Acta Physiol Scand 1993, 149, 105–115

Effect of ethanol on hippocampal neurons depends on their behavioural specialization

YU. I. ALEXANDROV, YU. V. GRINCHENKO, S. LAUKKA[1], T. JÄRVILEHTO[1], V. N. MAZ[2] and A. V. KORPUSOVA
Institute of Psychology, Russian Academy of Sciences, Moscow, Russia; [1] Department of Behavioural Sciences, University of Oulu, Oulu, Finland; [2] Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Moscow, Russia

ALEXANDROV, YU. I., GRINCHENKO, YU. V., LAUKKA, S., JÄRVILEHTO, T., MAZ, V. N. & KORPUSOVA, A. V. 1993. Effect of ethanol on hippocampal neurons depends on their behavioural specialization. *Acta Physiol Scand* 149, 105–115. Received 8 June 1992, accepted 16 March 1993. ISSN 0001–6772. Institute of Psychology and Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Moscow, Russia, and Department of Behavioral Sciences, University of Oulu, Finland.

Acute effect of ethanol on hippocampal neurons was studied during food acquisition behaviour in seven rabbits. The rabbits were taught to acquire food from a feeder by pressing a pedal on the same side of the cage. The behaviourally specialized units (L units related to newly *learned* behaviour and M units related to behaviour formed before learning, e.g. certain *movements*) were comparable with the 'place' (projectional pyramidal and granular cells) and 'displace' (non-pyramidal interneurons) units of the current classification. The same direction of ethanol effects was found as for the limbic cortex; the number of certain kinds of L units decreased and that of M units increased but there was no significant change in the relative number of L and M units as a whole. The background frequency of L units decreased, but the frequency within activations increased. The results confirm our earlier findings on the most marked depressive effect of ethanol on L units and show that it is the behavioural specialization, not the morphological unit type, which is a major determinant of the ethanol influence.

Key words: hippocampus, ethanol, rabbit, neurons, unit activity, behaviour.

In our studies on the behaviour of rabbits we observed qualitative differences in the acute effects of ethanol on the activity of neural units in the cortical part of the limbic system (area 29d; Alexandrov *et al.* 1990b) and in the motor cortex (Alexandrov *et al.* 1991). In the limbic, but not in the motor cortex, the number of active units decreased after ethanol administration. The pattern of behavioural specialization of the units also changed (Alexandrov *et al.* 1990a, b). The relation between the number of L units activated in a constant relation to newly *learned* phases of behaviour, and M units activated in relation to 'old' phases of behaviour formed before learning the task, e.g. to certain *movements*, was reversed. In the motor cortex there was a change only in the number of behaviourally related units in the upper and lower cortical layers.

The task of the present study was to investigate the influence of ethanol on the activity of the neural units in the hippocampus, a structure which is particularly sensitive to ethanol (Klemm *et al.* 1976, Grupp & Perlanski 1979). The comparison of the effects of ethanol on units in this structure with our earlier findings is especially interesting because of the specific morpho-functional relations in the hippocampus. In the hippocampus the neurons which have different discharge characteristics (complex or simple

Correspondence: Yuri Alexandrov, Institute of Psychology, Russian Academy of Sciences, Yaroslavskaya 13, 129366 Moscow, Russia.

spike), usually belong to different morphological types; i.e. projection pyramidal and granular cells or non-pyramidal interneurons (short axon cells, Golgi type II) (Ranck 1973, O'Keefe 1979, Fox & Ranck 1975, Sinclair *et al.* 1982). It is usually believed that ethanol has a more marked depressive effect on the activity of interneurons and associative structures than on the large projection neurons and structures (for reviews, see Klemm 1979, Zornetzer *et al.* 1982). Therefore, acute influence of ethanol should be more prominent on the non-pyramidal interneurons of the hippocampus (simple spike units). Our earlier data, however, indicate that the decisive factor in the influence of ethanol on neural units is the type of behavioural specialization of the units, their morphological type being only one out of a set of characteristics determining the behavioural specialization (Alexandrov *et al.* 1990 b). We therefore propose that the influence of ethanol on hippocampal neurons is not simply determined by their morphology, but is related to their behavioural specialization.

