of time perception described above.

> On each occasion on which an organism attends to time, as opposed to external stimulus events, the attentional gate opens more frequently, thereby allowing more pulses to be transferred from the pacemaker to the cognitive counter.... The attentional-gate model...includes and elaborates the notion that a subject may divide attentional resources between attending to external events and attending to time. (1996, 155)

Zakay and Block here contrast attention to time with attention to external stimulus events (cf. Figure 1 where attention to 'time' is contrasted with attention to 'events'). Yet, on the face of it, the durations to which attention is supposed to facilitate awareness simply are the durations of the external stimulus events. And as Le Poidevin puts it, in a different context, 'I cannot be aware *just* of the duration of an event, independently of my awareness of the event itself' (2007, 99). So how can external events distract from attending to the passage of time? The best way to make sense of the passage, I suggest, is to treat Zakay and Block as rejecting equivalence. Attending to time contrasts attending to external stimulus events because, at least in the relevant contexts, it is not a form of perceptual attention at all.[20]

Before developing my positive proposal concerning attention to time, let me summarise the discussion thus far. First, I showed that despite the presumptive fact that 'awareness of change is the condition on which our perception of time's flow depends' (James 1890, 620), it is not possible to understand attention to time simply as a form of attention to perceived change. Second, I claimed that, given the data concerning bidirectional interference, it is not possible to conceive of attention to time as a form of feature-based attention to stimulus duration. However, as Kant famously emphasised, time is the form of *inner* as well as outer sense. Pursuing this idea, I now suggest that we should conceive of attention to time as a form of *internal* attention. In particular, I claim that attention to time can be identified with conscious activity within non-perceptual consciousness: thought for short. The reason time perception involves attention so understood is because such non-perceptual activity provides for us an important measure of perceived duration. In §6, I show why a connection between activity in the stream of conscious thought and our sense of time's passage can explain the dual-task interference data outlined in §2. In §7, I conclude by exploring the relationship between conscious mental activity and our awareness of the passage of time in more detail.

5. Time Perception, Internal Attention, and the Stream of Conscious Thought

James tells us: 'Every one knows what attention is . . . . It is the possession by the mind, in clear and vivid form, of one out of what seems several possible objects or trains of thought' (1890, 403–4). Thus, the very first thing James has to say about our ordinary understanding of attention is that it can be a matter of the mind taking possession, not only of objects, but of *trains of thought*.[21] Recently, Chun et al. (2011) have emphasised James' distinction between what they call 'external' (or 'perceptual') and 'internal' (or 'central', or 'reflective') attention as the starting point for a taxonomy of attention.[22] Following James, Chun et al. distinguish between the two forms of attention in terms of their objects.

> Sitting at your desk, you can focus on the information on the computer screen, a conversation in the hallway, or the taste of the stale coffee brew in your cup. These examples of external attention can be distinguished from how you could instead be focusing your attention on your thoughts, contemplating a talk you just heard, trying to remember the author of a paper you want to find and cite, or trying to decide where to go to lunch, all while staring at your computer screen with conversations going on in the hallway. (2011, 76–7)

Straightaway, note two things about this non-technical characterisation of internal attention. First, although Chun et al. talk about focusing attention on *thoughts*, the examples they give make clear that they really mean focusing attention on the *subject matter* of those thoughts: the recent talk, the forgotten author, a possible lunch venue. In other words, internal attention is nothing different in these examples from thought itself: evaluating, trying to bring to mind, deliberating and so forth. This relates to an important *structural* contrast between internal and external attention which Martin points to.

> In general, whatever we are prepared to call an object of thought—be it the things thought about, what one thinks about them, or the proposition one thinks in thinking these things—we can also take to be an object of attention. Conscious, active thought is simply a mode of attending to the subject matter of such thoughts.... Arguably, it is part of the manifest image of the mind that we are aware of objects of sense experience in a different way from being aware of the objects of thought, and that this is reflected in the ways attention can relate to an object of sense as opposed to thought.... it is tempting to think of experience in terms of a whole array of items stretching beyond what I have focused my attention on at a time... There seems to be no corresponding array of items to shift one's attention over in thought: if we think of thoughts as determinations of attention, then there can be no way of thinking of something without thereby to some extent to be attending to it. (1997, 77–8)

This suggests that we might contrast internal and external attention not in terms of their objects—after all, can you not think about or imagine the very same object which just now you were visually attending to?—but rather in a *structural* way. Perceptual attention seems to range over an array of objects of which we are already aware. Internal attention does not range over contents, some of which were already objects of thought; internal attention just is that determination of attention which is conscious thought. The stream of perceptual consciousness is divided by attention; the stream of thought simply is a stream of attention. Of course, Martin's particular structural contrast will be rejected by someone convinced that there is no perceptual awareness outside attention. But such a theorist can still contrast internal and external attention insofar as they take there to be *some* structural difference between non-perceptual and perceptual modes of consciousness. And that is surely plausible.

The second thing to note about Chun et al.'s initial characterisation of internal attention is that their examples—assessing a talk, trying to recall an author, figuring out where to go to lunch—do little justice to the great variety within our streams of thought. Compare a recent discussion from Baars.

> The stream of spontaneous thought is remarkably rich and self-relevant, reflecting one's greatest personal concerns, interpersonal feelings, unfulfilled goals and unresolved challenges, worries and hopes, inner debates, self-monitoring, feelings of knowing, visual imagery, imaginary social interactions, recurrent beliefs, coping reactions, intrusive memories, daydreams and fantasies, future plans, and more—all of which are known to guide the stream of thought. Spontaneous ideation goes on during all of one's waking hours, according to randomly timed thought monitoring studies. (2010, 208)

Baars warns psychologists of the dangers of neglecting this aspect of our psychological lives. The stream of spontaneous thought, he suggests, may play a vital role in our cognitive economies, even if we are not always aware of its relevance, or even meta-cognitively aware of its contents.[23] Of course, given this concern, his quoted characterisation tends to neglect the ways in which spontaneous thought is often of no great concern at all, a barely smouldering hubbub of half-formed ideas, images and vague feelings, filling the passing time to no obvious end. Nonetheless, whether the contents of the stream of thought are of great concern or not, in my view Baars is absolutely right to emphasise its importance. As I now suggest, part of that importance lies in its connection to our perception of time.[24]

My suggestion is that our sense of how long a time has elapsed between one perceptual experience, or witnessed environmental event, and another, is importantly a matter of how much mental activity has occurred in the stream of non-perceptual consciousness between the two events. These events could be the onset and offset of a visual stimulus, the instruction to start a card sorting task and the instruction to stop, or simply the beginning of a tedious wait and its eventual end. In each case, an important aspect of one's sense of the lapse of time between the two events is the amount of activity that occurs within the stream of non-perceptual consciousness between them. We can think of the amount of activity in terms of the number of changes in the stream of thought, where thought is intended to cover all aspects of non-perceptual consciousness, including mental imagery and episodic memory.

This suggestion retains the basic insight that 'awareness of change is the condition on which our perception of time's flow depends' (James 1890, 620). It simply recognizes that our consciousness is replete with *internal* as well as *external* change. The suggestion also makes sense of the idea of there being an 'attentional set' for time. In particular, it makes sense of the basic idea that the more we attend to time, the slower time seems to run. Duration perception is influenced by how much we attend to time in this way because to attend to time is to generate conscious mental activity. Given that how much conscious mental activity occurs concurrently with a perceived event provides a key measure of the duration of that event, attending to time thus increases perceived duration. I explore this suggestion in more detail in §7. First, however, I explain how this basic idea that our sense of time's passage is significantly a matter of the amount of activity in the stream of conscious thought can help explain the dual-task interference data left unaccounted for above.

6. The Interference Effect Explained

Any understanding of attention to time must make sense (a) of the basic interference effect and (b) of the pattern of bidirectional interference discussed above. This section shows how the hypothesis that attention to time is internal attention or conscious thinking does so. On the face of it, dual-task effects where the concurrent non-timing task is an executive task are the hardest to account for on this proposal. Consequently, I take such cases first, before turning to the case of perceptual and motor-task interference.

