

P.A. Hancock

## **Time and the Privileged Observer**

“I would query by what sense it is we come to be informed of Time; for all the information we have from the senses are momentary, and only last during the impressions made by the object.”

Robert Hooke (quoted in Whitrow, 2003)

### ABSTRACT

This paper addresses the persistent problem concerning the integration of physical (external) with psychological (internal) expressions of time. While the history of cosmological science demonstrates the fallacy of the conception of the physically privileged observational point in the Universe, I argue that it is just such a privileged position which characterizes the unitary nature of individual human consciousness. A rational, but flawed implication of this latter observation is that there is a unique spatio-temporal point within the brain at which reality is experienced. This flaw can be exposed through reference to the sensory simultaneity problem. Evidence indicates that since no such unique neural location exists, the brain finesses the issue of absolute timing at a sensory level by simply avoiding the problem of time-tagging such events altogether. While this finesse solves the simultaneity conundrum at a sensory level, I argue that the need for personal temporal continuity and the ability to outpace exogenous time by the projection of possible futures are solved elsewhere in the brain. A brief account of these latter properties is also presented.

## Our Place in the Physical and Teleological Universe

It is now a common perspective, but one not without challenge or dispute, that the progress of human knowledge can be represented as the burgeoning recognition of our collective place in the physical Universe. It is traditional to conceive of this journey of social consciousness as one of displacement from the nominal center of the Universe to our present day understanding which emphasizes that there is no privileged point of observation in the physical Universe. This argument, made both logically and persuasively by, for example Koestler (1968), affirms that the perceived relationship of the earth with respect to the Universe as a whole has changed with each new proposed cosmological order (and see also Connor, 2004). While this putative 'progress' has been neither as pristine nor as linear as we might like to believe, it is the case that the earth-centered, to sun-centered, to 'no' center conceptions do parallel the diminution of human importance in the physical, but crucially not the teleological Universe (and see Bronowski, 1973; Hancock, 2002).

Despite the progress in celestial observation and the accompanying physical comprehension, a comparable evolution in our perceived intellectual position in the Universe has yet to flower. If, as one religion confidently asserts, humans are made in the image of a Universal God, then it is indeed parsimonious to conclude that the spiritual position and thus physical location of these humans, so created, would also be extremely special, if not unique (although, of course, this form of radical anthropocentrism would be endemic to any such sentient beings holding this belief, wherever they were actually located). If the history of human beings in our first five recorded millennia has been the discovery of our collective insignificance as to location in the physical Universe, perhaps in our next five millennia we will similarly disillusion ourselves in respect to our comparable teleological position in the Universe. However, there are a number of significant barriers to such a development.

A primary barrier to achieving such insight is the personal and unified nature of consciousness. Although phenomenologically a unitary experience, consciousness is, in actuality, an emergent property of a multiplicity of neural processes. Embraced in the notion of a *'Society of Mind'* (Minsky, 1988), the propositional impasse of a unified consciousness is intimately linked to the personal privileged observer myth. Although we now accept that there is no

physical 'universally' privileged observer, this has not disposed of the belief that we each appear to ourselves, consciously in the ultimately privileged position. Indeed, all of our insights into our place in the physical Universe have never really disturbed, and perhaps have even actually reinforced this implicit notion that there indeed is a uniquely advantaged neural location, the place where phenomenologically we are 'us'. We perceive ourselves to be discrete, single, unified entities located somewhere "just behind the eyes", from which location all of experience is centered. By extension, and beyond simple metaphorical equivalence, this implies there is a privileged observational point in the brain and that the observer at that point IS us. A great problem arises if we accept this proposition by considering that this latter observer is simply a smaller replica or homunculus of our larger selves. Such an idea leads to an immediate impasse with an infinite regress of a series of 'observers' stacked one inside another like a set of Chinese boxes. The latter notion (who observes the observer themselves) reminds us of Luvenalis (Juvenal's) inquisition "*quis cusodiet ipsos custodes?*" (who will guard the guards themselves).