In the present study we first determine the relation of the hippocampal units to different phases in the behaviour of a freely moving rabbit performing a food-acquisition task. Secondly, we relate the recorded units to the current classifications of the hippocampal units. Thirdly, we compare the influence of ethanol on units with different discharge types (morphological type) and behavioural specialization. Finally, we compare hippocampal data with those obtained earlier on the effects of ethanol on the limbic and motor cortex in the same experimental situation.

MATERIALS AND METHODS

Subjects. The experimental animals were seven male adult rabbits (*Orictolagus cuniculus*; weight 2–3 kg).

Experimental procedure. Freely moving animals were taught to acquire food by pressing one of two pedals in the experimental cage (described in detail in Alexandrov *et al.* 1990a). Pressing the pedal activated an automatic feeder on the same side of the cage. Each rabbit repeatedly carried out the food-acquisition task with a constant series of acts (behavioural cycle: pressing the pedal, turning to the feeder and taking food from the feeder), at both sides of the cage (front and rear walls in relation to the video camera; see recording techniques), in the control and in the ethanol experiment.

In the ethanol experiments ethanol was injected intraperitoneally (12% v/v ethanol in isotonic solution) using a dose of 1 g kg^{-1} and thereafter 0.3–0.5 g kg^{-1} ethanol was added every 1.5–2 h until the end of the experiment. This procedure produced an average blood ethanol level of 0.9 g l^{-1} in 15–20 min, which decreased to a level of approximately to 0.4 g l^{-1} in 40–60 min, this was maintained throughout the experiment. Blood ethanol level (sampled from the marginal vein of the rabbit's ear) was determined by gas chromatography (see Alexandrov *et al.* 1990b). In the control experiment the same amount of isotonic solution was used.

Recording techniques. Electrophysiological and behavioural recording techniques, analysis of unit activity, the criteria for activation of a unit and also the classification of the behavioural specialization of units have been described in detail elsewhere (Alexandrov *et al.* 1990a, b).

Unit activity was recorded in the control and ethanol experiments from the area CA1 of the cornu ammonis and dentate gyrus (Dg), including CA4. The coordinates of recording were (P4, L4) (according to McBride & Klemm 1968). The total number of units during each microelectrode penetration was recorded with a micromanipulator with a scale showing the vertical location of the recording tip.

Unit activity, EMG and actographic marks of the behaviour (see Alexandrov *et al.* 1990a) were tape-recorded. In addition, the exact moment of the animal's movement from the pedal to the feeder, or vice versa, was recorded by a photocell, fixed to the head of the animal, which responded to photodiodes located in the middle of the front and rear walls of the cage between the pedal and the feeder. Hippocampal ripples (see, e.g. Kanamori 1986) were recorded (bandwidth 0.5–10 kHz) during resting before unit recording of behaviour. The incidence of ripples was counted in 2 s intervals. The rabbit's behaviour and unit activity (audio-channel) was video-recorded simultaneously; light indicators denoted pedal pressing and head lowering, and counters recorded cumulative number of spikes and time.

Behavioural and neural analysis. Both the duration of each behavioural cycle and the number of mistakes (for definition, see Alexandrov *et al.* 1991) performed during both control and ethanol experiments were determined and compared (t- and χ^2 tests, respectively).

The units were first divided into two groups: non-involved (not activated) and involved (activated in constant relation to a certain phase of the repeated behavioural cycle) in the food-acquisition behaviour. The latter group was further divided into two groups with different behavioural specialization (M and L units; cf. Alexandrov *et al.* 1990a, b; see also Results). The statistical significance of differences between number of units belonging to different groups and between number of units belonging to the same groups in both control and ethanol experiments was

estimated by χ^2 and Fisher's exact tests (significance limit $P < 0.05$).

Morphological analysis. After the experiments the rabbits were sacrificed with an overdose of Nembutal, the brains were fixed in 10% formalin and dehydrated by increasing concentrations of ethanol. Serial frontal slices were cut (thickness 10–20 μm) and every 10th section was stained by the Nissl method. In the contralateral site (symmetrical to the site of the recording) neural structure was analysed by light microscope; also the thickness of CA1 and Dg corresponding to the position of the microelectrode track was determined. The location of the units in CA1 or Dg was determined on the basis of micromanipulator readings and this analysis.

