A Note on the Autoregressive Process During the Conditioned Avoidance Response in Rats

Time series, consisting of observations which are dependent on one another, present special problems in statistical analysis. The employment of the classical working procedure is based on the assumption that the sample data follow a linear stationary Gaussian stochastic process[1]. Otherwise it is well known that, in an important case of biological time series, in reaction times (RT) measured during the acquisition of a conditioned avoidance response (CAR), the assumption is not fulfilled.

Table I. Noncircular serial correlation coefficients of lag k (k-th order) obtained by measuring of reaction times during a CAR

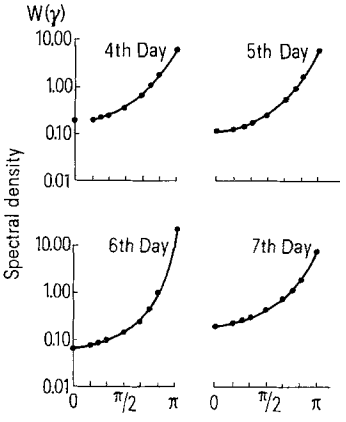
Days	lag 1	lag 2	lag 3	lag 4	lag 5
2	0.41	−0.48	0.10	0.40	0.35
3	−0.50	−0.30	0.31	0.01	−0.12
4	−0.69[a]	0.35	−0.25	0.25	−0.21
5	−0.78[a]	0.55	−0.18	0.15	−0.03
6	−0.88[a]	0.80[a]	−0.11	0.08	0.01
7	−0.68[a]	0.35	−0.10	0.05	0.00
8	−0.45	−0.22	0.25	0.00	−0.08
9	−0.30	−0.43	0.30	0.07	−0.05
10	0.35	−0.36	0.22	0.31	0.20
11	−0.46	0.29	0.34	0.02	−0.13
12	−0.47	0.34	0.28	0.05	−0.14
13	0.39	−0.33	0.29	0.34	0.21
14	−0.34	−0.20	0.32	0.00	−0.05

[a] Statistical significance at 0.05.

Table II. Multivariate partial serial correlation coefficients (a_{kk}) of order k of reaction times from the significant autocorrelation (Table I)

Days	a_{11}	a_{22}	a_{33}	a_{44}	a_{55}
4	−0.69[a]	−0.25	0.26	−0.01	0.00
5	−0.78[a]	−0.17	0.49	−0.10	−0.02
6	−0.88[a]	−0.17	0.34	−0.17	0.06
7	−0.68[a]	−0.17	0.17	0.01	−0.04

[a] Statistical significance at 0.05.



Spectral densities W of the mean reaction times from the significant autocorrelation (c.f. Table I) plotted against $\gamma = (0, \ldots, \pi)$.

This means that the estimation of the autocorrelation and the spectral density function (FOURIER cosine transform of the autocorrelation) is biased, a property which does not hold in the noncircular case[2]. The purpose of this paper is to examine whether the oscillatory components of RT measured during the training of a CAR in rats are caused by the special learning task or by the spontaneous background activity in the central nervous system. Therefore the noncircular definition of the autocorrelation is used.

Material and methods. In this study 6 hooded rats (DRUCKREY-rats of a closed colony) were used, aged 6 months, with a mean weight of 380 g, having free access to a standard food (R 19) and water. The animals were trained to avoid a footshock (50 v) by jumping on a hanging rod (pole-climbing method[3]), the conditioned stimulus (CS; a tone of 1.5 kc/sec) was switched 3.5 sec before the unconditioned stimulus (UCS), and 10 combinations were applied from 1st to 14th day of training. The maximal duration of UCS in the first session was 20 sec. The intertrial intervals were varied from 10 to 90 sec using a random number table. The RT (from CS to jumping on the rod) were measured with an automatic stop watch (in sec.) Following, in the statistical part, strictly the working procedure proposed by MAGER[4], we calculate the noncircular serial correlation[2] and the multivariate partial serial correlation[4] of the means $\bar{x}_1, \ldots, \bar{x}_{10}$ of the RT (the means were obtained at each day of training by the 6 rats). Otherwise it is well known that biological time series cannot be consistently estimated from the classical periodogram intensity, which tends to be exponentially distributed and has a zero correlation between the values calculated at intervals of the spectrum frequency. The fundamental relationship existing between the noncircular definition of the autocorrelation and the spectral densities is given in KENDALL and STUART[5].

Results and discussion. The noncircular serial correlation coefficients of the mean of RT in each session from the 2nd to the 14th day of CAR are indicated in Table 1; the autocorrelation is significant at the 4th to 7th day of training at lag 1, and the correlograms are damped harmonic. The partial serial correlation of the *significant* serial correlation (Table II) decays exponentially to zero oscillation in sign, and only the partial serial correlations of lag 1 (order 1) are nonzero. In the Figure are given the spectral densities, the high frequencies are predominating.