6.1. Interference in Executive Tasks

Dual task situations in which the non-timing task is an executive (e.g., mental arithmetic) task, lead to an under-estimation of duration. On the current proposal, under-estimations of duration arise when there is less non-perceptual conscious mental activity ('thinking') per unit time. This might seem counter-intuitive because we might initially think that demanding mental arithmetic tasks would involve more thinking per unit time than, say, a simple number reading task. There is a sense in which this is right. Difficult mental arithmetic tasks are demanding of *cognitive processing*. However, this is fundamentally different from their demanding a greater degree of *conscious mental activity*. Let me illustrate the distinction and its role in relation to the interference effect by discussing a particular experiment.

Burnside (1971) contrasted reproductions of time for intervals where the subject had to *read* numbers on a series of cards, *add* numbers, *multiply* them, or *obey* an instruction to perform a more complex operation (add and multiply).[25] What Burnside found is that subjects produce increasingly shorter intervals, moving through these increasingly difficult conditions. To explain this he supposes that whilst subjects are 'processing at full capacity in each condition', they are 'performing different types of processing' (1971, 406). In particular, he suggests that 'estimates of duration . . . decrease as [the] amount of necessary information processing [to complete each individual problem, i.e. processing per card] increase[s]' (ibid.). Burnside thinks of this in terms of what is stored in memory relating to the interval. He suggests that the steps to each solution are discarded from memory, and only the solutions retained. Thus, duration is measured by the number of stored solutions (ibid., 404). However, we can arguably better understand the effect in terms of conscious versus unconscious processing. This is a more fundamental explanation than Burnside's insofar as only conscious processing (or the conscious products of processing) are eligible for storage in memory.

The processing by which we solve basic mental arithmetic problems is largely unconscious. As Sloman puts it, 'conclusions simply appear at some level of awareness, as if the mind goes off, does some work, and then comes back with a result' (1996, 3). Or as Abbott puts it more dramatically, 'In mental arithmetic . . . the processing is as hidden and mysterious as it is using a pocket calculator. Only the result flashes up on the little liquid crystal display screens of the mind' (1999, 74). Of course, more complicated problems involve the conscious structuring of the arithmetical procedure. But if we focus on each step of the process, the more difficult the individual step, the more processing will be required to reach a given result. If we think of the output of the process as a conscious product – a new element in the stream of thought – then the more difficult a step, the more processing it will demand, and so the longer it will take to produce a product at the level of consciousness (resources being limited). In general, then, the more difficult the task, the more unconscious processing will be required, and so the 'thinner' the stream of *conscious* thought will become. The harder the task, the less conscious activity.[26]

Burnside suggests that his memory-storage view helps 'clarify the familiar paradox that time seems to pass either very quickly or very slowly when one is exceptionally busy. Time may seem to pass quickly when a lot of processing is done to obtain a few solutions, but it may seem to pass slowly while one is performing a tedious task in which all the substeps are remembered' (ibid., 406). On the view suggested here, the paradox is resolved by noting that harder tasks demand a lot of unconscious processing and so yield fewer changes *within the stream of consciousness*; whereas a tedious task allows more to happen *within awareness*. This fits not just mental arithmetic data but other executive tasks used in dual task paradigms. Recall, for example, Hicks et al.'s card counting task described above. Here subjects simply counting cards into a single pile for 42s managed on average to count out 75 cards. They estimated the period as being 53s long on average. As response uncertainty increased because subjects had to sort the cards by colour or suit, the average number of cards dealt out decreased (to 46 and 35 cards respectively), and estimates of time's passage decreased also (roughly linearly, to 43s and 31s respectively). Again, we might suppose that increased processing associated with categorising and correctly sorting each card was largely unconscious, with only the decision ('red . . . right pile', 'spade . . . bottom left stack') being conscious.[27] As a result, the more demanding sorting task led to fewer conscious products (less conscious thought) per unit time.

Further data, including crucially the bidirectional data, associated with the interference effect is easily explained too. The instruction to pay (more) attention to timing, will incline a subject to pay (increasingly) less attention to the mental arithmetic task, and to engage in other forms of thinking in order to generate more change within the stream of thought. This will not only lead to increased estimates of time (as more occurs within the stream of thought) but lead to a reduced performance on the concurrent arithmetic task (as processing resources are drawn away from that task). Conversely, focused solely on a mental arithmetic task, we will often try to hold spontaneous thought in abeyance, thereby reducing our sense of the passage of time.

6.2. Interference in Non-Executive Tasks

We can now turn to the interference of perceptual and motor tasks on timing. Since these tasks do not obviously rely on executive resources, the current proposal raises a question as to how to explain their impact on timing. Brown offers an answer here: it is the *co-ordination* required for multi-tasking of *any* kind which creates executive resource demands (2010, 117; also Brown 1997). As Lavie puts it, 'Cognitive control functions are loaded when people have to switch back and forth between different tasks' (2010, 147). Plausibly, it is these demands of multi-tasking that interfere with timing.[28] There is no interference of timing on the perceptual or motor tasks because these tasks do not themselves draw on executive resources, and so are unaffected by the executive resource demands of multi-tasking. They will only be affected when the situation involves a concurrent task drawing on shared resources.

A similar hypothesis explains what is occurring in the other cases mentioned above. Listening to music and driving can be thought of as tasks which distract attention away from time (that is, reduce conscious thinking) in much the way that the more sterilised visual and motor tasks do. When either is combined with a timing task this leads to the same multi-tasking effect. As a result there is a shortening of perceived duration caused by a reduction in concurrent mental activity. In the watched pot experiment reported, the opposite occurs. The uninterrupted 'watching' condition leaves thought wholly undistracted by either the demands of multi-tasking, or executive processing. In contrast, the boiling and questioning conditions effectively create dual-task conditions, respectively of a perceptual or an executive kind.

Whether non-executive task interference effects are entirely due to multi-tasking, or whether in fact perceptual and motor tasks do at a certain level of difficulty draw on executive resources—and so introduce the potential for bidirectional effects—is unclear. If so, part of the effect of music, for instance, might be understood as reducing the number of changes in the stream of conscious thought independently of multi-tasking demands. Clearly, the explanations offered here are highly speculative. My aim is only to recommend a certain understanding of attention to time for further investigation in the light of a more fully worked-out theory of the resource structure of cognition.

Since the dual-task data here accounted for are the crucial data lying behind the appeal to attention to time, we have successfully answered Block's challenge to say what attention to time is. Attention to time is internal attention, which is to say non-perceptual conscious activity broadly classifiable as thinking. In the next and final section I explore the general hypothesis which underlies this claim, namely that a key measure of perceived duration is how much concurrent mental activity occurs within the stream of thought.

7. Mental Activity as Our Measure of Perceived Duration

I have thus far stated the general hypothesis that non-perceptual conscious activity is an 'important' or 'key' measure of time's passage with deliberate imprecision. How important a measure? Is our sense of perceived duration always a matter of how much mental activity has occurred during the relevant period or event? Or is such activity simply one amongst many potential measures of elapsed time? This question is closely related to the question whether attention to time is necessary for duration perception, or simply an important influence on it (see the ambivalence on this score within empirical discussion, noted in §2). Of course, both questions are largely empirical matters which cannot be settled conclusively by philosophical/conceptual analysis. Nonetheless, I want to end this paper by raising a number of considerations which might seem to tell against the idea that conscious mental activity is our sole measure of perceived duration, and ask how powerful they really are. I begin by discussing two broadly conceptual objections to the claim (§7.1). I then consider whether conscious thought can plausibly provide a measure of duration even at sub-second timescales (§7.2). Finally, I consider whether the hypothesis that conscious thinking is our measure of duration can be extended to account for effects usually considered to be a result of arousal (§7.3).

