Consciousness and Cognition 53 (2017) 136–150

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

EEG correlates of cognitive time scales in the Necker-Zeno model for bistable perception

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ARTICLE INFO

Keywords:
Ambiguous figures
Bistable perception
Necker cube
EEG
Event-related potentials
Meditation
Cognitive time scales
Necker-Zeno model
Quantum cognition

ABSTRACT

The Necker-Zeno model of bistable perception provides a formal relation between the average duration of meta-stable percepts (dwell times T) of ambiguous figures and two other basic time scales (t_0, ΔT) underlying cognitive processing. The model predicts that dwell times T covary with t_0, ΔT or both. We tested this prediction by exploiting that observers, in particular experienced meditators, can volitionally control dwell times T.

Meditators and non-meditators observed bistable Necker cubes either passively or tried to hold their current percept. The latencies of a centro-parietal event-related potential (CPP) were recorded as a physiological correlate of t_0.

Dwell times T and the CPP latencies, correlated with t_0, differed between conditions and observer groups, while ΔT remained constant in the range predicted by the model. The covariation of CPP latencies and dwell times, as well as their quadratic functional dependence extends previous psychophysical confirmation of the Necker-Zeno model to psychophysiological measures.

1. Introduction

1.1. Background

In recent decades, there has been accumulating evidence that central conceptual features of quantum theory, such as non-commuting operations, are also of pivotal significance outside the domain of physics, e.g. in psychology and cognitive science (for overviews see Busemeyer & Bruza, 2012; Wang, Busemeyer, Atmanspacher, & Pothos, 2013; Wendt, 2015). As opposed to a number of approaches trying to describe brain activity in terms of quantum physical processes, this research program utilizes mathematical features of quantum theory to describe cognitive processes without explicit reference to quantum processes in the brain.

Intuitively, it is not difficult to understand why features such as non-commuting operations should be relevant, even inevitable, for systems that have nothing to do with quantum physics. Simply speaking, the non-commutativity of operations means nothing else than that the sequence, in which operations are applied, matters for the final result. This is obvious in psychology and cognitive

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http://dx.doi.org/10.1016/j.concog.2017.04.011
Received 23 February 2017; Received in revised form 7 April 2017; Accepted 15 April 2017
Available online 27 June 2017

