Relation between baseline firing rate and the direction of neuronal responses to noradrenaline: a species comparison

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Noradrenaline applied by microelectrophoresis can evoke both excitatory and depressant responses on single cortical neurons in the cat (Krnjević & Phillis, 1963; Johnson, Roberts & others, 1969; Frederickson, Jordan & Phillis, 1972; Bevan, Bradshaw & others, 1974; Bradshaw, Roberts & Szabadi, 1974) and in the rat (Stone, 1973; Bevan, Bradshaw & Szabadi, 1977; Jones & Roberts, 1977; Sharma, 1977). We have reported earlier that, in the cat, there is a statistically significant correlation between the baseline firing rates of the neurons and the proportions of neurons responding with excitation or depression: as the firing rate increases, the proportion of excitations decreases, and the proportion of depressions increases (Szabadi, Bradshaw & Bevan, 1977). We have now extended this observation, and examined whether a similar correlation could be detected in the rat.

Spontaneously active single neurons were studied in the somatosensory cortices of male albino Wistar rats anaesthetized with halothane (0·6–1·0%). Our methods for the surgical preparation of the animals, for the manufacture of six-barrelled micropipettes, for the recording of action potentials, and the electrophoretic application of drugs have been described elsewhere (Bradshaw, Szabadi & Roberts, 1973; Bevan & others, 1974; Bradshaw & others, 1974). The recording site was defined by the following stereotaxic coordinates: A 4·8–6·5; L 0·9–2·4 (König & Klippel, 1963). The area of recording was prepared as described previously (Bradshaw & Szabadi, 1972); the dura was either incised with a hypodermic needle under microscopic control, or was penetrated directly with the micropipette. The micropipettes contained 4 M NaCl (two barrels: one for recording and the other for current balancing), and in one of the remaining barrels a 0·05 M (—)-noradrenaline bitartrate solution (pH 3·0–3·5). (The other barrels contained other agonists and antagonists according to the requirement of the experiment.)

For the assessment of the relation between firing rate and direction of response, spontaneously active neurons were selected which gave consistent excitatory or depressant responses to noradrenaline applied with an ejecting current of +25 nA. (Between drug applications a retaining current of —10 nA was passed.)

The total population of 332 noradrenaline-sensitive cells was divided into seven groups on the basis of the firing rate (spikes s^{-1}): 0–5; 6–10; 11–15; 16–20; 21–25; 26–30; 31–50 (see Szabadi & others, 1977). The proportions of cells excited and depressed by noradrenaline were calculated separately for each firing rate category. The results are shown in Fig. 1: with increasing firing rates the proportion of excitations decreased, and the proportion of depressions increased (product moment correlation: $r = 0{\cdot}84$, $P < 0{\cdot}02$).

We have also compared the proportions of cells excited and depressed in the cat and in the rat (for details of the experiments with cats see Szabadi & others, 1977). In the cat, out of 496 cells giving consistent responses to noradrenaline, 388 cells (78%) were excited, and 108 cells (22%) were depressed. In the rat, out of 477 noradrenaline-sensitive cortical neurons, 338 (71%) responded with excitation, and 139 (29%) responded with depression. There was a small, but statistically significant difference between the frequencies of occurrence of excitations and depressions in the two species: in the cat, excitations were slightly more common, and depressions slightly less common than in the rat (χ^2 test, $P < 0{\cdot}01$). Since the proportions of cells excited and depressed depend on the firing rate in each species (see above and Szabadi & others, 1977), it was of interest to examine whether the inter-species difference in the proportions of cells excited or depressed could reflect a difference between the base-line firing rates of the neurons in the two species.

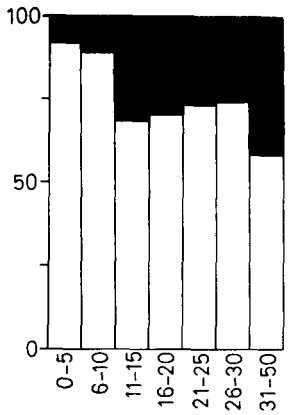

FIG. 1. Relation between the percentage of cells excited and depressed by noradrenaline (ordinate) and the spontaneous firing rate (spikes s^{-1}) in the cerebral cortex of the rat. Shaded area: depression; unshaded area: excitation. The percentage of cells depressed by noradrenaline (25 nA) was positively correlated with the spontaneous firing rate ($r = 0{\cdot}84$, $P < 0{\cdot}02$). $n = 332$.

* Correspondence.

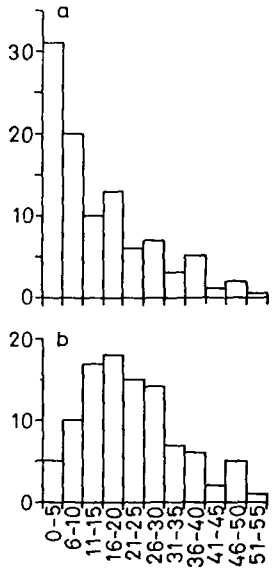

FIG. 2. Firing rate distributions of noradrenaline-sensitive cells in the cerebral cortices of the cat (a) and the rat (b). Ordinate: percentage of neurons. Abscissa: spontaneous firing rate (spikes s^{-1}). The frequency distribution was different in the two species (median test; $P < 0.001$). a: n = 496; b: n = 477.

The distribution of the neurons between eleven firing rate categories is shown in Fig. 2. It is apparent from the figure that the frequency distribution of firing rates was different in the two species: the distribution obtained in the cat having a greater skew to the left than the distribution obtained in the rat. This is reflected in a lower median firing rate in the cat (10 spikes s^{-1}) than in the rat (20 spikes s^{-1}). The difference between the two patterns of distribution is statistically significant (median test; $P < 0.001$).

The present findings demonstrate a basic similarity between the responses of cortical neurons to noradrenaline in the cat and in the rat. Firstly, in both species, a similar proportion of cells is excited or depressed by noradrenaline: about three quarters of the noradrenaline-sensitive cells respond with excitation, and only one quarter of the cells respond with depression. Secondly, in the rat, similarly to earlier observations in the cat (Szabadi & others, 1977), the direction of the response is related to the baseline firing rates of the neurons: as the firing rate increases, the relative number of excitations decreases, while the proportion of depressions increases.

The present comparison has revealed a subtle difference between the two species: excitatory responses are slightly more common, and depressant responses are slightly less common in the cat than in the rat. This difference may be related to the different firing rate distribution of neurons in the two species (see Fig. 2): in the cat there is a greater preponderence of slowly firing neurons than in the rat.

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