



# Timing and time perception: A selective review and commentary on recent reviews

Richard A. Block<sup>1\*</sup> and Simon Grondin<sup>2</sup>

<sup>1</sup> Department of Psychology, Montana State University, Bozeman, MT, USA

<sup>2</sup> École de psychologie, Université Laval, Québec City, QC, Canada

\*Correspondence: [block@montana.edu](mailto:block@montana.edu)

## Edited by:

Claire Zedelius, University of California, Santa Barbara, USA

## Reviewed by:

Hedderik Van Rijn, University of Groningen, Netherlands

**Keywords:** time perception, attention, animals, humans, commentary

## A commentary on

### Perception and estimation of time

by Fraisse, P. (1984). *Annu. Rev. Psychol.* 35, 1–36. doi: 10.1146/annurev.ps.35.020184.000245

**Properties of the internal clock: first- and second-order principles of subjective time**  
by Allman, M. J., Teki, S., Griffiths, T. D., and Meck, W. H. (2014). *Annu. Rev. Psychol.* 65, 743–771. doi: 10.1146/annurev-psych-010213-115117

A clear example of the progress in the field of timing and time perception could be obtained by contrasting two articles published 30 years apart in the influential *Annual Review of Psychology* (ARP): one by Fraisse (1984), and one by Allman et al. (2014). The fact that there was one author 30 years ago, and a group of authors now, is a tangible sign of the contemporary way of approaching scientific research. In his review, Fraisse emphasized the distinction between time perception and time estimation; in their review, Allman et al. focused on the internal clock and the cerebral bases of timing and time perception.

Fraisse's review was published when a very important event happened in the field of timing and time perception: a conference was held in New York, in 1983, where researchers from both human and animal time perception met to communicate with one another. The conference led to the publication of the classical book edited by the late John Gibbon and the late Lorraine Allan (Gibbon and Allan, 1984). This meeting probably catalyzed the

research on timing and time perception, especially the one emphasizing the scalar expectancy theory and, more generally speaking, the internal clock perspective, a clock described as a pacemaker-counter device.

It is somewhat surprising that there was no mention in Fraisse (1984) of this promising (to say the least) pacemaker-counter perspective, which was already available in the human timing literature (Creelman, 1962; Treisman, 1963). Moreover, the modest portions of information in Fraisse dedicated to the cerebral bases of timing exemplify the gap between the contemporary research in the field and the state of the literature 30 years ago.

With its emphasis on neuroscience literature (e.g., brain areas, cortical circuits, pharmacological effects, and pathologies), Allman et al. wrote an important, well-structured, and interesting state-of-the-art review on the cerebral bases of the time perception mechanisms. It is a bit surprising though that the scalar property is taken for granted, given actually Fraisse's fundamental distinction between time perception and time estimation, a distinction that could find some echoes in the limitation of the stability of the Weber fraction for time (see Figure 3 in Gibbon et al., 1997; or, for instance, Grondin, 2001, 2010b, 2012, 2015). Moreover, assuming the linearity between psychological and physical time (psychophysical law) remains disputable (Eisler, 1976).

By emphasizing the internal clock perspective, it was not possible for Allman et al. (2014) to refer to other recent developments in the field. Amongst the

portions of the literature the reader might want to consider, there is one on retrospective timing (Block and Zakay, 1997; Tobin et al., 2010). There is also some interesting research (e.g., Boltz, 1998; Brown, 2008) offering a purely cognitive explanation of psychological time and timing—without reference to an internal clock (see reviews by Block et al., 1999, 2010; Block, 2003). Even within the perspective of an internal clock, the attentional-gate model (see for example, Zakay and Block, 1995 and later articles), which in an extension of the scalar expectancy theory, is worth mentioning.

Indeed, with the large increase of research in the field of timing and time perception in the Twenty-first century, it is not surprising to see so many recent special issues of journals on this topic, or close variants of them. The explosion is such that researchers have written a large number of recent review articles (see Table 1). This was partly described in an annotated bibliography on “Time Perception” (Block and Hancock, 2013). Another tangible sign of the vitality of this research field is exemplified by a large COST grant funded by the E.U. (title: “Time In MEntAL activiTY,” or “TIMELY”) and the resulting founding of the Brill's new scientific journal dedicated to the psychology of time, *Timing and Time Perception*, co-edited by Meck et al.