These results demonstrate that from the 4th to 7th day of CAR each observation (RT) x_i depends only upon the last available x_{i-1} (and not upon the x_{i-2}, x_{i-3}, ...). The linear filter model of this type is called an autoregressive process of 1st order which obtains high frequencies (MARCOV series). Otherwise the noncircular serial correlation coefficients are zero from 2nd, 3rd, 8th to 14th day of CAR. If the spontaneous background biorhythms during the training are responsible for the appearance of significant autocorrelations, such auto-

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[5] M. G. KENDALL and A. STUART, *Advanced Theory of Statistics* (Griffin, London 1966), vol. 3, p. 410.

regressive periods should be found in all phases of CAR and not only during the 4th to 7th day. Therefore 2 oscillatory processes may be assumed during the CAR; 1st the spontaneous background activity in the CNS[6], and 2nd an autoregressive periodicity during the 4th to 7th day of CAR (consolidation phase), which is perhaps based on negative feedback mechanisms (overlying of activating and relaxing processes which tend to an equilibrium). It was pointed out[7] that a system with negative feedback presents periodicities which are damped harmonic. Therefore it is possible that the level of unspecific activity is reduced during the 4th to 7th day of CAR to an optimum of learning, which means an enhancement of learning in the consildation phase.

Zusammenfassung. Es wurden Reaktionszeiten, die während einer instrumentellen Konditionierung bei Ratten automatisch gemessen wurden, hinsichtlich ihrer Autokorrelations- und Spektraldichtefunktion untersucht. Die autoregressiven Oszillationen der Reaktionszeiten vom 4.–7. Tag des Trainings basieren auf einem nicht-zirkulären MARCOV-Prozess.

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Does Axonal Sprouting Occur in Dystrophic Mouse Muscles?

Muscles of dystrophic mice are known to contain some fibres which are 'functionally denervated'. No action potential appears in such fibres when the motor nerve is given supramaximal stimulation[1–5]. However, the functionally denervated fibres of the dystrophic soleus muscle change their properties when the muscle is denervated[5]. Although it is possible that such muscle fibres are entirely without motor innervation, they could be supplied by sprouts from remaining motor neurons. In the latter case there should be an increase in the size of individual motor units. Furthermore, if functional denervation and axonal sprouting are gradual processes of nerve deterioration and recovery during which the release of acetylcholine (ACh) is incomplete, there should exist transitional periods when end-plate potentials (EPP) can be detected among the dystrophic muscle fibres upon supramaximal stimulation of the innervating nerve.

Materials and methods. Soleus nerve-muscle preparations[5] from male mice of the Bar Harbor 129 Re-J/dy strain were used. Both the dystrophic mice, and their normal litter-mates were 3–4 months old at the time of sacrifice.

Fibres in dystrophic muscles were impaled with microelectrodes and checked for innervation by stimulating the motor nerve with a voltage pulse of 0.2 msec., delivered at twice the strength necessary for a maximal muscle twitch. If no sign of an action potential was observed, the fibre was considered to be 'functionally denervated' (see Figures a and b).

Staining of muscles for acetylcholinesterase was used to compare the number of motor end-plates in the normal

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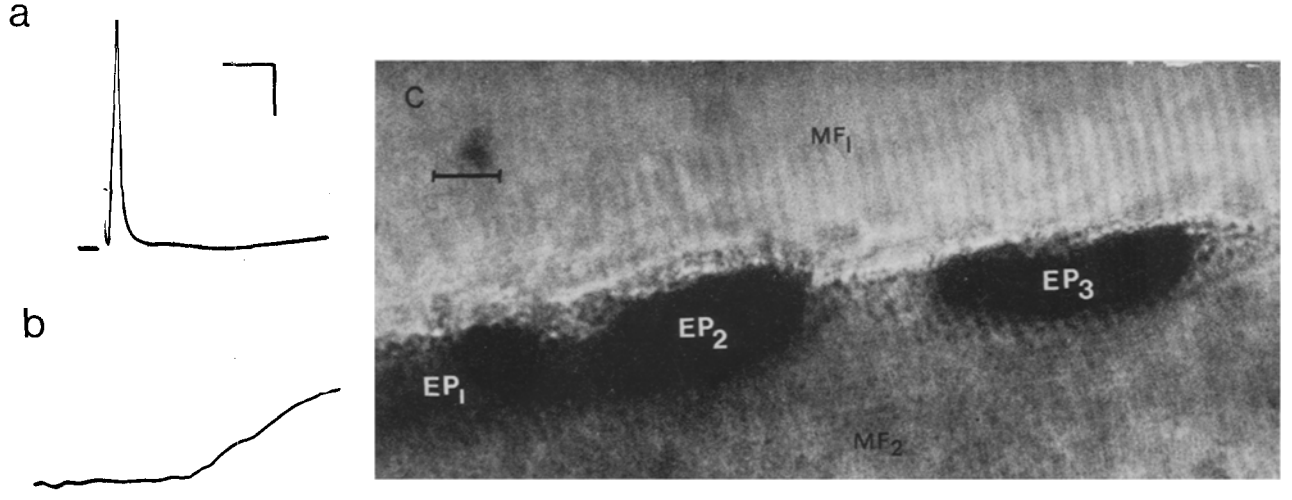

a) Intracellular recording of action potential from innervated dystrophic soleus fibre. b) Suprathreshold indirect stimulation failed to evoke an action potential from a functionally denervated soleus fibre. The movement artifact indicates that the recording microelectrode was displaced slightly during muscle contraction. Calibrations: 20 mv and 4 msec. c) Acetylcholinesterase staining of dystrophic soleus muscle to show the presence of more than 1 motor end-plate on a muscle fibre. Calibration mark, 25 μm. MF_1, MF_2, muscle fibres; EP_1, EP_2, EP_3, end-plates.