RESULTS

Pattern of behavioural specialization of hippocampal neurons in the control experiments

Unit recordings were obtained from six rabbits during food-acquisition performance in both control and ethanol experiments; for one rabbit only the number of active units was counted during microelectrode penetrations in both experiments.

In control experiments 37% of all units ($n = 160$) recorded during the food-acquisition task were involved units (Table 1). The rest of the units had no constant relation to any phase of the behaviour (non-involved units). The majority of the recorded units had complex spikes in their discharge.

Table 1. Change of proportion of units in control (C) and ethanol (E) situations

Experimental situation	L units		M units		Non-involved units	
	C	E	C	E	C	E
Σ (total %)	21	17	16	24	63	59
Subgroups	'pedal'				'slow'	
	4	1*	—	—	39	28*
CA1 (total %)	18	21	17	26	65	53
Subgroups					'slow'	
	—	—	—	—	39	25
Dg (total %)	24	13	14	22	62	65
Subgroups	'place'					
	14	1**	—	—	—	—

* $P < 0.01$; ** $P < 0.001$.

L units were activated in relation to phases of behaviour formed during the learning of the food-acquisition task in the experimental cage: the approach to the feeder, seizure of the food from the feeder, approach to the pedal, and pressing the pedal. The majority (73%) of these units was activated during only one behavioural cycle, either at the front or the rear wall. The remainder (27%) were activated during both behavioural cycles. L units could be activated during the rabbit's approach to one or both feeders, and also during approach to and/or pressing of one or both pedals.

The activation of L units during food seizure was not due to the seizure itself but was caused by specific conditions of learned behaviour (Alexandrov *et al.* 1990a) (see Fig. 1). L units were also classified as 'place' units (Fig. 2; cf. O'Keefe, 1976), i.e. units which were only activated when the rabbit was located in a certain place within a varying behavioural context. When only effective food-acquisition behaviour was considered, the activity of the 'place' unit in Fig. 2 did not differ greatly from that of the unit shown in Fig. 1. However, activation appeared in the 'place' unit during both exploratory behaviour (Fig. 2c–e) and additional testing (Fig. 2f), indicating marked differences between the two units.

M units were activated in relation to different movements of the body and/or head in varying behavioural contexts. The majority (81%) of M units were activated during all large spatial movements. In the food-acquisition behaviour they were activated during both the cycles with movements between pedal and feeder, and in some cases during the seizure of food. More than half of M units (54%) had marked rhythmical bursting activity related to large spatial movements an seizure of food. The average frequency of the bursts during large spatial movements was $7.3 \pm 0.7\ s^{-1}$ (mean $\pm$ SD). The rest of M units was activated with other types of movement.

There was a significant difference in the relative number of complex spike units among L and M units (85 and 19%, respectively, $P < 0.001$), the remainder of both groups being simple spike cells.

Among the non-involved units more than half (61%) were units with slow ($< 1\ s^{-1}$) background frequency (determined as the mean frequency of those discharged during the behaviour cycles, not including the periods of