In conclusion, being a researcher in the field of timing and time perception has never been as exciting as it is at present, given the growth of its popularity, which has been enhanced by the arrival of contributions from neuroscientists. This

**Table 1 | Selected list (in reverse chronological order) of reviews since 2010 on the psychology of time.**

Type	Authors	Year	Title
Book	Merchant and de Lafuente	2015	Neurobiology of interval timing
SI	Medina et al.	2014	Advances in modern mental chronometry
Book	Vatakis and Allman	2014	Time distortions in mind: temporal processing in clinical populations.
Rev	Allman et al.	2014	Properties of the internal clock: first- and second-order principles of subjective time
Rev	Block and Gruber	2014	Time perception, attention, and memory: a selective review
SI	Broadway et al.	2014	The long and short of mental time travel– self-projection over time-scales large and small
SI	Buhusi	2014	Associative and temporal learning: New directions
Book	Lloyd and Arstila	2014	Subjective time: the philosophy, psychology, and neuroscience of temporality
Rev	Matthews and Meck	2014	Temporal perception: the bad news and the good
SI	Tucci et al.	2014	Timing in neurobiological processes: from genes to behavior compiled
SI	Vatakis and Ulrich	2014	Temporal processing within and across senses (two <i>Acta Psychologica</i> special issues)
Bib	Block and Hancock	2013	Time perception (annotated bibliography)
SI	Coull et al.	2013	How does the brain process time?
Rev	Merchant et al.	2013	Neural basis of the perception and estimation of time
Rev	Wittmann	2013	The inner sense of time: how the brain creates a representation of duration
Rev	Allman and Meck	2012	Pathophysiological distortions in time perception and timed performance
Rev	Hancock and Block	2012	The psychology of Time: a view backward and forward
SI	Meck et al.	2012	Interval timing and time-based decision making
Rev	Coull et al.	2011	Neuroanatomical and neurochemical substrates of timing
Rev	Gorea	2011	Ticks per thought or thoughts per tick? A selective review of time perception with hints on future research
SI	Vatakis et al.	2011	Multidisciplinary aspects of time and time perception
Rev	Block et al.	2010	How cognitive load affects duration judgments: a meta-analytic review
Rev	Grondin	2010a	Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions

Book is an edited book. Rev is a review article. SI is a special issue. Bib is a bibliography.

excitement could be extended if one considers psychological time in an even larger perspective, or larger scale from the memory for the past events (Friedman, 1993) to the capacity to predict the duration of future events (Roy et al., 2005).

## ACKNOWLEDGMENT

We thank Keith Hutchison and an anonymous reviewer for their very helpful suggestions on drafts of this commentary.