7.1. Conceptual Objections

The claim that mental activity is our measure of perceived duration might seem to entail that our thinking itself could never seem to run faster or slower, it being our sole measure of duration. Yet, as Reid objects to Locke in discussing his theory of duration perception: 'every man capable of reflection will be sensible, that at one time his thoughts come slowly and heavily and at another time have a much quicker and livelier motion' (1827, III, v, 171).[29] It is important to appreciate that the hypothesis under consideration does *not* claim that mental activity is our sole measure of duration, but only our measure of *perceived* duration. The idea is that environmental events are perceived as having durations relative to concurrent mental activity. But we can further add that the pace of thought can be measured by reference to the amount of concurrent apparent perceptual change in our environment.[30] As a result we can make sense of thoughts coming swiftly or slowly *relative to the pace of environmental change*; just as I am suggesting we think of environmental change as seeming to occur fast or slow *relative to the pace of our conscious mental activit*y. It is true that a consequence of this picture is that there will be no difference from the inside between a situation in which one's speed of thought is decelerated and one in which change in one's environment is accelerated. In either case, the world will seem fast *relative to your mental speed*, and your mental speed slow *relative to the pace of worldly events*. But there is no reason to think that this consequence is unacceptable.[31]

A related objection is that it is perfectly possible to imagine awareness of the passage of time in the complete absence of perceptual experience, i.e. in a hypothetical total sensory deprivation tank. On the above account one might question how this could be possible, since in such a tank we will lack any measure of the pace of thought, viz. apparent perceptual change. This objection relies on a highly controversial empirical claim: not just that it is possible to lack all perceptual awareness but that it is possible to lack all apparent perceptual awareness (including hallucinatory awareness) and yet continue to think consciously. There is, of course, no reason to think that actual sensory deprivation tanks achieve this, and it does not strike me as unreasonable simply to doubt the possibility supposed here. A more concessive reply is available, however. This is to suggest that the possibility of being aware of the passage of time without perceptual awareness only arises because we can *remember* the kinds of perceptual changes that normally occur concurrent with our thinking. In full sensory deprivation, we can retain our sense of passing time only insofar as we retain a sense that our current thinking is of the kind that is usually matched by a certain amount of apparent change in our environment. What will not be possible in this situation, however, will be to have any sense of one's stream of thought *as a whole* being slowed down or sped up. Again I see no reason to think this consequence unacceptable.[32]

7.2. Clunkiness

Another natural objection to the suggestion that mental activity provides our sole measure of perceived duration is that thought is insufficiently fine grained, too 'clunky', to provide our measure of perceived duration at short timescales. Even if this is so and thought fails to provides our standard measure of sub-second durations, the story above may still be right concerning supra-second timescales. This connects to a large and ongoing empirical dispute as to whether timing operates differently at millisecond and second timescales, a leading hypothesis here being that supra-second timing relies on cognitive, attentional mechanisms, whereas sub-second timing is 'sensory' and independent of supra-second mechanisms.[33] Note that since the concept of attention to time which is the focus of this paper is typically invoked in the context of supra-second timing, the objection leaves untouched the interpretation of that concept above.

A distinct but related objection is that taking conscious thinking to be our measure of duration is simply a version of the view that duration perception involves counting. Yet, the objection continues, counting is inadequate as an account of perceived duration in general, and especially at short timescales. How powerful are these concerns?

Certainly, an obvious way in which duration perception might require a form of internal attention would be if duration perception required explicit chronometric counting.[34] Explicit counting can undoubtedly make a dramatic difference to the accuracy of our estimates of elapsed time, at least at intervals greater than about 1.2s (Grondin, Meilleur-Wells and Lachance 1999).[35] However, it seems implausible to claim that duration perception requires explicit counting. This is in part because experimentalists take steps to prevent subjects from counting, for example by demanding concurrent verbalization of temporally irregular random numbers (e.g., Nichelli, Alway, and Grafman 1996; Wearden, Rogers, and Thomas 1997; see also the discussion in Wearden, Denovan, et al. 1997, esp. Experiment 3), and yet this does not appear to prevent subjects from tracking the passage of time (even if their accuracy is diminished).[36] However, there is no reason to think that such experimental interventions eliminate the spontaneous stream of thought—indeed, arguably concurrent verbalization involves a form of thinking out loud. Thus, subjects prevented from explicit chronometric counting may nonetheless sustain the spontaneous mental activity characteristic of the stream of thought. As a result, it remains open to suggest that our measure of time's passage is change within the stream of thought.

Nonetheless, a common argument against treating all interval timing as involving counting is naturally redeployed against this more general proposal. The argument is that timing can occur at sub-second timescales, and that such sub-second timing is incompatible with the 'clunkiness' of counting or thought in general. Coull responds to prima facie neurological evidence of language areas being involved in timing tasks in just this way.

> [F]rontal operculum (ventral premotor cortex) is recruited . . . in all . . . aspects of temporal attention and timing behaviour. Frontal operculum, at least in the left hemisphere, is also intimately linked to language function. However, activation of frontal operculum during timing tasks is unlikely to simply represent a linguistic strategy, such as sub-vocal counting, since the time-frame involved in our tasks is only around 1500 ms or less. (2004, 224)

Likewise, Wearden, Denovan, et al. write that they use 'short-duration stimuli (usually tones) less than 1.0 s long . . . to prevent chronometric counting' (1997, 502).

As mentioned, explicit counting only seems to *improve* performance at timescales above 1.2s (Grondin, Meilleur-Wells and Lachance 1999). But this finding does not show that counting never occurs at timescales below 1.2s. Moreover, even if over such timescales subjects are not motivated to count since they (rightly) see no benefit in doing so, the absence of explicit, sub-vocal counting must be distinguished from the absence of activity within the stream of thought. If all timing involves thought, then the fact that timing benefits from a chronometric counting strategy at 1.2s may only show that counting is a way of structuring thought in the service of more accurate timing for durations of 1.2s and above.

Counting aside, there is in fact positive reason to think that thought can provide a measure of duration down to the kinds of sub-second timescales over which duration perception occurs. As Papafragou notes, 'Humans can comfortably produce speech at the rate of four words per second, and comprehension follows the speech of production' (2009, 519). The rate of syllable and phoneme production is correspondingly higher: around six syllables and up to sixteen phonemes a second in English. Assuming these timescales are mirrored by inner speech, and making the (obviously extreme) over-simplification that the stream of thought is a stream of inner speech (i.e., inner speech provides our sole vehicle of thought), then we can think of perceived duration as measured in units of words (viz., ~250msec units), syllables (viz., ~167msec units) or phonemes (viz., ~62msec units). Thought then can in fact plausibly provide a measure of duration at the timescales over which we make perceptual duration judgments.[37] In consequence, the objection that thought is simply too coarse-grained or 'clunky' to provide our measure of perceived duration is much weaker than it might first appear.

7.3. Other Factors Affecting Duration Perception

Many other factors influence our judgments of elapsed time. The extent to which these too can be understood in terms of an increase or decrease in the amount of conscious mental activity engaged in during the period to be timed tests the *extent* to which mental activity provides our measure of the passage of time: whether at the extreme it is our sole measure of perceived duration, or whether it is simply one amongst many factors.