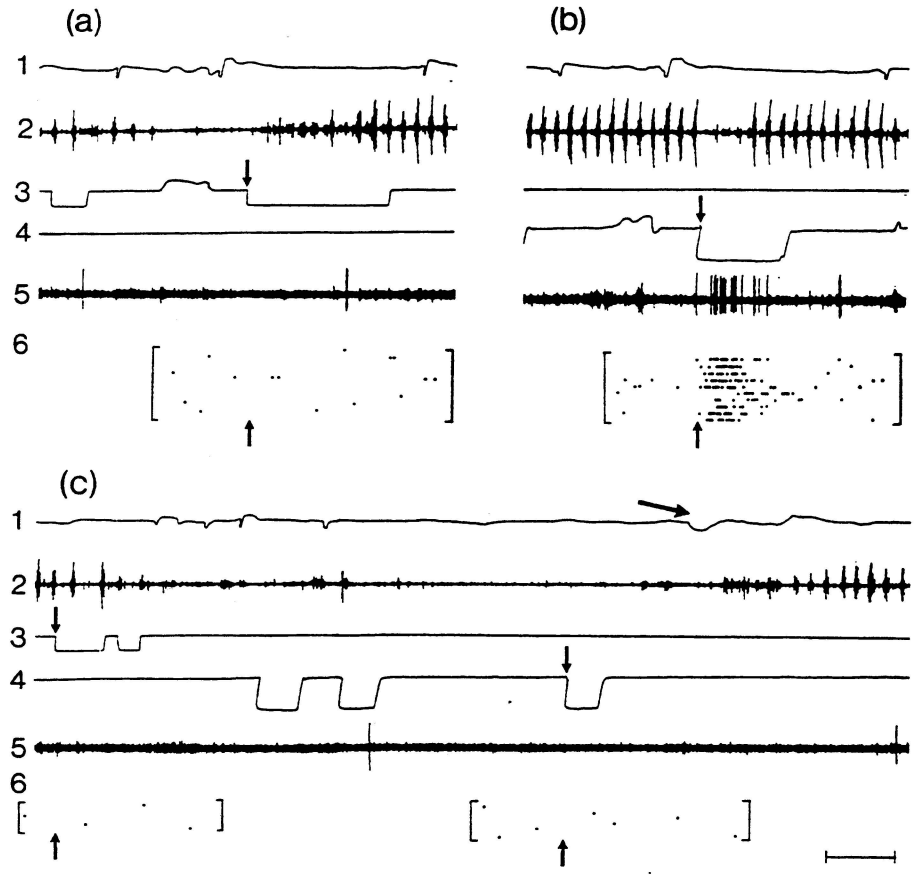

Fig. 1. Complex spike L unit activated only during food seizure at rear feeder (ethanol experiments). Numbers on the left: 1, record of animal's displacements along the walls; fast deflection during behavioural cycle in the record shows the instant of crossing midline of wall. 2, EMG of m. masseter (low-amplitude bursts – taking food and grinding; high-amplitude bursts – regular chewing). 3, 4, Record of pressing pedal (deflection upwards) and lowering head into feeder (deflection downwards) at front (3) and rear (4) walls. 5, Unit recording. 6, Rasters of unit activity during consecutive behavioural cycles. (a) Behavioural cycle at front wall, (b) at rear wall, (c) lowering head when checking empty feeders (from beginning of record) and seizure of food from experimenter's hand (oblique arrow). Note no activation occurred during these acts, or during the forced lowering of animal's head into rear feeder (not shown in figure). Vertical arrow, instant of lowering head into feeder. In the raster arrow shows the corresponding instant. Calibration, 1 s.

activation). The rest of the units had a higher discharge frequency. Similarly, as for L units, the group of slow background frequency units consisted mainly of complex spike units (83%), this relative number differing significantly from the corresponding number in the group of M units ($P < 0.001$).

Out of 160 units 152 were localized in CA1 (102 units) and in Dg (50 units). For the relative amount of different units, see Table 1.

Influence of ethanol on unit activity with different behavioural specialization

In the ethanol experiments activity of 153 hippocampal units was analysed and 151 units