The implication of a single observational point in the brain requires the parallel assumption of a single observational time. For, as is clear from the observation of the German physicist Minkowski: "*who has seen a time except at a place and who has been at a place except at a time.*" Thus we are ourselves - now, at this point in time, as much as we are ourselves here at this point in space. Coded in neuro-physiological conceptions such as the 'single command neuron,' this entrenched belief is fundamentally an extension of the Cartesian assumption that self is embodied in the pineal gland where, purportedly, the corporeal met the incarnate (and see Dennett & Kinsbourne, 1992). This latter, mind-body issue is a division with which both the philosopher Plato and geographer Ptolemy struggled in their seminal codifications of the conception of the Universe and our personal place within it.

## **The spatial nature of time and the temporal nature of space**

Almost all people, including most scientists, find it easier to deal with the spatial and therefore the static, as opposed to the temporal, and therefore the dynamic. As a consequence even in neuroscience, the spatial distribution of neural systems has been studied extensively, especially as most recent

neuro-imaging techniques provide significantly better spatial compared with temporal resolution. However, it is evident after even a brief epoch of cogitation that however much static, spatial knowledge we gain, time is the more fundamental problem. For example, Block (1990) concluded that: *“psychological time can no longer continue to be ignored by (scientists) who propose models of non-temporal behavior, because non-temporal behavior does not exist.”* The question crystallizes rapidly into one of how the brain processes time itself. Initially, this does not appear to be a problem at all! After all, we see, we hear, or we feel a discrete event in the environment and then react to it in some fashion and so we can establish a neural time course of events from stimulus reception to response execution. Somewhere along this passage, the traditional conception tells us, either explicitly or implicitly, that this processing sequence must reach a momentary ‘now’. Like much that is apparently simple, this conception hides many layers of complexity (and see Russell, 1915).

Let us approach the problem by considering the question of synchronicity. This is not a side-step but rather an extension of the same question. That is, supposing two related events happen, such as an individual is both seeing and hearing a car door slam. How does the brain solve the problem of synchronizing these discrete signals to different sensory systems so that they appear phenomenologically as a single, unified event? Clearly if we look at the sensory systems involved, the difference in the lag in transmission time between two systems such as are involved in visual and auditory processing is not insignificant. Also, from a purely physical perspective, the light reaches the retina with virtually no temporal lag, whereas the auditory signal from the same event can take several orders of magnitude longer to reach the tympanic membrane. The various processing times across the cortex can be equally disparate. How then does the brain apparently compensate for all of these different temporal lags from both the external environment and lags within the brain itself? Of course, the first thing to note is that the brain does not *always* achieve this synchronicity anyway. Indeed, we know of environmental situations which regularly fracture this synchronization. In thunderstorms, of which there are many in Florida, one sees a lightning flash and then some appreciable time later, hears the accompanying peal of thunder. Such disparity between the two can be used to provide an approximation of just how far away the lightening strike has occurred. In a severe thunderstorm, of

which there are many in Florida, multiple lightening strikes cause significant confusion as to which peal of thunder is related to which lightening strike. This confusion is only disambiguated by either a very close strike in which sound and light virtually meld together, or when the storm is dying down and the frequency of strikes diminishes. We feel no disparity in our sense of consciousness in such circumstances since we have come to learn that this particular desynchronization of environmental events is, in these circumstances 'normal.' However, if all experience were so represented and the inter-sensory disparity between more than one sensory system was a frequent occurrence, one can immediately envisage the mental mayhem it would potentially wreak, and indeed such forms of temporal, sensory desynchronization have been thought to lie behind some forms of mental illness, (see Mundell, Mayes, MacDonald, Pickering, & Fairbairn, 1991; Tallal, Galaburda, Llinas, & von Euler, 1993).

## **How the Brain Finesses the Problem of Inter-Sensory Synchronization**

*"If the perception of time is based on inbuilt mechanisms, the problem of identifying them arises."* (Treisman, 1999).

It was during such a lightning storm while considering the nature of the synchronization problem that it first occurred to me that the brain largely does not NEED to solve this on-going series of synchronization problems that inter-sensory simultaneity appears to pose. Let us explore this proposition of non-necessary synchronization a little further. For the sensory system dealing with olfaction, the onset of a smell can be attention getting and if the smell has hedonic properties we may follow it and try to ascertain its source. For example, a fast-food restaurant, of which there are many in Florida, will give out an enticing aroma but we do not perceive either the onset or the offset of the smell to be an obvious, discrete event that regularly acts as an unequivocal sensory marker in time. Indeed, despite the example of coffee as a stimulus to get up each morning, smell is a much more continuous experience which has the character of ebb and flow or waxing and waning rather than sudden onset and offset. I believe this property of fuzzy identification in time (this being largely an attribute of human sensory capacities of course), is not

happenstance but is part of a specific strategy of the assemblage of sensory capacities. Since olfaction is often considered relatively low on the scale of sensory importance in human beings, it fits in where it can to the overall experience of reality - timewise. If smell begins to finesse the problem of synchronization in time by fuzzy temporal identity what then of the other sensory systems?

