



# The cognitive neuroscience of time perception: How psychological studies might help to dissect the timing system

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## ABSTRACT

It is argued that the cognitive neuroscience of time perception does not make sufficient use of a range of experimental techniques and theoretical approaches which might be useful in “dissecting” the human timing system, and thus helping to uncover its neural basis. These techniques are mostly inspired by scalar expectancy theory, but do not depend on acceptance of that model. Most of the methods result in the same physical stimuli giving rise to systematically different time judgements, thus they avoid problems of control which have haunted some areas of the cognitive neuroscience of timing. Among the possibilities are (a) changing the basic duration judgement of stimuli and events, (b) manipulating working memory and reference memories for duration, and (c) changing temporal decision processes.

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### Nothing is impossible for the person who doesn't have to do it themselves

(non-sexist update of an old saying).

## 1. Introduction

In this article, I want to emphasize the limited extent to which the cognitive neuroscience of time perception (CNTP) has exploited experimental techniques and theoretical analyses developed by psychologists studying human timing, and argue that this neglect is unjustified. These techniques, and the theoretical models used to interpret data, seem potentially very useful in dissecting the neural mechanisms underlying what seem to be necessarily different parts of the timing system, and here I try to convince sceptical readers, or those unfamiliar with the work in question, of this. The first sections of this article provide the basic framework, and later I will discuss the material in some of the articles in the current issue of *Neuropsychologia* in the light of the ideas advanced earlier.

## 2. Clocks, memories, and decisions

In the last 30 years, the psychological study of human timing in the hundreds of milliseconds to seconds range (to minutes in animals) has been markedly influenced by clock-memory-decision models like those of Treisman (1963) or the very similar, but more

developed, scalar expectancy theory (SET) of Gibbon, Church and Meck (1984). Space does not permit a detailed exposition of this approach (see Wearden, 2003, for a simple one) but in outline, SET proposes that timed behaviour (in humans, often in the form of verbal responses) results from a cascade of clock, memory, and decision processes. The “raw” representations of the duration of an event to be timed are generated by a pacemaker-accumulator clock. There are short-term/working memory representations of durations, as well as a “reference” memory where “important” times (such as those associated with reinforcer delivery in animal experiments, or standard durations valid for a number of trials in human studies) are stored. Finally, time judgements result from decision processes which, usually, act by comparing the contents of working memory (e.g., the duration of an event just presented) with a sample from reference memory (e.g., what the “standard” is in the study). Decision rules can vary depending on the task in hand, and play a critical role in determining behaviour (Wearden, 2004).

An obvious problem with approaches based on SET is that behaviour results from the interaction of a number of processes, so attributing effects to one or another (clock versus memory, for example) is difficult. But this issue has been long recognised (if not completely solved, see Wearden, 1999), and SET, as applied to human timing, at least, has spawned a host of methods for “isolating” different parts of the proposed system. From the point of view of the CNTP as applied to humans, it seems to me that these methods, and the theoretical models related to them, would help with two current problems. One involves comparisons of the behaviour of patient groups with controls. CNTP is, obviously, hampered by the absence of “temporal amnesics” (i.e., individuals as impaired on time perception tasks as amnesics are on some sorts of memory), but patients with specific lesions of certain brain structures, or groups with particular illnesses such as

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Parkinson's Disease (Claassen et al., *this issue*), Attention Deficit Disorder (Noreika, Falter, & Rubia, *this issue*) or schizophrenia, are often (although not always) reported to behave differently on timing tasks, albeit sometimes only slightly, from appropriate controls. Yet, it is usually unclear how the differences observed can be interpreted; do they result from differences in basic duration representation (what SET might call “clock”) processes, in working or reference memory for duration, or in decision processes? Indeed in schizophrenia, timing difficulties may not be due to impairments in any of these processes, but rather to problems in integrating and binding information within a brief temporal window (see Moore, Cambridge, Morgan, Giordano, & Fletcher, *this issue*; Martin, Giersch, Huron, & van Wassenhove, *this issue*; Parsons et al., *submitted*). Wearden and Jones (*in press*) used computer modelling to illustrate how between-group differences might (and, in some cases, should not) be interpreted, although in practice most research in the CNTP area comparing different groups contents itself with a demonstration of a statistical difference between groups on some measure of timing, usually without further theoretical analysis.

The second problem with which experimental and theoretical work from basic time perception might help CNTP is that of *control*. In the CNTP field, studies using event-related potentials or various sorts of imaging appear to concentrate on two issues. One is demonstrating specific activation caused by timing, as opposed to something else. The second issue, less studied than the first, is to try to observe the timing process as it operates, that is, to try to dissect it into its various components. It is in this area that fairly recent research in the experimental psychology of time might help CNTP. Mainly as a result of a desire to isolate the different components of the SET model, methods have been developed to alter basic timing (“clock”) processes, memory, and decision mechanisms, leaving the rest of the system constant. In many cases, these methods can produce an experimental situation where the *same* physical stimuli give rise to systematically *different* time judgements. The situations compared thus provide perfect controls for one another: the stimuli judged are physically the same, and the type of duration judgement is also the same, but some component of the system has been manipulated to produce the behavioural effect observed. Recent work by Bueti and Macaluso (2011) exploited the fact that faster-moving stimuli tend to result in longer subjective durations, and that tones of higher pitch tend to be judged as longer than those with lower pitch, in their research to discover physiological correlates of subjective time judgements.