In §2, we encountered the idea that timing should be modelled in terms of an internal-clock. Such a view remains popular amongst theorists, despite a number of concerns about the hypothesis, not least the fact that the clock and its pulses remain elusive.[38] What attracts people to the model in the first place is the wealth of evidence that perceived duration is increased by factors associated with arousal, e.g., rises in body temperature, dopamine agonists, emotional (and especially fear-related) stimuli, and repetitive bursts of stimulation such as click or flicker trains. These effects are widely interpreted as due to an arousal-driven increase in the pulse rate of the internal clock, leading to more pulses being produced per unit time, and thus a greater number of accumulated pulses during the relevant interval, with a consequent increase in apparent duration. Again see Figure 1.[39]

Can the idea that mental activity provides our measure of perceived duration explain such data? It will be able to do so to the extent that interventions which lead to increased duration judgments lead to an increase in the amount of conscious activity within the stream of thought. A major barrier to testing this is the lack of a clear operational measure of such activity. But there is at least some suggestive evidence that various arousal effects do correlate with increased mental activity. I confine myself to three brief points here concerning what is an extremely complicated and developing literature.[40]

Firstly, there is a wealth of anecdotal evidence which connects reports of time seeming to slow down in extreme situations with an increase in conscious mental activity during the relevant events. For instance, in their investigation of the subjective effects of life threatening danger, Noyes and Kletti (1977) report 'altered passage of time' (with 'few exceptions' a slowing down) in 78% of subjects who believed they were about to die, and an 'increased speed of thoughts' in 68% of subjects, as well as 'unusually vivid thoughts' in 65% of these subjects. Further, in their collected anecdotal reports, a direct connection between the slowing of time and speed of thought is repeatedly drawn. One individual (a car-crash victim) recalls: 'My mind speeded up. Time seemed drawn out.' (ibid.: 376); another that as 'the time in which everything happening seemed to slow down, my thoughts speeded up' (ibid.: 378); and yet another that 'my thinking processes increased at an incredible [sic.] rapid rate so that my movements, in relation to them, seemed extremely slow' (ibid., 387).[41]

Secondly, the pharmacological interventions known to affect duration perception typically also affect mental function in broadly the way predicted by the mental activity hypothesis. Thus, dopamine antagonists (e.g., anti-psychotics such as haloperidol) lead to underestimates of perceived duration (Rammsayer 1989; Rammsayer 1999), as would be predicted given that they have a 'robust "tranquilizing" action', leading to a reduction in alertness and 'a blunting of cognition' (Nasrallah and Tandon 2009, 538–9). Conversely, dopamine agonists (e.g., traditional psychostimulants such as methamphetamine) lead to an overestimation of intervals as might be predicted given that they increase alertness and 'enhance waking cognitive functions' by increasing cerebral blood flow (Ballas, Evans, and Dinges 2009, 846).[42]

Finally, it is well-known that stimuli preceded or accompanied by a train of repetitive stimulation (periodic clicks or flashes) are perceived as if their duration is increased compared to a control (Treisman et al. 1990; Penton-Voak et al. 1996; Wearden, Philpott, and Win 1999; and Droit-Volet and Wearden 2002). This effect is standardly understood in terms of an arousal-based increase in internal clock rate (see Wearden 2003 as well as the papers just cited). However, recent work by Jones, Allely and Wearden (2011) has established a connection between click trains and speed of information processing across a range of tasks, including a mental arithmetic task where responses were substantially speeded by clicks (yet unaffected by white noise which also has no effect on duration judgments). Of course, the established correlation is just that. But again the prospect of unifying the data by thinking of perceived duration as measured by concurrent mental activity remains tantalisingly open.

To the extent that mental activity is at the heart of these kinds of arousal effects, we can significantly simplify the attentional gate model in Figure 1 above, effectively identifying the arousal, pacemaker, and attentional gate system with conscious thought. Indeed, if attention to time just is mental activity, and mental activity is our internal clock, then there is no need to build attention to time into the model at all. To attend to time just is to generate pacemaker activity, viz. thought. Of course, this does not mean that we do not need to locate neural timing mechanisms at lower levels (either of explanation, or arguably timescale). Nonetheless, this unification provides a way of making sense of cryptic remarks made by Zakay when he suggests that 'attention to time is the energy that activates the counter' (1990, 61) and that "temporal information" is not external but rather an internal input to the time processor'. Understandably these remarks have met with some scepticism (e.g., Sawyer, Meyers, and Huser 1994, 656) but they can perhaps be understood as gesturing towards the way in which conscious thought is our basic measure of perceived duration. For, if what I have argued is right, attention to time is a matter of conscious thinking, and the quantity of such thinking provides for us a key measure of the passing of time.[43]

Notes

1. For instance: ‘the time which we feel is probably due to the work of attention’ (Mach, quoted in James 1890, 635); ‘in periods of boredom or expectation we pay more attention to the passage of time than usual . . . in periods in which we are deeply interested in what we are experiencing, we have little attention to spare for the lapse of time’ (McTaggart 1927, 277, §618); Stout: ‘in general, temporal perception is bound up with the process of attention . . . What measures the lapse of time is the cumulative effect of the process of attending’ (1932, 499–501). As for folk wisdom, witness sayings such as ‘a watched pot never boils’, ‘time flies when you’re having fun’, or, most explicitly, ‘when you’re not paying attention’.
2. The relevant literature does not distinguish between ‘attending to time’, ‘attending to the course/flow/passage of time’, and ‘attending to time-in-passing’. I follow suit. Note, however, that attention to time is different from attention *within* time, which is not the target of the present discussion. On the distinction see Coull 2004. I am also not concerned with the fact that both exogenous and endogenous *spatial* attention increase the perceived duration of a stimulus relative to an unattended stimulus (e.g., Mattes and Ulrich 1998; Enns, Brehaut, and Shore 1999; Yeshurun and Marom 2008; and Seifried and Ulrich 2011).
3. Dutke cites experimental evidence going back to Hülser 1924.
4. Cf. Tse who, surveying the literature, takes the claim that ‘the prospective judgment of time requires attention to the passage of time’ to be part of a “standard attentional model” of time perception’ supported by ‘[t]he majority of work in the time literature’ (2010, 138). Prospective judgments are judgments made by subjects who are aware during the interval to be timed that timing is a task-requirement. Such judgments contrast retrospective judgments, and are thought to track perceived duration as opposed to duration constructed via memory. The data in this paper solely concerns prospective judgments. For more on the distinction see, e.g., Block and Zakay 2004; and Block, Hancock, and Zakay 2010.
5. Likewise, Fortin and Couture 2002; for reviews see Brown 1997, 2008, and 2010; and Block, Hancock, and Zakay 2010.
6. Further examples from a large literature include the following. Curton and Lordhal: ‘time estimates were reliably lower for Ss performing an attention-demanding task [alphabetically connecting a randomly ordered circle of 26 letters] during [a 5–19s] interval than for those engaged in a task designed to focus attention on the passage of time [connecting dots at a rate of 1 dot/sec]’ (1974, 861); McKay: ‘time estimation of a standard interval was significantly lower when subjects attended to the stimulus material than when attending to the interval of passing time’ (1977, 584); Coull et al.: ‘subjects attended to time and/or colour attributes of visual stimulus pairs’ under five attentional conditions; results confirmed that ‘the subjective duration of stimulus presentation is increasingly shortened the more subjects attend to nontemporal stimulus features’ (2004, 1506); Grondin and Macar: ‘Our data generally show . . . that decreasing attention

to time decreases subjective duration' (1992, 127). I discuss a variety of other tasks below.

7. The status of these pulses is obscure. Macar et al. describe the basic idea as follows: 'the pulses that are assumed to be stored . . . may be viewed as chemical changes at the cell level, as spikes within neural networks, or as any other physiological event; their nature remains quite speculative' (1994, 674).
8. Early clock models were developed in Creelman 1962 and Treisman 1963. The most influential model is the scalar timing (or expectancy) theory (SET) due to Gibbon (1977), developed in Gibbon et al. 1984, and applied to human timing in, e.g., Wearden 1991. For reviews of the development and controversies surrounding such models see, for instance, Wearden 2001 and 2003, and Buhusi and Meck 2005. In all these models, the clock-accumulator system is only one part of a more sophisticated cognitive system for producing time judgments, involving short- and long-term memory stores and decision mechanisms.
9. Likewise, Fortin et al.: 'Concurrent nontemporal processing would put the gate in an "off" state, and would temporarily interrupt the accumulation process' (1993, 536). See also, Thomas and Brown who suggest a rather different attentional model according to which during 'periods of inattention . . . the passage of time is not recorded' (1974, 456).
10. In addition to the experimental work already cited, important contributions to the development of attentional approaches to time perception include: Thomas and Weaver 1975; Hicks et al. 1977; Fraisse 1984; Brown 1985; Brown and West 1990; and Zakay 1989.
11. See also Underwood and Swain 1973, 105.
12. That said, Block and Brown both make clear that their understanding of 'attention to time' is broader than simply attention to perceived change. Later, Block mentions 'changes in events or cognitions' (1990, 22), and, in addition to stimulus changes, Brown also mentions 'the ordering or succession of events, and the organization of those events', and further that, in paying attention to time, a subject 'may engage in some type of timekeeping strategy such as chronometric counting, executing a series of repetitive movements (e.g., rhythmical tapping) or visualising the sweep of a second hand on a clock face' (2008, 114). Some of these ideas are of course much closer to the account developed below. My only claim here is that understanding attention to time as attention to perceptible change is a very natural view to take. That said merely broadening temporal information out from perceived change to include 'the ordering or succession of events, and the organization of those events' will not save the view from the critique below. The critique therefore applies to the view in Michon and Jackson 1984 that temporal information is entirely a matter of the 'simultaneity and order' relations amongst events.
13. Brown cites Jones and Boltz 1989. Cf. Large and Jones: 'we offer a theory about how people attend to events that change over time. Our theory begins with audition . . . because a most persuasive case for positing dynamic attending comes when we consider attending to speech and music. . . . We take the time structure of events as a point of departure by assuming that, in acoustic patterns, it can capture and maintain attending' (1999, 120).
14. Cf. Langer who declares: '*Music makes time audible, and its form and continuity sensible*' (1953, 110; emphasis in original).