Let us next consider tactile-kinesthesia. Body sense and the tactile boundary conditions of the sense of self is how we physically touch the world. As such these capacities code sensory stimulation which is literally close to our hearts. Tactile stimulation requires that you are within touching distance of something and recursively, it is within touching distance of you. Setting the overall argument of sensory synchronicity in an evolutionary context, the fundamental problem that any living being including human beings, are faced with upon encountering an entity in the environment is either to consume it or consummate it (McBride, 2005). Of course, in the contemporary world of human beings we now hopefully possess a somewhat broader repertoire of behavioral response. For example, one might well chose to ignore it - whatever *it* is. Indeed, if it does not trigger responses suggestive of either food or fertility, in an energy-critical world, simply passing by may be the preferred or indeed optimal response. Indeed, in earlier times, one would often wish to run away from such contact since the entity itself might well see you as food, or even worse! But touch is a very time critical sense. Due to the issue of physical proximity, one has to react quickly, if one is to preserve the chance to react later at all. Thus, what I am suggesting is that while sensory systems each transduce different spatial ranges of energy, they possess a complimentary distribution in the temporal range of their capacities also in order to construct the experience of reality.

Having considered the sensory capacities of olfaction and tactile kinesthesia, we have to understand how the strategy of absolute temporal finesse applies to the major sensory systems of vision and audition. In general terms, vision and audition work in the same general fashion. One part of each of these systems is especially sensitive to change and serves to direct a second part of each system, composed of finer levels of processing, toward sources of perceived greatest importance. Vision and audition are relatively slow sensory systems since much top-down expectation enters the ebb and flow of what

is perceived as being seen and heard. If every stimulus in vision and audition had to be individually time-tagged and then passed through some form of cortical simultaneity comparator, information transmission through the active nervous system would quickly become overloaded and grind to a fatal halt as demands quickly overwhelmed any possible processing capacity. However, we have an existence proof that this does not happen and thus we need to understand how the brain solves the problem. The following section indicates one way in which I suggest the simultaneity (time-tagging) question is finessed by the brain in the real-world.

## **Levels of detail**

We can pose the simultaneity question from another perspective; that of the outside in. That is, does the brain actually have to solve the stimulus simultaneity problem and if so what would connote a possible form of solution. Sometimes the best answer to a difficult question is to object that the question is really not a question at all! If we are considering the simultaneity question from the outside in, one way of approaching this is to ask questions about how people build surrogate worlds. Today, there is a very active branch of science which seeks to accomplish just such a goal - the area of simulation. In a rather tortuous analogy, the brain like the simulation scientist has to 'create' a world (Hancock, 2005). I shall not enter here into the fundamental philosophical issue of reality as externally created versus self-generated, it is merely sufficient to say that the simulation scientist is faced with the challenge of creating a coherent world. Like the under-funded simulation scientist, and there are many of these in Florida, the brain has limited resources and cannot call upon infinite computational capacity. Compromises and sacrifices therefore have to be made. The simulation scientist achieves a degree of compromise by a strategy that is often called 'levels of detail' programming (Hancock, 2005). In essence, what the eye does not see, the computer does not grieve over.