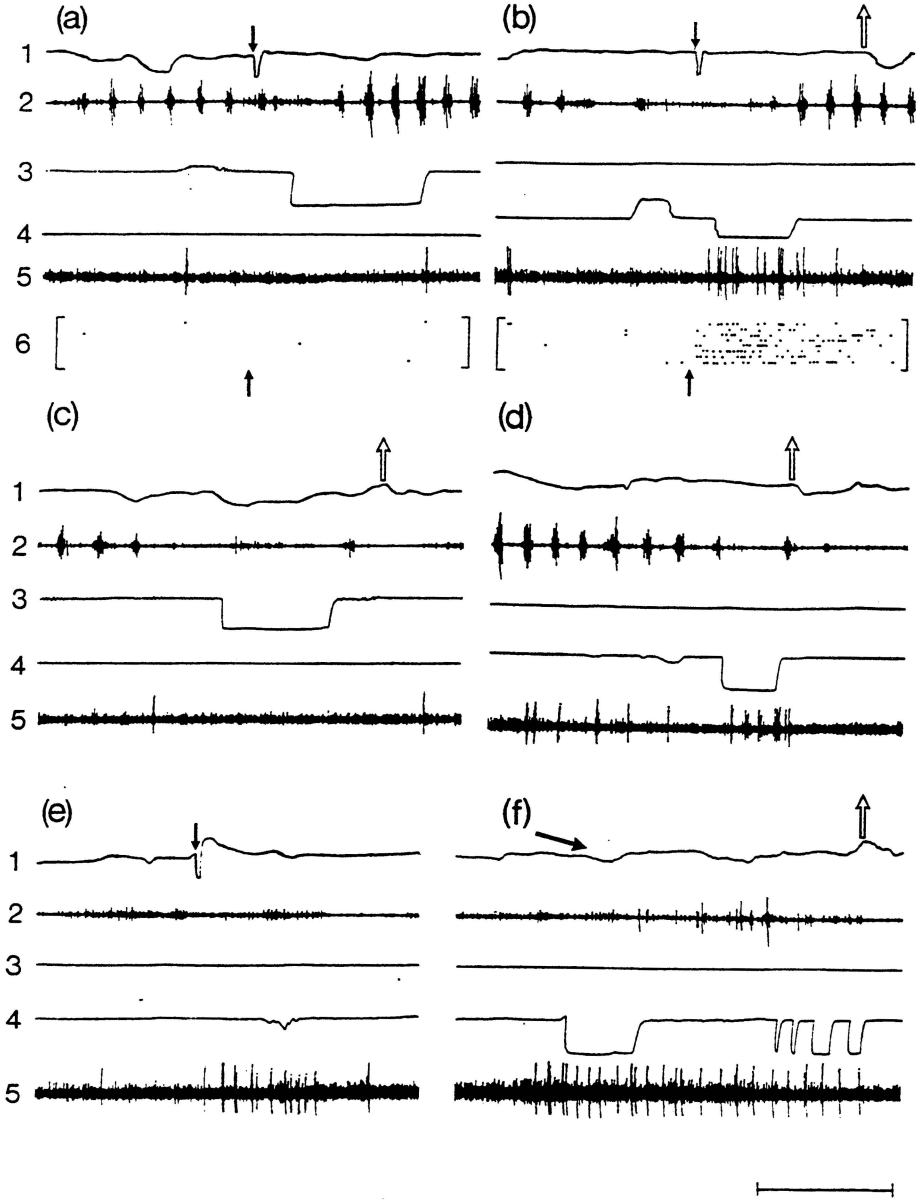

Fig. 2. Complex spike L unit activated at rear feeder in different behavioural acts (control experiment). 1–6, See Fig. 1. (a) Behavioural cycle at front wall; note no activation. (b) Behavioural cycle at rear wall; activation occurs during the end of approach to feeder and during food seizure. (c) Sitting near and checking front wall feeder; no activation. (d) Sitting near and checking rear wall feeder; activation occurs. (e) Approaching rear feeder without lowering head; activation occurs. (f) Forced pushing (oblique arrow) and keeping animal close to rear feeder and lowering its head into feeder. Notice continuous activation during this defensive behaviour. Black vertical arrow – crossing midline of the wall during approaching feeder (rasters constructed from this instant). White arrow – going away from feeder. Calibration, 1 s.