## REFERENCES

- Allman, M. J., and Meck, W. H. (2012). Pathophysiological distortions in time perception and timed performance. *Brain* 135, 656–677. doi: 10.1093/brain/awr210
- Allman, M. J., Teki, S., Griffiths, T. D., and Meck, W. H. (2014). Properties of the internal clock: first- and second-order principles of subjective time. *Annu. Rev. Psychol.* 65, 743–771. doi: 10.1146/annurev-psych-010213-115117
- Block, R. A. (2003). “Psychological timing without a timer: the roles of attention and memory,” in *Time and Mind II*, ed H. Helfrich (Cambridge, MA: Hogrefe & Huber), 41–60.
- Block, R. A., and Gruber, R. P. (2014). Time perception, attention, and memory: a selective review. *Acta Psychol.* 149, 129–133. doi: 10.1016/j.actpsy.2013.11.003
- Block, R. A., and Hancock, P. A. (2013). “Time perception,” in *Annotated Bibliography* (Oxford Online Bibliographies), 284–295. <http://www.oxfordbibliographies.com>
- Block, R. A., Hancock, P. A., and Zakay, D. (2010). How cognitive load affects duration judgments: a meta-analytic review. *Acta Psychol.* 134, 330–343. doi: 10.1016/j.actpsy.2010.03.006
- Block, R. A., and Zakay, D. (1997). Prospective and retrospective duration judgments: a meta-analytic review. *Psychon. Bull. Rev.* 4, 184–197. doi: 10.3758/BF03209393
- Block, R. A., Zakay, D., and Hancock, P. A. (1999). Developmental changes in human duration judgments: a meta-analytic review. *Dev. Rev.* 19, 183–211. doi: 10.1006/drev.1998.0475
- Boltz, M. G. (1998). The processing of temporal and nontemporal information in the remembering of event durations and musical structure. *J. Exp. Psychol. Hum. Percept. Perform.* 24, 1087–1104. doi: 10.1037/0096-1523.24.4.1087
- Broadway, J. M., Zedelius, C., Schooler, J., and Grondin, S. (2014). The long and short of mental time travel– self-projection over time-scales large and small. *Front. Psychol. Perception Science*.
- Brown, S. W. (2008). “Time and attention: review of the literature,” in *Psychology of Time*, ed S. Grondin (Bingley: Emerald), 111–138.
- Buhusi, C. V. (2014). Associative and temporal learning: new directions. *Behav. Process.* 101, 1–3. doi: 10.1016/j.beproc.2014.01.005
- Coull, J. T., Cheng, R.-K., and Meck, W. H. (2011). Neuroanatomical and neurochemical substrates of timing. *Neuropsychopharmacology* 36, 3–25. doi: 10.1038/npp.2010.113
- Coull, J. T., Van Wassenhove, V., and Coslett, H. B. (eds.). (2013). How does the brain process time? *Neuropsychologia* 51, 187–384.
- Creelman, C. D. (1962). Human discrimination of auditory duration. *J. Acoust. Soc. Am.* 34, 582–593. doi: 10.1121/1.1918172
- Eisler, H. (1976). Experiments on subjective duration 1878–1975: a collection of power function exponents. *Psychol. Bull.* 83, 185–200. doi: 10.1037/0033-2909.83.6.1154
- Fraisse, P. (1984). Perception and estimation of time. *Annu. Rev. Psychol.* 35, 1–36. doi: 10.1146/annurev.ps.35.020184.000245
- Friedman, W. J. (1993). Memory for the time of past events. *Psychol. Bull.* 113, 44–66. doi: 10.1037/0033-2909.113.1.44
- Gibbon, J., and Allan, L. G. (eds.). (1984). *Annals of the New York Academy of Sciences. Vol. 423. Timing and Time Perception*. New York, NY: New York Academy of Sciences.
- Gibbon, J., Malapani, C., Dale, C. L., and Gallistel, C. (1997). Toward a neurobiology of temporal cognition: advances and challenges. *Curr. Opin. Neurobiol.* 7, 170–184. doi: 10.1016/S0959-4388(97)80005-0
- Gorea, A. (2011). Ticks per thought or thoughts per tick? A selective review of time perception with