To be more specific, in a simulation, if the scene contains for example mountains in the background, the simulation scientist does not spend significant computational time and power simulating these mountains in all their three-dimensional glory since the individual will probably never reach them. (As

a general comparable example one may recall that the producers did not spend large amounts of money decorating the horizon on the 'Trueman Show' since they thought his fear for water would prevent him ever reaching such a location). Far distant objects in simulation can be just as easily and much more elegantly (in computational terms) be represented by a two dimensional surface with a single, general texture map. Thus, in ground-vehicle simulation (such as a driving simulator), it is much better spending your computational capacity on the details of objects much closer to 'home.' Home, in simulation science is ubiquitously specified as the referential eye-point of the observer (this, of course, being simply another instantiation of the privileged observer notion). When faced with a different challenge, such as flight simulation, the simulation scientist now *does* choose to spend his or her computational resources on mountains since they have much greater relevance to the presently simulated world, but not, for example, on the details of a road-side stop sign, which cannot be 'seen' at 1,000 mph and from 20,000 ft. anyway. Parenthetically, this serves to indicate why helicopter simulation is so expensive, since it has to satisfy the demands of both ground and flight simulation. The scientist's answer in this case is simply to acquire a much more powerful computer system. However, since we cannot extend the cortex on demand, what does the brain do?

In a general sense, the brain solves the problem in the same fundamental manner. The brain provides a natural 'levels of detail' processing in that various thresholds describe the limits of resolution power for each respective sensory system. If one's office is at the top of a particularly high building, as one looks out of the window, one might touch the glass, hear the bird sing from a nearby ledge but actually see something like forty miles (which is actually the maximum nominal visibility distance given in aviation). Now consider what the brain needs to solve in terms of temporal 'levels of detail' in this circumstance. If, from this window, one sees a ship on a distant river, one could certainly not touch it (the visual-tactile simultaneity problem is immediate redundant). If the ship is far enough away, one would not hear the engines despite being able to see that it is in motion (formally, the auditory threshold is exceeded well before the visual threshold is reached). Similarly, it may be belching out a tremendous smell but unless there is a specific wind direction and the window were open, one would not be able to smell it and

remember the olfactory system obviates many such problems by its inherently fuzzy nature. I could continue with a potentially endless set of examples of this levels of detail finesse, however, hopefully the point is clear. There are many, if not most, environmental circumstances in which the whole problem of stimulus simultaneity is simply avoided.

This 'levels of detail' argument also provides an evolutionary reason why vision is the dominant sensory system. It is not simply that light provides the best adaptive zeitgeber for sensory registration of spatio-temporal experience (Gibson, 1979), it is evidently the case that one sensory capacity must over-dominate in order to resolve any ambiguity problems that do periodically arise. This is a solution to an old conundrum which says that an individual with one watch knows what the time is, while an individual with two watches is never sure. The sensory systems present the opportunity for several acute time representations and in order to resolve any ambiguity that is not solved by first pass finesse derived from the 'levels of detail' strategy, one has to assume that the over-dominance of one system (i.e., vision - believing one's eyes first) will provide (right or wrong) an answer. It is only then in very arcane psychological experimental situations in which can generate sensory illusions in time such as the Pulfrich effect (Pulfrich, 1922). Simultaneity, is thus finessed at multiple levels of the sensory 'clocking' system which, in using levels of detail and dominance and the finesse of never sensory time-tagging anyway, does not have to face the problem of absolute time resolution. Interestingly, information from inter and intra-sensory comparisons can however, still be used to coordinate action, as is discussed below.

The brain still has to register self-continuity in time. That is, there must be some part of neural processing that permits the individual to perceive their own continuing existence. Given that this is not now conceivable if the sensory systems work in the temporal manner I have suggested, this has to be supplied by some other part of the brain. I would argue that self-continuity is a very primitive requirement and extends well beyond human beings since almost all organisms have to have a continuing awareness of self in both space and time (and see Hume, 1739). Imagine, for example, if one did not have such an awareness - an organism might very well start to eat itself. This continuity function has been suggested as located in the limbic system and

has been observed to be temperature dependent (cf., Hancock, 1993; Matell & Meck, 2000; Treisman, 1999). If this primitive system permits temporal continuity, there is also a counter-part in the frontal lobes which permits the individual to go 'faster than time.' This is accomplished by the generation of numerous 'what-if?' scenarios that means the individual does not always have to process time in a reactive mode (and see Hancock, Szalma, & Oron-Gilad, 2005). This observation actually implies that memory has nothing to do with the past and is simply the tool that the brain uses to construct useful "what-if" scenarios for the future (and see Staddon, 2005). This sentiment is very much in accord with Dennett's (1991) comment that all brains are essentially, anticipation machines. The present focus on sensory clocking mechanisms can make it seem as if the human being is simply a detached observer of the world (as the privileged observer notion also implies), instead of an active player within it. If the account I have given, by which the sensory systems finesse the simultaneity problem, is to be at all valid it has also to deal with the way in which individuals engage in synchronized activities within the world. It is this issue which is the focus of the final section of this work.