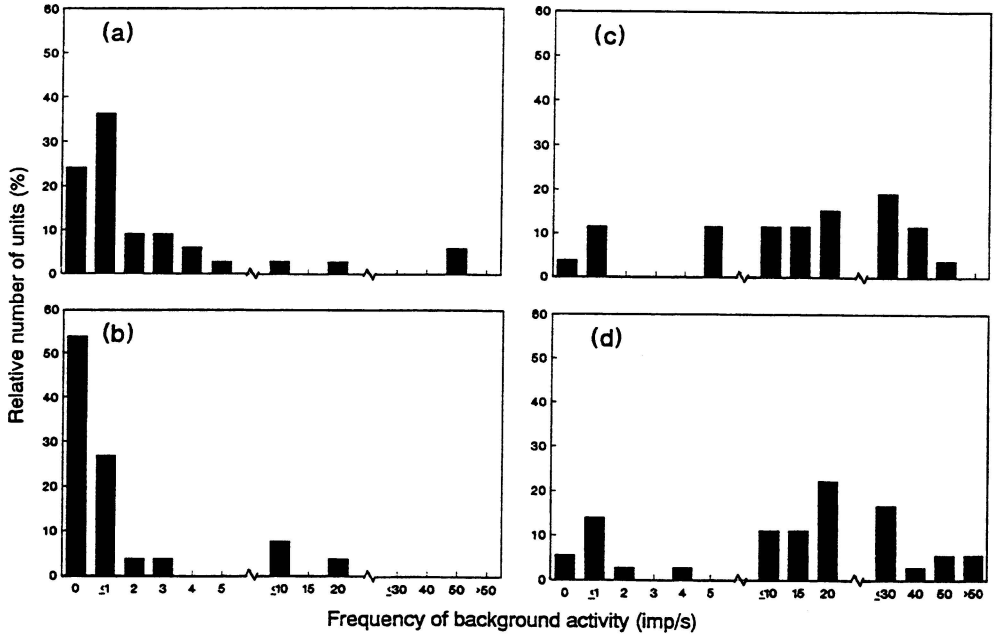

Fig. 3. Distribution of units with different background frequency. (a, b) L units, control ($n = 33$) and ethanol ($n = 26$) experiments, respectively. (c, d) M units, control ($n = 26$) and ethanol ($n = 36$) experiments, respectively.

were located in CA1 (75) and Dg (76). For the relative amount of different units, see Table 1.

Ethanol had no effect on the number of L units as a whole. However, the number of L units activated with the pedal pressing decreased in the ethanol experiments (Table 1). Also the relative number of 'slow' non-involved units in the ethanol experiment showed a decrease from control (Table 1).

Injection of ethanol had the opposite effect on the number of CA1 and Dg units, whose activity could be detected during microelectrode penetration (m.p.). In CA1 the average number of units decreased from 6.7 ± 3.4 m.p.$^{-1}$ (control) to 4.9 ± 1.8 m.p.$^{-1}$ (ethanol), i.e. by 27% ($P < 0.02$). However, in Dg the number of units increased by 28% (from 5.0 ± 2.1 m.p.$^{-1}$ in control to 6.4 ± 2.1 m.p.$^{-1}$ in ethanol; P 0.02).

The decrease in the number of active units in CA1 was apparently due to the decrease in the number of slow, non-involved units: from 39% in the control experiments to 25% in the ethanol experiments ($P < 0.05$). We examined this proposition using the statistical method we employed earlier (prediction of the number of observed units with the hypothesis that the absolute number of units of the given group remained constant; see Alexandrov *et al.* 1990b). There was a significant difference between the predicted and experimental value of the slow, non-involved units ($P < 0.005$) indicating a decrease in the absolute number of these units. There was also a decrease in the absolute number of non-involved units as a whole ($P < 0.001$). In the control experiments the relative number of non-involved units was significantly larger than that of involved units ($P < 0.001$). In the ethanol experiments there was no significant difference.

In Dg the relation between involved and non-involved units did not change: in both control and ethanol experiments the relative number of non-involved units was larger than that of involved units ($P < 0.05$). However, the number of place units of the L group decreased in the ethanol experiments (Table 1). Also the comparison of the predicted and observed values (significant difference, $P < 0.01$) indicated that the absolute number of place units decreased. In