15. Ornstein claims that we can explain the watched pot phenomenon in terms of our being 'more vigilant than usual', since '[a]n increase in vigilance should result in a greater amount of awareness to input, and consequently a lengthening of duration experience' (1969, 112). It is unclear what this amounts to. On a natural interpretation it implies that our awareness of change is heightened, returning us to the criticism in the text. Cf. Underwood and Swain who reject Ornstein's view of the watched pot phenomenon, preferring the view 'that the increase in attention itself is causing the increase in duration experience' (1973, 101). That said, if vigilance is understood in terms of an increase in non-perceptual conscious activity, then Ornstein's view can be brought in line with that suggested below.
16. Likewise, Coull: 'The less we attend to an event's duration, the shorter it seems to last' (2004, 1506). Also Tse et al.: 'paying more (less) attention to the duration of an event increases (decreases) its perceived duration' (2004, 1172). Underwood and Swain discuss attention to time in terms of selectivity but for them it is 'attention to a particular source of stimuli, to the exclusion of other stimuli available in the environment' (1973, 104). This kind of selectivity cannot be used to explain the results in the present context.
17. Coull explicitly invokes analogical reasoning (2004, 222f.), drawing on work on selective attention to specific stimulus features such as colour and motion to argue for a similar picture of attention to time. It is notable that the experimental cues (e.g., 'attend selectively to stimulus time more than colour') used in her experiments presume the equivalence.
18. Brown notes that performance in the more difficult version of his rotor tracking task was in fact *improved* with the addition of a timing task (1997, 1133). In other conditions, timing had no significant effect: 'Tracking and visual search were essentially unaffected by the addition of a timing task, whereas mental arithmetic was disrupted by concurrent timing' (ibid., 1118). In Macar et al.'s study discussed above, 'the effect of attention sharing was significant in the duration but not in the intensity task' (1994, 680; see data on p.679), again manifesting the lack of bidirectional interference in this perceptual task.
19. Indeed, Thomas and Weaver (who developed the first modern attentional model of timing) think of attention as divided between 'a visual information processor and a timer' (1975, 363). In doing so they evidently contrast timing and visual information processing, in clear tension with *equivalence*.
20. Cf. Block: 'temporal information probably also includes changes in internal attributes, including proprioceptive information, moods or emotions, kinds of cognitive processes, and so on' (1990, 22).
21. James later distinguishes 'sensorial attention' to 'objects of sense', from 'intellectual attention' to 'ideal or represented objects' (1890, 416).
22. For further discussion of the notion of internal attention see De Brigard 2012. De Brigard, and indeed Chun et al. (2011), is principally interested in internal attention understood at an informational processing level. My interest is principally in the personal level phenomenon.
23. Baars draws attention to the extraordinary amount of resource the brain commits to spontaneous thought, suggesting that it would extremely implausible if this resource were being spent to no end.

24. A connection of this kind, though developed in a very different way, is central to O'Shaughnessy's work. In particular, O'Shaughnessy claims that 'an active process of thinking must be going on continuously' (2000, 267) as 'a categorically necessary condition of consciousness' (ibid., 100), and further that ongoing mental activity is part of what guarantees that in 'experiencing anything one experiences the passage of time' (ibid., 272). For discussion of O'Shaughnessy here see Soteriou 2011.
25. See further: Hawkes and Sherman 1972; Wilsoncroft and Stone 1975; and Wilsoncroft et al. 1978.
26. A research programme suggests itself here, exploiting what is known about mathematical cognition to test this picture of time perception.
27. For further examples of interference effects of this kind see, for example, the mental rotation task in Fortin and Breton 1995, and the anagram and Stroop tasks in Sawyer, Meyers, and Huser 1994. For a review of the many similar studies see again Brown 1997.
28. See Dutke 2005 for evidence supporting this hypothesis.
29. Locke develops his theory in his *Essay* (1975, II, xiv). Locke's view is clearly an important precursor of the view developed in this paper.
30. An analogous reply is available in relation to the analogous (and equally flawed) objection to body-relative accounts of size-perception, namely that such accounts are committed to one's body always seeming to be the same size.
31. Cf. The false opposition that lies behind the opening remark of a recent paper on body-relative spatial perception by van der Hoort et al.: 'Imagine that during your sleep you shrank to the size of a Barbie doll. Upon awakening, would you feel your body to be small, or would you sense that you were normal in a gigantic world inhabited by giants?' (2011, 1). The analogous question in the temporal case presupposes an equally false opposition. Of course in both spatial and temporal cases our perceptual experience exploits the natural measure it does (i.e., our body/our thoughts) in part because that measure is reasonably stable over time. As Locke puts it, the 'appearance of [ideas] in train, tho' perhaps it may be sometimes faster, and sometimes slower, yet, I guess, varies not very much in a waking man' (1975, II, xiv, 9).
32. Of course, our stream of non-perceptual consciousness is far from homogeneous as the quotation from Baars' above brings out. Thus, in such a situation it might be that we could gain some sense of *aspects* of our stream of thought slowing down or speeding up relative to other aspects. For example, we might experience our stream of auditory imagery as slowed relative to our stream of visual imagery.
33. For neurological evidence here see, e.g., Kagerer et al. 2002; Gutyrchik et al. 2010; and the review in Coull et al. 2011. For psychophysical evidence see, e.g., Ulbrich et al. 2007; and Zélanti and Droit-Volet 2011.
34. Recall Brown's remarks that in attending to the passage of time a subject 'may engage in some type of timekeeping strategy such as chronometric counting, executing a series of repetitive movements (e.g., rhythmical tapping) or visualising the sweep of a second hand on a clock face' (2008, 114). Tellingly, Underwood writes, 'A watched pot or a boring lecture may take a subjectively long period to terminate because we are attending to and counting the passage of time' (1975, 291). Consider also this very suggestive passage describing the model developed

in his paper: 'This model assumes that we gain an impression of the passage of time by consideration of the events occupying an interval, and accounts for the phenomenon of the watched pot (which never boils) by assuming that the activity of considering the events occupying an interval is in itself an event which will contribute to the next judgement of the extent of the interval. The more such judgements of time there are, the greater will be successive estimations of that same interval.' (ibid., 295)