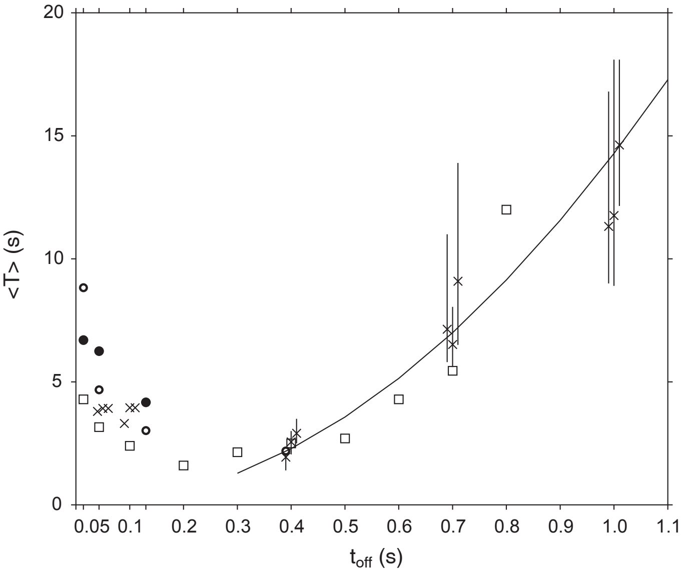

Fig. 1. Psychophysical evidence for the Necker-Zeno model. Experimentally obtained mean dwell times $\langle T\rangle$ (inverse reversal rates) for the perception of a discontinuously presented ambiguous Necker stimulus. Two ranges of different behavior of $\langle T\rangle$ as a function of t_{off} are to be distinguished: (a) $t_{off} \geq t_0 = 300$ ms, (b) $t_{off} \leq t_0 = 300$ ms. (a) Crosses mark results from Kornmeier and Bach (2004); for each off-time t_{off}, $\langle T\rangle$ (including standard errors) is plotted for three on-times of 0.05 s, 0.1 s, and 0.4 s. Squares mark results without errors indicated from Orbach et al. (1963) for an on-time of 0.3 s. The solid line shows a quadratic least-squares fit of $\langle T\rangle$ as a function of off-times t_{off} according to Eq. (1) with $\Delta T \approx 70$ ms. (b) Empty circles are dwell times as observed by Kornmeier et al. (2007), full circles are due to simulations for assumed parameters $\Delta T \approx 30$ ms and $t_0 = 300$ ms as described in Atmanspacher et al. (2008).

science (and in everyday life). Psychology has traditionally not considered effects of non-commutative operations throughout its history. But there are quite a number of psychological phenomena showing clear features of such an approach. Some of them, which have been worked out in recent years, are decision (or judgment) processes, semantic associations, learning, order effects in questionnaires and surveys, and multistable perception. For some more details and references see the review by Atmanspacher (2015), which highlights this line of thinking in Section 4.7.

The target of the present paper is the application of non-commuting operations to multistable perception. During the observation of a two-dimensional representation of a 3D cube, our perception gets unstable and alternates repeatedly between the two possible 3D interpretations (Fig. 1, Blake & Logothetis, 2002; Kornmeier & Bach, 2012; Long & Toppino, 2004).

From a broader point of view, this phenomenon can be considered as a low-level, spontaneous version of a cognitive decision process (e.g. Leopold & Logothetis, 1999). The first quantum-inspired treatment of the relevant time scales of bistable perception has been worked out within the so-called Necker-Zeno model by Atmanspacher, Bach, Filk, Kornmeier, and Römer (2008), Atmanspacher and Filk (2010, 2013), and Atmanspacher, Filk, and Römer (2004, 2009). Some basic features of the model that are essential for the present study are described in Appendix A, where the following quantitative relation between three different time scales is derived:

$$\langle T\rangle \approx \frac{t_0^2}{\Delta \mathrm{T}} \tag{1}$$

$\langle T\rangle$ (≈ 3 s) is reflected in the "dwell time", i.e. average duration of a stable percept T during the observation of the Necker cube (e.g. Kornmeier, Hein, & Bach, 2009). Dwell times can be calculated as the transient duration of an unchanged percept between two reversals. This time scale has also been discussed as an extended duration of the experienced present, a fundamental temporal window of integration in cognitive processing (Pöppel, 1997; von Steinbüchel, Wittmann, & Szelag, 1999).

t_0 (≈ 300 ms) is assumed to be the time between stimulus onset and its conscious perception. Its physiological correlate can be estimated by the latency of the P300 event-related potential component of the electroencephalogram (Dehaene & Changeux, 2011; Kornmeier & Bach, 2012). In the Necker-Zeno Model t_0 is the dwell time that would arise in the hypothetical case of no observation (Atmanspacher et al., 2004).

ΔT (≈ 30 ms) is assumed as the "order threshold", i.e. the minimal temporal distance between two successive stimuli (across sensory modalities), allowing the identification of their order (Babkoff & Fostick, 2013; Pöppel, 1997). In the Necker-Zeno Model ΔT is interpreted as an internal perceptual update time (Atmanspacher et al., 2004).

So far, a number of psychophysical studies confirmed this relation of cognitive time scales (Eq. (1)). The corresponding experimental set-up utilized the so-called onset-paradigm (Kornmeier & Bach, 2004; Kornmeier, Heinrich, Atmanspacher, & Bach, 2001; Orbach, Ehrlich, & Heath, 1963; O'Donnell, Hendler, & Squires, 1988) with discontinuous stimulus presentation. Other than in continuous presentation mode, the ambiguous stimulus is presented for a certain duration followed by off-times with a blank screen.

The time scale t_0 can then be substituted by off-times t_{off} as long as $t_{off} \geq t_0 = 300$ ms because t_{off} delays the unperturbed period of the switching process and, thus, introduces an effective Hamiltonian H_{eff} different from H as discussed in Appendix A (if $t_{off} \leq t_0$ this