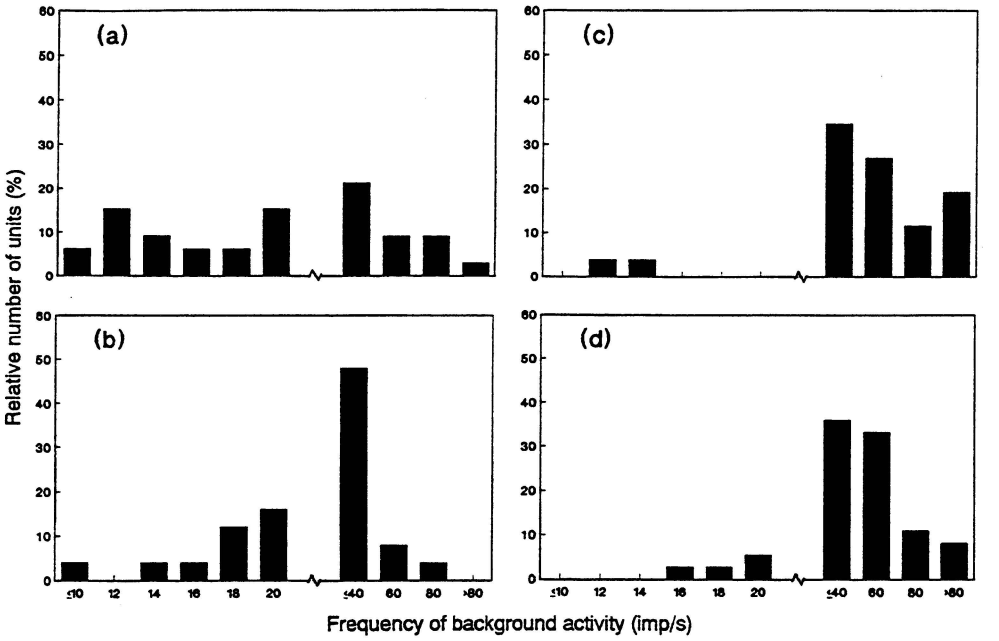

Fig. 4. Distribution of units with different frequency of activation. L units: (a) control ($n = 33$) and (b) ethanol ($n = 25$) experiments, respectively. M units: (c) control ($n = 26$) and (d) ethanol ($n = 36$) experiments, respectively.

contrast, the absolute number of M units increased ($P < 0.05$) explaining the increase in the number of active units in Dg.

Frequency parameters of the discharges of units with different behavioural specialization and effect of ethanol

Figures 3 and 4 show the distribution of the number of L and M units classified on the basis of frequency of background activity and frequency of activation during related behavioural phase. Similarly, as Ranck (1973), we counted complex spike as a single potential.

The background frequency (Fig. 3) was significantly higher for M than for L units. In the control experiments 85% of L units had a background frequency $< 5\ s^{-1}$ and 85% of M units had a frequency $\geqslant 5\ s^{-1}$ ($P < 0.001$). Injection of ethanol led to a significant increase in the number of L units which had no background activity (from 24 to 54%, $P < 0.05$) and, consequently, to a relative decrease of units with a higher background frequency.

The firing frequency within activations (Fig. 4) was higher for M units: significantly more L than M neurons had a frequency of activation $\leqslant 20\ s^{-1}$ (58 *vs* 8%, $P < 0.001$) and significantly more M than L had frequency of activations $> 40\ s^{-1}$ (58 *vs* 21%, P 0.01). Injection of ethanol led to a decrease in the number of L units with frequency of activation $< 15\ s^{-1}$ (from 30 to 8%) and to an increase in the number of units with frequency of activation $\geqslant 15\ s^{-1}$ ($P < 0.05$).

The activation/background (a/b) ratio was higher for L than for M units. In the control experiments only 15% of L units had a ratio $\leqslant 5$; however, there were 73% M units with this ratio ($P < 0.001$). The number of units with an a/b ratio > 20 was higher for the L group (49%) than for the M group (15%) ($P < 0.01$). In the ethanol experiments this difference became even more marked. The number of L units with an a/b ratio $\leqslant 20$ decreased from 51 to 23%, and the number of units with an a/b ratio > 20 increased ($P < 0.05$). For M units there was no significant change in either

background activation or a/b ratio frequency with ethanol.

Hippocampal ripples in the control experiment and after injection of ethanol

In the control experiments hippocampal ripples (burst duration 50–130 ms) always appeared when the electrode reached the hippocampus. The ripples were most marked in the depth corresponding to the pyramidal cell layer of CA1, they were observed when the animal was resting and disappeared with a change to active behaviour. The within-burst frequency of waves differed significantly between CA1 and Dg, being $133.1 \pm 11.6\ s^{-1}$ and $89.7 \pm 12.2\ s^{-1}$, respectively ($P < 0.001$).

