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# T-pattern analysis for the study of temporal structure of animal and human behavior: A comprehensive review

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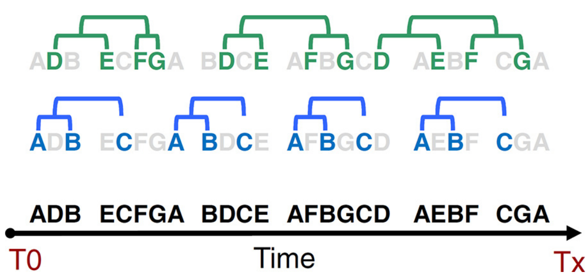
## HIGHLIGHTS

- T-pattern analysis is a multivariate approach for the detection of the temporal structure of behavior.
- By means of T-pattern analysis recurring sequences of behavioral events can be detected and described.
- T-pattern analysis can be applied to the study of the temporal characteristics of behavior in different species from rodents to human beings.
- Background for researchers who intend to employ such a refined multivariate approach to the study of behavior is given.

## GRAPHICAL ABSTRACT

Short string of 25 hypothetical events (black letters) occurring in a given time window (T0–TX). Albeit two different sequences of events (occurring four and three times, respectively) are present, the detection of such sequences is not an easy task if only the bottom row is observed. On the contrary, if the "extraneous" events are removed the two sequences A–B–C and D–E–F–G become evident. Such an example shows how easy it can be to ignore something we have before our very eyes.

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## ABSTRACT

A basic tenet in the realm of modern behavioral sciences is that behavior consists of patterns in time. For this reason, investigations of behavior deal with sequences that are not easily perceivable by the unaided observer. This problem calls for improved means of detection, data handling and analysis. This review focuses on the analysis of the temporal structure of behavior carried out by means of a multivariate approach known as T-pattern analysis. Using this technique, recurring sequences of behavioral events, usually hard to detect, can be unveiled and carefully described. T-pattern analysis has been successfully applied in the study of various aspects of human or animal behavior such as behavioral modifications in neuro-psychiatric diseases, route-tracing stereotypy in mice, interaction between human subjects and animal or artificial agents, hormonal–behavioral interactions, patterns of behavior associated with emesis and, in our laboratories, exploration and anxiety-related behaviors in rodents. After describing the theory

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and concepts of T-pattern analysis, this review will focus on the application of the analysis to the study of the temporal characteristics of behavior in different species from rodents to human beings. This work could represent a useful background for researchers who intend to employ such a refined multivariate approach to the study of behavior.



**Contents**



## 1. Introduction

Fourth century BC. Hellenic philosophers, such as Plato and Aristotle, theorized that human governments were characterized by a cyclic evolution of events, the so called "anacyclosis", a concept largely reprised also by the historian Polybius (Waterfield, 2010). Actually, more than two thousand years after, various aspects essentially consistent with the idea of repetition of events in time can be found in the thought of intellectuals such as Machiavelli (Mansfield and Tarcov, 1998), Vico (Goddard Bergin and Fisch, 2011) or Nietzsche (Nauckhoff and Del Caro, 2001), to name a few. It is evident that, through centuries of human thinking, the idea of the recurrence of events in time has a very long and rooted history.

Interesting topics of discussion arise when, beside the succession of governments and other "macro" events, as debated by philosophers and historians, the concepts of temporal patterns and recurrence of events are applied to the scientific study of human or animal behavior. A first obvious question could be, simply, if repeated patterns of events exist in human or animal behavior. An affirmative answer should surprise no one, in line with the modern view of biological phenomena, as clearly expressed by the Nobel Prize winner Francis Crick: "*Another key feature of biology is the existence of many identical examples of complex structures*" (Crick, 1988). Also, it is essential to consider the concrete possibility to study, from a scientific perspective, these repeated behavioral sequences and, last but not least, their putative role in terms of the resulting behavioral organization. Actually, from the perspective of the behavioral scientist, the possibility that the behavior of a subject does encompass a number of repeated sequences of acts may represent the essential substrate for the existence of a habit. Indeed, as underlined by Graybiel (2008), a behavior is defined as "habitual" when it occurs repeatedly over the course of time. Such a repeated occurrence of behaviors can become remarkably fixed. An intriguing neurophysiological research line concerns the identification of the putative neural substrate(s) linked with organization of these repeated patterns of behavior. Important evidences indicate that various circuits connecting the neocortex and regions of the basal ganglia may embody the anatomic–functional network underlying the control of repetitive behaviors. Coherently, anomalies in basal ganglia circuitry represent a critical aspect shared by numerous illnesses characterized by the abnormal presence of repetitive behaviors, such as Huntington's disease, Tourette's syndrome or obsessive compulsive disorder, among others (Graybiel, 2008). However, independently from their physiological or pathological nature, and independently from the performing subject, the detection of a repeated sequence of behavioral acts, may be a difficult task. Three critical issues determine how easily a sequence of behavioral events can be perceived/noticed by an observer: first of all, the *order* of each event, second, the *frequency* of the comprehensive sequence (namely, how many times it occurs) and, finally, the occurrence, within the sequence, of behavioral events irrelevant to the sequence itself. For instance, during a meal, the sequence of acts that a person must perform to consume a dish and/or a glass of wine can be easily detected because (1) the behaviors are relatively invariant in their order, (2) the whole resulting sequence is quite frequent, and (3) the progression of events within the sequence is rarely interrupted by the occurrence of other events. On the contrary, if a succession of behavioral events is infrequent and/or if a number of "extraneous" events occur, then it may be extremely difficult to perceive the presence of a given sequence. To better clarify such an aspect, the following example may be enlightening. Fig. 1a shows a short string of hypothetical events (black letters) occurring in a given time window (T0–TX). Two different sequences of events, occurring five and four times respectively, are present.

The detection of such sequences is not an easy task by observing only Fig. 1a. The reason is that, on the basis of the three aspects mentioned above, both the sequences: (1) always encompass events in an identical order and (2) are repeated various times; nonetheless, the third requirement is missing because several "extraneous" events occur between the sequences and within each sequence. As

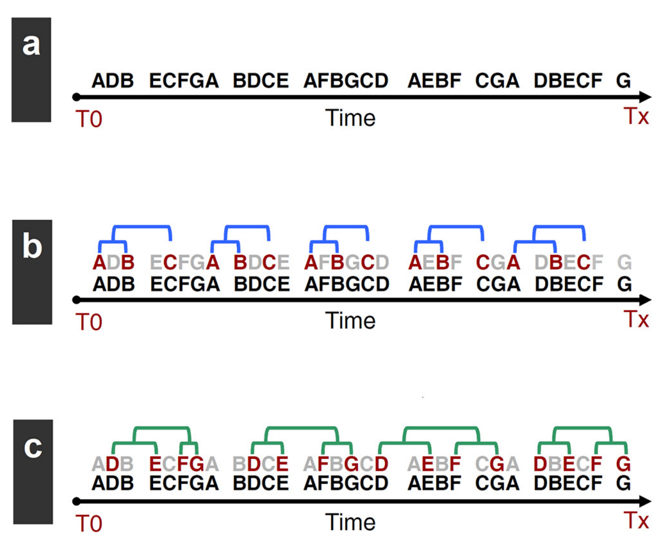


**Fig. 1.** String of hypothetical events (black letters) occurring during a given T0–TX time window. Two recurring sequences of events are present. If the extraneous events are removed the two sequences in (b) and (c) become evident.