### **Embracing, Ignoring, or Avoiding**

In the environment in which human development occurs, action leads perception just as much as perception supports action (Powers, 1973). As mentioned earlier, under the mandate of consuming, consummating, or circumnavigating entities we encounter in the environment, physical actions can be generally categorized into colliding, embracing, ignoring, or actually avoiding other objects altogether. However, our focus is on time and so we need to explore these different set of acts in terms of their temporal implications. Whatever action one takes, the problem to be solved is time-to-contact. [Unfortunately, at this juncture, it is necessary to introduce specific terms employed in the area of ecological psychology and a brief diversion is necessary]. If one is seeking an embracing action, then contact with any specified surface is usually soft or benign. This is a subcategory of overall time-to-contact termed Time-to-Soft-Contact (TTSC). This would be used in cases where one seeks to manipulate objects or entities in the environment - typing on a computer say, or picking up a coffee cup. Conversely, if one ignores the entity

in a general sense then this would be Time-to-Non-Contact (TTNC) and implies an avoiding action (and see Hancock & Manser, 1997). Some rare situations encourage the individual to make heavy contact with another object or entity, i.e., hitting. Since there is a constant danger of personal damage in these situations, such time-to-hard-contact (TTHC) cases are relatively rare. In these specialized circumstances (for example in sports like karate and boxing) one should ensure that the resilient pieces of one's own body meets the vulnerable parts of one's opponent. The crucial issue here is that each of these sets of actions in the environment are subsumed under the general realm of time-to-contact (Hancock & Manser, 1998). The crucial thing to understand, and indeed the central pillar of all of ecological psychology, is that such time-to-contact derivations can be accomplished totally within the sensor itself and thus access to any centralized timing system (and thus reference to absolute timing) remains unnecessary (cf., Hancock & Manser, 1997; Wickens & Holland, 1999). In the eye, for which capacities have been most thoroughly investigated, the 'calculation' (if calculation it can be called) is accomplished by comparison of innervation areas on the retina itself. As has been shown by Lee and Reddish (1981), Gibson (1979), and others, symmetrical expansion about the central axes uniquely designate incipient contact, and the rate at which that object expands on the retina uniquely specifies 'time-to-contact' or more generally the constraints on temporal action. While the cases for objects that will by-pass an individual are mathematically more complex, the sensory array still provides direct temporal information - independent of the necessity to access higher neural functioning (Hancock & Manser, 1998). Now we can see that the way that the brain finesses time at the sensory level is to encode temporal perception and time for action at the level of the sensory system itself, leaving the necessity to access any reference to absolute time for such events totally circumvented.

It is, of course, possible to force the sensory systems to search for simultaneity, but these circumstances occur naturally at a far less frequent rate than one might imagine. Also, in searching specifically for sensory simultaneity, we have the great advantage of feed-forward via top-down processes from the frontal cortex. In these conditions, expectation can overwhelm any minor discrepancy between sensory streams. It is important to reiterate then that my central point is that sensory systems do not ever need to actually have direct

access to any source of 'absolute' time. In so doing, they overcome the problem of having a momentary point in space and time of privileged observation within the brain. The continuing sense of self is generated at another level of the brain altogether and provides the experience of personal continuity, but not in terms of the immediate experience of reality that the notion of consciousness implies (Poppel, 1985; Smith & Hancock, 1995). Let me also add in closing, that this finesse in relation to absolute, or external time, does not obviate the utility of information derived from intra- and inter-sensory modality comparisons. In principle, the present argument can also be applied to other temporal properties such as duration estimation. However, this requires and elaborated argument upon how individual sensory systems interconnect with the continuity mechanism often referred to as the biological, chemical, or more generally internal clock (Francois, 1927; Hancock, 1993, Hoagland, 1933; Lewis & Walsh, 2002). Such efforts require further sophisticated theoretical advance (see Dennett & Kinsbourne, 1992; Treisman, 1963) and the integration of complex neuro-physiological evidence (Meck, 2005; Meck & Benson, 2002). Such work has been on-going and continues to progress (see Hancock, Szalma, & Oron-Gilad, 2005).