35. At even slightly longer timescales of 5s or so, subjects appear to engage in 'ancillary timekeeping strategies (such as finger tapping, rhythmical motions, and visualization of clock faces) to supplement counting' (Brown, Newcomb, and Kahrl 1995, 536).
36. Interestingly, Rattat and Droit-Volet (2011) suggest that simply instructing subjects not to count is the best method for preventing counting without distorting timing processes.
37. Note that these timescales are longer than timescales over which we are capable of judging order and succession, but as Fraisse argues, 'The perception of duration, *stricto sensu*, is situated at a level above 100 ms' (1984, 30).
38. See, e.g., Mauk and Buonomano 2004; Buhusi and Meck 2005; and Karmarkar and Buonomano 2007. See also the closing remarks in Droit-Volet and Gil 2009.
39. Internal clock models were in fact first developed in response to data concerning the influence of body-temperature on perceived duration (see Hoagland 1933). For a recent review of this data see Wearden and Penton-Voak 1995.
40. I discuss these ideas in much greater detail in my 'Perceiving the Passing of Time' (in preparation).
41. Many of the anecdotes also support the common place idea that one's life flashes before one's eyes in such situations (Noyes and Kletti 1977, 387–8; 380–1). For further anecdotal evidence see Flaherty 1999 which collects a vast number of accounts of temporal distortions in various situations, many of which highlight the intimate connection between increased mental activity and a sense of time being stretched out or slowed down (i.e. an increase in perceived duration). See also Hancock and Weaver 2005. For recent laboratory based studies of the effect of emotional stimuli on time perception see, e.g., Droit-Volet and Meck 2007; Droit-Volet and Gil 2009; and Tipples 2011.
42. Work on amphetamine and cocaine is largely confined to rat studies (e.g., Maricq et al. 1981) given ethical limitations. That said, it is fair to say that the presumption in the field is that such effects are to be found in humans. For an overview of the effect of pharmacological interventions on duration perception in humans and non-human animals see Meck 1996.
43. I presented versions of this paper at ASSC16 at the University of Sussex, and at a conference on Attention at the University of Antwerp. I am very grateful to the audiences on those occasions, and especially to my two commentators in Antwerp: Chris Mole and Chris Peacocke for their extremely thoughtful replies. Particular thanks to Ned Block, Brit Brogaard, John Campbell, Dave Chalmers, Tim Crane, Felipe De Brigard, Carolyn Dicey Jennings, Imogen Dickie, Katalin Farkas, Craig French, Angelica Kaufmann, Fiona Macpherson, Bence Nanay, Casey O'Callaghan, Adrienne Prettyman, Jesse Prinz, Susanna Siegel, Barry Smith, Maja Spener, James Stazicker, Michael Tye, Sebastian Watzl, Keith Wilson, and Wayne Wu, and many others. Finally, special thanks as always to Hanna Pickard for her invaluable advice and constant support.

References

Abbott, R. 1999. *The World as Information*. Exeter: Intellect Books.

Ayers, M. 1991. *Locke*: *Epistemology and Ontology*. London and New York: Routledge.

Baars, B. J. 2010. "Spontaneous repetitive thoughts can be adaptive: Postscript on 'mind wandering'" *Psychological Bulletin* 136(2): 208–210.

Baldauf, D., E. Burgard, and M. Wittmann. 2009. "Time perception as a workload measure in simulated car driving." *Applied Ergonomics* 40(5): 929–35.

Ballas, C. A., D. L. Evans, and D. F. Dinges. 2009. "Psychostimulants and Wakefulness-Promoting Agents." In *The American Psychiatric Publishing Textbook of Psychopharmacology*, edited by A. F. Schatzberg and C. B. Nemeroff, 843–860. Arlington, VA.: American Psychiatric Pub.

Block, R. A. 1979. "Time and consciousness." In *Aspects of consciousness*, edited by G. Underwood and R. Stevens. Vol. 1 of *Psychological issues*, 179–217. London: Academic Press.

Block, R. A. 1990. "Models of psychological time." In *Cognitive models of psychological time*, edited by R. A. Block, 1–35. Hillsdale, NJ.: Erlbaum.

Block, R. A., E. J. George, and M. A. Reed. 1980. "A watched pot sometimes boils: A study of duration experience." *Acta Psychologica* 46: 81–94.

Block, R., and D. Zakay. 2004. "Prospective and retrospective duration judgments: an executive control perspective." *Acta Neurobiologiae Experimentalis* 64: 319–328.

Block, R., P. Hancock, and D. Zakay. 2010. "How cognitive load affects duration judgments: a meta–analytic review." *Acta Psychologica* 134(3): 330–43.

Bortolussi, M. R., B. H. Kantowitz, and S. G. Hart. 1986. "Measuring pilot workload in a motion base trainer: A comparison of four techniques." *Applied Ergonomics* 17(4): 278–283.

Brown, S. W., and E. D. Bennett. 2002. "The role of practice and automaticity in temporal and non–temporal dual–task performance." *Psychological Research* 66: 80–89.

Brown, S. W., D. C. Newcomb, and K. G. Kahrl. 1995. "Temporal-signal detection and individual differences in timing." *Perception* 24: 525–538.

Brown, S. W, and A. N. West. 1990. "Multiple timing and the allocation of attention." *Acta Psychologica* 75: 103–121.

Brown, S. W. 1985. "Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration." *Perception and Psychophysics* 38: 115–124.

Brown, S. W. 1997. "Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks." *Perception and Psychophysics* 59(7): 1118–1140.

Brown, S. W. 2008. "Time and attention: review of the literature." In *Psychology of Time*, edited by S. Grondin, 111–38. Bingley: Emerald.

Brown, S. W. 2010. "Timing, resources, and interference: attentional modulation of time perception." In *Attention and Time*, edited by A. C. Nobre and J. T. Coull, 107–121. Oxford: OUP.

Brown, S. W., and C. T. Frieh. 2000. "Information processing in the central executive: Effects of concurrent temporal production and memory updating tasks." In *Rhythm perception and production*, edited by P. Desain and L. Windsor, 193–196. Lisse, The Netherlands: Swets & Zeitlinger.

Brown, S. W., and A. N. West. 1990. "Multiple timing and the allocation of attention." *Acta Psychologica* 75: 103–121.

Buhusi, C. V. and W. H. Meck. 2005. "What makes us tick? Functional and neural mechanisms of interval timing." *Nature Reviews Neuroscience* 6(10): 755–765.

Burnside, W. 1971. "Judgment of short time intervals while performing mathematical tasks." *Perception and Psychophysics* 9(5): 404–406.

Cahoon, D., and E. M. Edmonds. 1980. “The watched pot still won’t boil: Expectancy as a variable in estimating the passage of time.” *Bulletin of the Psychonomic Society* 16: 115–116.

Carrasco, M. 2011. “Visual Attention: The past 25 years.” *Vision Research* 51: 1484–1525.

Chun, M. M., J. D. Golomb, and N. B. Turk-Browne. 2011. “A Taxonomy of External and Internal Attention.” *Annual Review of Psychology* 62: 73–101.

Correa, A., and A. C. Nobre. 2008. “Spatial and temporal acuity of visual perception can be enhanced selectively by attentional set.” *Experimental Brain Research* 189(3): 339–44.

Coull, J. T. 2004. “fMRI studies of temporal attention: allocating attention within, or towards, time.” *Cognitive Brain Research* 21: 216–226.

Coull, J. T., R. K. Cheng, and W. H. Meck. 2011. “Neuroanatomical and neurochemical substrates of timing.” *Neuropsychopharmacology* 36: 3–25.

Coull, J. T., F. Vidal, B. Nazarian, and F. Macar. 2004. “Functional anatomy of the attentional modulation of time estimation.” *Science* 303: 1506–1508.

Creelman, C. D. 1962. “Human discrimination of auditory duration.” *Journal of the Acoustical Society of America* 34: 582–593.

Curton, E. D., and D. S. Lordahl. 1974. “Effects of attentional focus and arousal on time estimation.” *Journal of Experimental Psychology* 103: 861–867.

Droit–Volet, S., E. Bigand, D. Ramos, and J. L. O. Bueno. 2010. “Time flies with music whatever its emotional valence.” *Acta Psychologica* 135: 226–236.

Droit–Volet, S., and S. Gil. 2009. “The time–emotion paradox.” *Phil. Trans. R. Soc. B* 364: 1943–1953.

Droit–Volet, S., and W. H. Meck. 2007. “How emotions colour our perception of time.” *Trends in Cognitive Sciences* 11(12): 504–513

Droit–Volet, S., and J. H. Wearden. 2002. “Speeding up an internal clock in children? Effects of visual flicker on subjective duration.” *Quarterly Journal of Experimental Psychology* 55B: 193–211.

Dutke, S. 2005. “Remembered duration: Working memory and the reproduction of intervals.” *Perception and Psychophysics* 67(8): 1404–1413.