### 3. Dissecting the timing system

Constraints of space only allow me a few examples of the way in which behavioural studies have tried to “dissect” the human timing system. Trains of clicks or flickering visual stimuli which precede events to be timed cause them to be judged as longer than without the preceding stimulation (Penton-Voak, Edwards, Percival, & Wearden, 1996, after Treisman, Faulkner, Naish, & Brogan, 1990; see also Droit-Volet, & Wearden, 2002), even when they are physically the same. Manipulations of arousal (e.g., Casini, Ramdani-Beauvir, Burle, & Vidal, *this issue*; Wearden, 2008) or perturbations to the vestibular system (e.g. Binetti, Siegler, Bueti, & Doricchi, *this issue*) may likewise, may cause the *same* stimuli to result in *different* subjective durations (e.g. Wearden, 2008). Finally, pharmacological manipulation of the dopaminergic system has long been associated with changes in speed of a putative clock (e.g. Lake & Meck, *this issue*; Meck, 1996). Employing electrophysiological or imaging techniques in these cases thus seems likely to inform CNTP about the initial

stages of formation of duration representations. Turning to other parts of the timing system proposed by SET, such as memory and decision processes, versions of standard tasks such as temporal generalization and bisection can be devised which either almost certainly depend on some sort of reference memory (Wearden, 1991, 1992) or use working memory alone (Wearden & Bray, 2001), in situations where the same physical stimuli are compared, so once again, these methods seem to offer the potential for insight into the neural basis of timing processes, this time relating to the question of how durations are stored in memory. Furthermore, reference memory can be manipulated by various means (Jones & Wearden, 2003, 2004), some of which produce dramatic changes in performance when the same stimuli and same sort of comparisons are used (Ogden, Wearden, & Jones, 2008). Decision processes can be changed by payoff manipulations (Balci, Wiener, Cavdaroglu, & Coslett, *this issue*; Wearden & Grindrod, 2003), or by changing the difficulty of the task (Ferrara, Lejeune, & Wearden, 1997), again resulting in the *same* physical stimuli producing *different* behavioural responses. Finally, speeded response methods can be used to provide insight into when people have sufficient information to make decisions on timing tasks (Klapproth & Muller, 2008; Klapproth & Wearden, 2011; Lindbergh & Kieffaber, *this issue*). These different methods are only a few of those that have been devised, and can be combined with other interesting manipulations, such as changing the modality of the stimuli timed, using cross-modal judgements, or moving stimuli (Matthews, 2011).

At present only a very small amount of research in CNTP has made any attempt to exploit these methods (see Paul et al., 2011, for a rare example, which used the method of Ferrara et al., 1997). I do not claim that these techniques can solve all the questions posed in CNPT, but they can surely make a contribution to some of them. For example, Wearden and Jones, (*in press*) carried out modelling of some data from two studies comparing patient groups with controls on a temporal bisection task (Wearden, 1991). One study (Elvevag et al., 2003) compared people with a diagnosis of schizophrenia with a control group, the other (Smith, Harper, Gittings, & Abernethy, 2007) compared patients with Parkinson's Disease with controls. In both cases there were statistically significant differences between performance of the patient group and controls, but according to Wearden and Jones' modelling the differences were due to quite different psychological processes. The people with schizophrenia showed markedly lower timing sensitivity than the control group, as well as exhibiting a response bias, whereas the people with Parkinson's Disease were only slightly lower in timing sensitivity, and unbiased, but had a tendency to make random responses to the stimuli, possibly as a result of attentional difficulties. The conclusions of this type of analysis might, of course, be linked to different physiological causes of the underlying condition in the two patient groups.

Paul et al. (2011), used a temporal generalization method, and exploited the finding of Ferrara et al. (1997) that more difficult discriminations changed responding to the same physical stimuli. They initially presented participants with a standard duration 600 ms long in the form of a small visual stimulus, then people received comparison durations, some shorter than the standard, some longer, and some the same duration, and had to judge whether each stimulus the standard duration or not, making a YES/NO response. In the conditions compared, comparisons were spaced around the standard either in 150 ms (easy) or 75 ms (difficult) steps. Some comparison durations (450 ms and 750 ms, as well as 600 ms itself) were common to both sets, but Paul et al. replicated Ferrara et al.'s finding that the 450 ms and 750 ms stimuli were less likely to be judged as the standard in the difficult condition compared with the easy one, and modelled

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