## **Summary and Conclusions**

In this brief work, I have tried to look at the problem of time from the outside in. While this inevitably implies a number of cosmological and philosophical questions such as the veridical existence of an external reality and how far the brain imposes structure on any such purported externality, as compared to discovering an intrinsic ordering within it, the main concern here has been with how the brain deals with, and integrates aspects of what is commonly referred to as, external or physical time. In psychology, this pursuit has a long history subsumed under the general topic of the duration of the psychological present. It is allied to the subject of Vierordt's Law (Vierordt, 1868) and was noted by James (1890), having now puzzled researchers for more than a century and a half. If you search for a value of this moment, or 'specious' present in any sensory system, you will always find an answer in the form of a particular duration (e.g., see Vroon, 1974). Indeed, a wide range of times have, and continue to be offered by many different scientists (see Coren, Ward, & Enns, 2004; Poppel, 1997; Stroud, 1955; White, 1963). However,

I propose that it is the premise of this search that is itself flawed. If the notion of a temporally privileged observer is simply incorrect, what flows from this flawed premise is itself, on each occasion necessarily, a flawed answer. Thus the way in which the brain deals with the issue of time-tagging each discrete sensory event is to simply finesse the problem and never require the sensory systems to perform this function in an absolute time frame. This solution requires that the sense of self-continuity is generated elsewhere in the brain and I have argued here for this functional division. These present observations do not represent a complete explanation of how the brain deals with time by any means. However, hopefully, they represent one small step along a path toward a synthesis of psychological and cosmological forms of time, a conundrum that has defied solution since humans first understood the issue (and see the exposition of Fraser, 1987 for complete discussion). That the present proposal can also serve to provide a propositional solution to the persistence psychological conundrum known as the 'binding' problem (O'Reilly, Busby, & Soto, 2003) is also self-evident.

## **Acknowledgements**

*This work was prepared under Grant #NBCH 1030012 from the Defense Advanced Research Projects Agency, (DARPA) via the Department of the Interior. The Grant Monitors for this work were Cmdr Dylan Schmorrow and LCDR Russ Shilling. The project itself is under the direction of Dr Dennis McBride of the Potomac Institute. I am most indebted to the concise and information comments of an anonymous reviewer of an earlier version of this work whose observations were most helpful. The view expressed here are those of the author and do not necessarily represent those of any named individual or agency.*

## **References**

- Block, R.A. (1990) (Ed.). *Cognitive models of psychological time*. Lawrence Erlbaum: Hillsdale, New Jersey.
- Bronowski, J. (1973). *The ascent of man*. Little, Brown & Co.: New York.
- Connor, J.A. (2004). *Kepler's witch: An astronomer's discovery of cosmic order amid religious war, political intrigue, and the heresy trail of his mother*. Harper Collins: New York.
- Coren, S., Ward, L.M., & Enns, J.T. (2004). *Sensation and perception*. Wiley: Hoboken, New Jersey.