Enns, J. T., J. C. Brehaut, and D. I. Shore. 1999. “The duration of a brief event in the mind’s eye.” *The Journal of General Psychology* 126: 355–372.

Flaherty, M. 1999. *A Watched Pot: How We Experience Time*. New York and London: NYU Press.

Fortin, C., and R. Breton. 1995. “Temporal interval production and processing in working memory.” *Perception and Psychophysics* 57: 203–215.

Fortin, C., and E. Couture. 2002. “Short–term memory and time estimation: beyond the 2-second ‘critical’ value.” *Canadian Journal of Experimental Psychology* 56: 120–127.

Fortin, C., R. Rousseau, P. Bourque, and E. Kirouac. 1993. “Time estimation and concurrent nontemporal processing: Specific interference from short–term–memory demands.” *Perception and Psychophysics* 53(5): 536–548.

Fraisse, P. 1963. *Psychology of Time*. New York: Harper & Row.

Fraisse, P. 1984. “Perception and Estimation of Time.” *Annual Review of Psychology* 35: 1–36.

Hancock, P. A., and J. L. Weaver. 2005. “On time under stress.” *Theoretical Issues in Ergonomics Science* 6: 193–211.

Hoagland, H. 1933. “The physiological control of judgments of duration: evidence for a chemical clock.” *Journal of General Psychology* 9: 267–287.

Gibbon, J. 1977. “Scalar expectancy theory of Weber’s law in animal timing.” *Psychological Review* 84: 279–325.

Gibbon, J., R. M. Church, and W. Meck. 1984. “Scalar timing in memory.” In *Timing and time perception*, edited by J. Gibbon and L. G. Allan. Vol. 423 of *Annals of the New York Academy of Sciences*, 52–77. New York: New York Academy of Sciences.

Gibson, J. J. 1975. "Events Are Perceivable but Time Is Not." In *The Study of Time II. Proceedings of the Second Conference of the International Society for the Study of Time*, edited by J. T. Fraser and N. Lawrence, 295–301. Berlin: Springer-Verlag.

Grondin, S., and F. Macar. 1992. "Dividing attention between temporal and nontemporal tasks: a performance operating characteristic—POC—analysis." In *Time, action, cognition: towards bridging the gap*, edited by F. Macar, V. Pouthas and W. Friedman, 119–128. Dordrecht: Kluwer.

Grondin, S., G. Meilleur–Wells, and R. Lachance. 1999. "When to start explicit counting in a time–intervals discrimination task: A critical point in the timing process by humans." *Journal of Experimental Psychology: Human Perception and Performance* 25: 993–1004.

Gutyrchik, E., J. Churan, T. Meindl, A. L. W. Bodke, H. von Bernewitz, C. Born, et al. 2010. "Functional neuroimaging of duration discrimination on two different time scales." *Neuroscience Letters* 469: 411–415.

Hawkes, G. R., and S. J. Sherman. 1972. "Vigilance effects for duration judgments with two levels of task demand." *Perceptual and Motor Skills* 34: 351–356.

Hicks, R. E., G. W. Miller, and M. Kinsbourne. 1976. "Prospective and Retrospective Judgments of Time as a Function of Amount of Information Processed." *The American Journal of Psychology* 89(4): 719–730.

Hicks, R. E., G. W. Miller, G. Gaes, and K. Bierman. 1977. "Concurrent Processing Demands and the Experience of Time-in-Passing." *The American Journal of Psychology* 90(3): 431–446.

Hülser, C. 1924. "Zeitauffassung und Zeitschätzung verschieden ausgefüllter Intervalle unter besonderer Berücksichtigung der Aufmerksamkeitsablenkung." [Time perception and time estimation of differently filled intervals with respect to distracted attention.] *Archiv für die gesamte Psychologie* 49: 363–378.

Hume, D. 1978. *A Treatise of Human Nature*. Edited by L. A. Selby-Bigge, 2nd edition revised by P. H. Nidditch. Oxford: Clarendon Press.

James, W. 1890. *The Principles of Psychology*. New York: H. Holt and company.

Jones, L. A., C. Allely, and J. H. Wearden. 2011. "Click trains and the rate of information processing: Does 'speeding up' subjective time make other psychological processes run faster?" *Quarterly Journal of Experimental Psychology* 64(2): 363–380.

Jones, M. R., and M. G. Boltz. 1989. "Dynamic attending and responses to time." *Psychological Review* 96(3): 459–491.

Kagerer, F. A., M. Wittmann, E. Szelag, and N. von Steinbüchel. 2002. "Cortical involvement in temporal reproduction: Evidence for differential roles of the hemispheres." *Neuropsychologia* 40: 357–366.

Kant, I. 2003. *Critique of Pure Reason*. Translated by N. Kemp Smith. New York: Palgrave Macmillan.

Karmarkar, U. R., and D. V. Buonomano. 2007. "Timing in the absence of clocks: encoding time in neural network states." *Neuron* 53(3): 427–38.

Kojima, Y., and F. Matsuda. 2000. "Effects of attention and external stimuli on duration estimation under a prospective paradigm." *Japanese Psychological Research* 42: 144–154.

Kouwenhoven, F. 2001. "Meaning and Structure: The Case of Chinese qin (zither) Music." *British Journal of Ethnomusicology* 10(1): 39–62.

Langer, S. 1953. *Feeling and form*. New York: Charles Scribner.

Large, E. W., and M. R. Jones. 1999. "The dynamics of attending: How we track time-varying events." *Psychological Review* 106: 119–159.

Lavie, N. 2010. "Attention, Distraction, and Cognitive Control Under Load." *Current Directions in Psychological Science* 19(3): 143–148.

Le Poidevin, R. 2007. *The Images of Time*. Oxford: OUP.

Locke, J. 1975. *An Essay Concerning Human Understanding*. Edited by P. H. Nidditch. Oxford: OUP.

Macar F. 2002. "Expectancy, controlled attention and automatic attention in prospective temporal judgments." *Acta Psychologica* 111(2): 243–62.

Macar, F., S. Grondin, and L. Casini. 1994. "Controlled attention sharing influences time estimation." *Memory and Cognition* 22(6): 673–86.

Martin, M. G. F. 1997 "The shallows of the mind." *Proceedings of the Aristotelian Society* 74(1): 75–98.

Maricq, A. V., S. Roberts, and R. M. Church. 1981. "Methamphetamine and time estimation." *Journal of Experimental Psychology: Animal and Behavioral Processes* 7: 18–30.

Mattes, S., and R. Ulrich. 1998. "Directed attention prolongs the perceived duration of a brief stimulus." *Perception and Psychophysics* 60: 1305–1317.

Mauk, M. D., and D. V. Buonomano. 2004. "The Neural Basis of Temporal Processing." *Annual Review of Neuroscience* 27: 307–40

McKay, T. D. 1977. "Time estimation: effects of attentional focus and a comparison of interval conditions." *Perceptual and Motor Skills* 45: 584–586.

McTaggart, J. M. E. 1927. *The Nature of Existence II*. Edited by C. D. Broad. London: CUP.

Meck, W. H. 1996. "Neuropharmacology of timing and time perception." *Cognitive Brain Research* 3: 227–242.

Michon, J. A. 1985. "The compleat time experiencer." In *Time, Mind, and Behavior*, edited by J. A. Michon and J. L. Jackson, 20–52. New York: Springer.

Michon, J. A. 1986. "J. T. Fraser's 'Levels of Temporality' as Cognitive Representations." In *The Study of Time V: Time, Science, and Society in China and the West*, edited by J. T. Fraser, N. Lawrence, and F. C. Haber, 51–66. Amherst, MA.: University of Massachusetts Press.

Michon, J. A. 1972. "Processing of temporal information and the cognitive theory of time experience." In *The study of time*, edited by J. T. Fraser, F. C. Haber, and G. H. Müller, 242–258. Heidelberg: Springer-Verlag.

Michon, J. A., and J. L. Jackson. 1984. "Attentional effort and cognitive strategies in the processing of temporal information." In *Timing and time perception*, edited by J. Gibbon and L. G. Allan. Vol. 423 of *Annals of the New York Academy of Sciences*, 298–321. New York: New York Academy of Sciences.