- hints on future research. *J. Physiol.* 105, 153–163. doi: 10.1016/j.jphysparis.2011.09.008
- Grondin, S. (2001). From physical time to the first and second moments of psychological time. *Psychol. Bull.* 127, 22–44. doi: 10.1037/0033-2909.127.1.22
- Grondin, S. (2010a). Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions. *Atten. Percept. Psychophys.* 72, 561–582. doi: 10.3758/APP.72.3.561
- Grondin, S. (2010b). Unequal Weber fraction for the categorization of brief temporal intervals. *Atten. Percept. Psychophys.* 72, 1422–1430. doi: 10.3758/APP.72.5.1422
- Grondin, S. (2012). Violation of the scalar property for time perception between 1 and 2 seconds: evidence from interval discrimination, reproduction, and categorization. *J. Exp. Psychol. Hum. Percept. Perform.* 38, 880–890. doi: 10.1037/a0027188
- Grondin, S. (2015). “About the (non)scalar property for time perception,” in *Neurobiology of Interval Timing*, eds H. Merchant and V. de Lafuente (New York, NY: Springer).
- Hancock, P. A., and Block, R. A. (2012). The psychology of time: A view backward and forward. *Am. J. Psychol.* 125, 267–274. doi: 10.5406/amerjpsyc.125.3.0267
- Lloyd, D., and Arstila, V. (eds.). (2014). *Subjective Time: The Philosophy, Psychology, and Neuroscience of Temporality*. Cambridge, MA: MIT Press.
- Matthews, W. J., and Meck, W. H. (2014). Time perception: the bad news and the good. *WIREs Cogn. Sci.* 5, 429–446. doi: 10.1002/wcs.1298
- Meck, W. H., Doyère, V., and Gruart, A. (2012). Interval timing and time-based decision making. *Front. Integr. Neurosci.* 6:13. doi: 10.3389/fnint.2012.00013
- Medina, J. M., Wong, W., Díaz, J. A., and Colonius, H. (2014). Advances in modern mental chronometry. *Front. Hum. Neurosci.*
- Merchant, H., and de Lafuente, V. (eds.). (2015). *Neurobiology of Interval Timing*. New York, NY: Springer.
- Merchant, H., Harrington, D. L., and Meck, W. H. (2013). Neural basis of the perception and estimation of time. *Annu. Rev. Neurosci.* 36, 313–336. doi: 10.1146/annurev-neuro-062012-170349
- Roy, M. M., Christenfeld, N. J. S., and McKenzie, C. R. M. (2005). Underestimation of future duration: memory incorrectly used or memory bias. *Psychol. Bull.* 131, 738–756. doi: 10.1037/0033-2909.131.5.738
- Tobin, S., Bisson, N., and Grondin, S. (2010). An ecological approach to prospective and retrospective timing of long durations: a study involving gamers. *PLoS ONE* 5:e9271. doi: 10.1371/journal.pone.0009271
- Treisman, M. (1963). Temporal discrimination and the indifference interval: implications for a model of the “internal clock.” *Psychol. Monogr.* 77, 576. doi: 10.1037/h0093864
- Tucci, V., Buhusi, C. V., Gallistel, R., and Meck, W. H. (2014). Timing in neurobiological processes: from genes to behaviour compiled. *Philos. Trans. R. Soc. B* 369:20120470. doi: 10.1098/rstb.2012.0470
- Vatakis, A., and Allman, M. J. (eds.) (2014). *Time Distortions in Mind: Temporal Processing in Clinical Populations*. Boston, MA: Brill Academic Publishers.
- Vatakis, A., Esposito, A., Giagkou, M., Cummins, F., and Papadelis, G. (2011). *Multidisciplinary Aspects of Time and Time Perception*. Vol. 6789. *Lecture Notes in Computer Science*, Berlin: Springer. doi: 10.1007/978-3-642-21478-3
- Vatakis, A., and Ulrich, R. (eds.). (2014). Temporal processing within and across senses. *Acta Psychol. (Amst.)* 147(pt 1 and 2), 149. doi: 10.1016/j.actpsy.2014.01.001
- Wittmann, M. (2013). The inner sense of time: how the brain creates a representation of duration. *Nat. Rev. Neurosci.* 14, 217–223. doi: 10.1038/nrn3452
- Zakay, D., and Block, R. A. (1995). “An attentional-gate model of prospective time estimation,” in *Time and the Dynamic Control of Behavior*, eds M. Richelle, V. D. Keyser, G. d’Ydewalle, and A. Vandierendonck (Liège, Belgium: Université de Liège), 167–178.

**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 02 May 2014; accepted: 06 June 2014; published online: 29 July 2014.

Citation: Block RA and Grondin S (2014) Timing and time perception: A selective review and commentary on recent reviews. *Front. Psychol.* 5:648. doi: 10.3389/fpsyg.2014.00648

This article was submitted to Perception Science, a section of the journal *Frontiers in Psychology*.

Copyright © 2014 Block and Grondin. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) or licensor are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.