- Dennett, D.C. (1991). *Consciousness explained*. Little, Brown & Co.: Boston.
- Dennett, D.C., & Kinsbourne, M. (1992). Time and the observer. *Behavioral and Brain Sciences*, **15** (2), 183-247.
- Fraser, J.T. (1987). *Time the familiar stranger*. Tempus Books; Redmond, WA.
- Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Hancock, P.A. (1993). Body temperature influences on duration estimation. *Journal of General Psychology*, **120**, 197-216.
- Hancock, P.A. (2002). The time of your life. *Kronoscope*, **2** (2), 135-165.
- Hancock, P.A. (2005). The future of simulation. In: D. Vicenzi and J. Wise (Eds.). *Human factors and simulation*. Erlbaum: Mahwah, New Jersey, in press.
- Hancock, P.A., & Manser, M.P. (1997). Time-to-contact: More than tau alone. *Ecological Psychology*, **9**, 265-297.
- Hancock, P.A., & Manser, M.P. (1998). Time-to-contact. In: A.M. Feyer and A.M. Williamson (Ed.). *Occupational injury*. London: Taylor and Francis.
- Hancock, P.A., Szalma, J.L., & Oron-Gilad, T. (2005). Time, emotion, and the limits to human information processing. In: D. McBride and D. Schmorow (Eds.). *Quantifying Human Information Processing*, (pp. 157-175), Lexington Books: Lanham, MD.
- Hoagland, H. (1933). The physiological control of judgments of duration: Evidence for a chemical clock. *Journal of General Psychology*, **9**, 267-287.
- Hume, D. (1739). *A treatise of human nature*. Noon: Cheapside.
- James, W. (1890). *Principles of psychology*. Holt: New York.
- Koestler, A. (1968). *The sleepwalkers*. MacMillan: New York.
- Lee, D.N., & Reddish, P. (1981). Plummeting gannets: A paradigm of ecological optics. *Nature*, **293**, 293-294.
- Lewis, P.A., & Walsh, V. (2002). Neuropsychology: Time out of 0mind. *Current Biology*, **12**, R9-R11.
- Matell, M.S., & Meck, W.H. (2000). Neuropsychological mechanisms of interval timing behavior. *Bioessays*, **22**, 94-103.
- McBride, D.K. (2005). The quantification of human information processing. In: D. McBride and D. Schmorow (Eds.). *Quantifying human information processing*, (pp. 1-41), Lexington Books: Lanham, MD.
- Meck, W.H. (2005). Neuropsychology of timing and time perception. *Brain & Cognition*, **58** (1), 1-8.
- Meck, W.H., & Benson, A.M. (2002). Dissecting the brain's internal clock: How frontal-striatal circuitry keeps time and shifts attention. *Brain and Cognition*, **48**, 195-211.
- Minsky, M. (1988). *The society of mind*. New York: Simon & Schuster.
- Mundell, P.R., Mayes, A.R., MacDonald, C., Pickering, A., & Fairbairn, A.F. (1991).

- Korsakoff amnesiacs are poor at judging the sequence of two tones. *Cortex*, **27**, 431-439.
- O'Reilly, R.C., Busby, R.S., & Soto, R. (2003). Three forms of binding and their neural substrates: Alternatives to temporal synchrony. In: A. Cleeremans (Ed) *The Unity of Consciousness: Binding, Integration, and Dissociation*, (pp. 168-192), Oxford: Oxford University Press.
- Poppel, E. (1985). *Mindworks: Time and conscious experience*. Harcourt, Brace, Jovanovich: Boston.
- Poppel, E. (1997). A hierarchical model of temporal perception. *Trends in Cognitive Science*, **1**, 56-61.
- Powers, W.T. (1973). *Behavior: The control of perception*. Aldine: Chicago.
- Pulfrich, C. (1922). Die stereoskopie in dienste der isochromen und heterochromen photometrie. *Naturwissenschaften*, **10**, 533-564.
- Russell, B. (1915). On the experience of time. *Monist*, **25**, 212-233.
- Smith, K., & Hancock, P.A. (1995). Situation awareness is adaptive, externally-directed consciousness. *Human Factors*, **37**, 137-148.
- Staddon, J.E.R. (2005). Interval timing: memory, not a clock. *Trends in Cognitive Sciences*, **9** (7), 312-314.
- Stroud, J.M. (1955). The fine structure of psychological time. In: H. Quastler (Ed.). *Information theory in psychology*. Glencoe, IL: Free Press.
- Tallal, P., Galaburda, A.M., Llinas, R.R., & von Euler, C. (1993). Temporal information processing in the nervous system: Special reference to dyslexia and dysphasia. *Annals of the New York Academy of Science*, **682**. New York: New York
- Treisman, M. (1999). The perception of time. In: J. Butterfield (Ed.). *The arguments of time*, (pp. 217-246). Oxford: Oxford University Press.
- Vierordt, K. (1868). Der zeitsinn nach l'ersuchen. [The sense of time in experiments]. Tübingen: Laupp.
- Vron, P.A. (1974). Is there a quantum in duration experience? *America Journal of Psychology*, **87**, 237-245.
- White, C.T. (1963). Temporal numerosity and the psychological unit of duration. *Psychological Monographs*, **77**, Whole No. 575.
- Whitrow, G.J. (2003). *What is time?* Oxford: Oxford University Press.
- Wickens, C.D., & Hollands, J. (1999). *Engineering psychology and human performance*. Prentice-Hall: Upper Saddle River, New Jersey.