Nasrallah, H. A., and R. Tandon. 2009. "Classic Antipsychotic Medications." In *The American Psychiatric Publishing Textbook of Psychopharmacology*, edited by A. F. Schatzberg and C. B. Nemeroff, 533–554. Arlington, VA.: American Psychiatric Pub.

Nichelli, P., D. Always, and J. Grafman. 1996. "Perceptual timing in cerebellar degeneration." *Neuropsychologia* 34(9): 863–71.

Noyes, R., and R. Kletti. 1977. "Depersonalization in Response to Life-Threatening Danger." *Comprehensive Psychiatry* 18(4): 375–384.

O"Shaughnessy, B. 2000. *Consciousness and the world*. Oxford: OUP.

Ornstein, R. E. 1969. *On the experience of time.* Harmondsworth: Penguin.

Papafragou, A. 2010. "Language" In *Encyclopedia of Perception*, edited by B. Goldstein, 519–522. Thousand Oaks: Sage.

Penton–Voak, I. S., H. Edwards, A. Percival, and J. H. Wearden. 1996. "Speeding up an internal clock in humans? Effects of clicks trains on subjective duration." *Journal of Experimental Psychology: Animal and Behavioural Processes* 22: 307–320.

Phillips, I. B. In preparation. "Perceiving the passing of time."

Rammsayer, T. 1989. "Is there a common dopaminergic basis of time perception and reaction time?" *Neuropsychobiology* 21: 37–42.

Rammsayer, T. 1999. "Neuropharmacological evidence for different timing mechanisms in humans." *Quarterly Journal of Experimental Psychology* 52: 273–286.

Rattat, A. C., and S. Droit-Volet. 2012. "What is the best and the easiest method of preventing counting in different temporal tasks?" *Behavior Research Methods* 44: 67–80.
Reid, T. 1827. *Essays on Powers of the Human Mind*. London: Thomas Tegg.
Sawyer, T. F., P. J. Meyers, and S. J. Huser. 1994. "Contrasting task demands alter the perceived duration of brief time intervals." *Perception and Psychophysics* 56: 649–657.
Seifried, T. and R. Ulrich. 2011. "Exogenous visual attention prolongs perceived duration." *Attention, Perception and Psychophysics* 73: 68–85.
Shoemaker, S. 1969. "Time Without Change." *Journal of Philosophy* 66: 363–81.
Sloman, S. A. 1996. "The empirical case for two systems of reasoning." *Psychological Bulletin* 119: 3–22.
Soteriou, M. J. 2011. "Occurrent Perceptual Knowledge." *Philosophical Issues* 21(1): 485–504.
Stout, G. F. 1932. *A Manual of Psychology.* London: W. B. Clive, University Tutorial Press Ltd.
Thomas, E. A. C., and T. I. Brown Jr. 1974. "Time perception and the filled–duration illusion." *Perception and Psychophysics* 16: 449–458.
Thomas, E. A. C., and W. B. Weaver. 1975. "Cognitive processing and time perception." *Perception and Psychophysics* 17: 363–367.
Tipples, J. 2011. "When time stands still: Fear–specific modulation of temporal bias due to threat." *Emotion* 11(1): 74–80.
Treisman, M. 1963. "Temporal discrimination and the indifference interval: Implications for a model of the 'internal clock'." *Psychological Monographs: General and Applied* 77: 1–31.
Treisman, M., A. Faulkner, P. L. N. Naish, and D. Brogan. 1990 "The internal clock: evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency." *Perception* 19: 705–743.
Tse, P., J. Intriligator, J. Rivest, and P. Cavanagh. 2004 "Attention and the subjective expansion of time." *Perception and Psychophysics* 66(7): 1171–1189.
Tse, P. U. 2010. "Attention underlies subjective temporal expansion." In *Attention and Time*, edited by A. C. Nobre and J. T. Coull, 137–150. Oxford: OUP.
Ulbrich, P., J. Churan, M. Fink, and M. Wittmann. 2007. "Temporal reproduction: Further evidence for two processes." *Acta Psychologica* 125: 51–65.
Underwood, G. 1975. "Attention and the perception of duration during encoding and retrieval." *Perception* 4(3): 291–296.
Underwood, G., and R. A. Swain. 1973. "Selectivity of attention and the perception of duration." *Perception* 2(1): 101–105.
van der Hoort, B., A. Guterstam, and H. H. Ehrsson. 2011. "Being Barbie: The Size of One's Own Body Determines the Perceived Size of the World." *PLoS One* 6(5): 1–10.
Wearden, J. H., L. Denovan, M. Fakhri, and R. Haworth. 1997. "Scalar timing in temporal generalization in humans with longer stimulus durations." *Journal of Experimental Psychology: Animal Behavior Processes* 23: 502–511.
Wearden, J. H. 1991. "Do humans possess an internal clock with scalar timing properties?" *Learning and Motivation* 22: 59–83.
Wearden, J. H. 2001. "Internal Clocks and the Representation of Time." In *Time and Memory*, edited by C. Hoerl and T. McCormack, 37–58. Oxford: OUP.
Wearden, J. H. 2003. "Applying the scalar timing model to human time psychology: progress and challenges." In *Time and mind II*, edited by H. Helfrich, 21–39. Gottingen: Hogrefe & Huber.
Wearden, J. H., and I. S. Penton-Voak. 1995. "Feeling the heat: body temperature and the rate of subjective time, revisited." *Quarterly Journal of Experimental Psychology* 48B: 129–141.
Wearden, J. H., K. Philpott, and T. Win. 1999. "Speeding up and (. . . relatively . . .) slowing down and internal clock in humans." *Behavioural Processes* 46: 63–73.
Wearden, J. H., P. Rogers, and R. Thomas. 1997. "Temporal bisection in humans with longer stimulus durations." *Quarterly Journal of Experimental Psychology* 50B: 79–94.

Wilsoncroft, W. E., and J. D. Stone. 1975. "Information processing and estimation of short time intervals." *Perceptual and Motor Skills* 41: 192–194.

Wilsoncroft, W. E., J. D. Stone, and F. M. Bagrash. 1978. "Temporal estimates as a function of difficulty of mental arithmetic." *Perceptual and Motor Skills* 46: 1311–1317.

Wittmann, M., V. van Wassenhove, A. D. Craig, and M. P. Paulus. 2010. "The neural substrates of subjective time dilation." *Frontiers in Human Neuroscience* 4(2): 1–9.

Woodrow, H. 1951. "Time perception." In *Handbook of Experimental Psychology*, edited by S. Steven, 1224–1236. New York: Wiley.

Yeshurun, Y., and G. Marom. 2008. "Transient spatial attention and the perceived duration of brief visual events." *Visual Cognition* 16: 826–848.

Zakay, D. 1990. "The evasive art of subjective time measurement: Some methodological dilemmas." In *Cognitive Models of Psychological Time*, edited by R. A. Block, 59–84. Hillsdale, NJ: Erlbaum.

Zakay, D., and R. A. Block. 1997. "Temporal Cognition." *Current Directions in Psychological Science* 6: 12–16.

Zakay, D. 1989. "Subjective time and attentional resource allocation: An integrated model of time estimation." In *Time and Human Cognition: A Life Span Perspective*, edited by I. Levin and D. Zakay, 365–397. Amsterdam, The Netherlands: North Holland.

Zakay, D., and R. A. Block. 1996. "The role of attention in time estimation processes." In *Time, Internal Clocks and Movement*, edited by M. A. Pastor and J. Artieda, 143–164. Amsterdam, The Netherlands: Elsevier.

Zakay, D., D. Nitzan, and J. Glicksohn. 1983. "The influence of task difficulty and external tempo on subjective time estimation." *Perception & Psychophysics* 34: 451–456.

Zélanti, P., and S. Droit–Volet. 2011. "Cognitive abilities explaining age-related changes in time perception of short and long durations." *Journal of Experimental Child Psychology* 109: 143–157.