After ethanol injection a marked decrease was observed in the incidence of ripples, this amounted to 48% in CA1 [from $2.3 \pm 1.6\ (2\ s)^{-1}$ to $1.2 \pm 1.2\ (2\ s)^{-1}$; $P < 0.001$] and 54% in Dg [from $2.6 \pm 1.7\ (2\ s)^{-1}$ to $1.2 \pm 1.5\ (2\ s)^{-1}$; $P < 0.001$].

Morphological control

Histological analysis of the hippocampal structures contralateral to the recorded site did not reveal any neuronal damage.

DISCUSSION

Comparison of the types of behavioural specialization of recorded units with the current classification of hippocampal units

The present results show that the neurons in the hippocampus can be divided into L and M groups of behaviourally specialized units. Such a division resembles the earlier classification of hippocampal units into 'place' units, having a discharge dependent upon the animal's location, and 'displace', 'movement' units, whose activity is related to motor behaviour regardless of the animal's position (O'Keefe 1976, O'Keefe & Dostrovsky 1971). The latter group is called also 'theta cells', as these units, having simple spikes, fire rhythmically with the hippocampal theta rhythm (Ranck 1973).

According to the criteria – such as relation to large spatial movements, firing frequency, type of spike – the majority of units which we classified as M units, had similar characteristics to theta units (Ranck 1973, Sinclair *et al.* 1982).

It was shown that 70–90% of complex spike units with low background frequency belong to 'place' cells (cf. Ranck 1973, O'Keefe 1979, Foster *et al.* 1989). Their relative number was much lower in our study. In our paper a unit was classified as a place unit if activity appeared in the same place with different behaviours. According to O'Keefe (1979) the part of the environment in which the place units have activations 'does not appear to be determined by such factors as the animals's attitude towards that place or the specific behaviour of the animal in that place' (p. 438). However, both our earlier and present data indicate that the activations of 'place' units correspond to space related to the results of behaviour, i.e. space which is divided into fields in relation to the behavioural acts which the animal performed in relation to the goal object in the given environment (Alexandrov 1989, p. 75). Such an interpretation is in keeping with the results and conclusions of Breese *et al.* (1989) and Wiener *et al.* (1989). However, Speakman & O'Keefe (1990) found that place fields changed after altering the reward place in only 2 out of 19 cells. Such a finding may be due to differences in the experimental designs, but, on the other hand, a constant relation between the firing of the unit and a given place could reflect the behavioural experience of the animal; together with the formation of new place fields, the old ones could persist.

If we accept the concept of behavioural dependence, all L units may be considered as 'place' units, which are active in a given place or places, because this place was related to some behavioural results. Thus the difference between the L units (classified as 'place' units in our study) and the other L units is that the latter belong to systems involved in food-acquisition behaviour, however, the 'place' units also belong to other acts performed within the environment of the experiment. Thus, the majority of M units are comparable with simple spike displace units or theta units, and L units with complex spike place units.

Thompson & Best (1989) showed that the place units fire in a 'field free' environment with a rate of 0.13 ± 1.6 spikes s^{-1}. Furthermore, approximately 90% of units with complex spikes are place units (O'Keefe, 1976). Therefore, it is

possible that many slow, complex spike, non-involved units were place units having place fields in some other environments. Some of these slow, non-involved units could also be L units related to some 'other behaviours', not analysed in the present study.

Effect of ethanol on the pattern of behavioural specialization and frequency parameters of the discharge

In the present study there were no differences in the relative number of L and M units between control and ethanol experiments. We found, however, a significant decrease in the number of L units related to pedal pressing, the latest phase of the learning process. Also the number of slow, non-involved units decreased. Consequently, ethanol selectively suppresses activity of the hippocampal L units, which belong to acts formed during the latest stages of individual development, but not M units which belong to systems formed in earlier phases of development. The number of M units may even increase. The effect of ethanol on frequency parameters of discharges was selective also: true of L units, but not of M units. The increase in the number of M units ('theta' units) with ethanol may be related to the finding that small doses of ethanol increase the markedness of the theta rhythm of the hippocampus of rat (Grupp & Perlanski, 1979) as well as of rabbit (Whishaw, 1976). If the theta rhythm of the EEG is related with the activation of limbic structures (cf. Westphal *et al.* 1990), then the increase in the number of M units may at least partly explain such changes in the EEG after injection of ethanol.

In contrast to earlier views about the more prominent depressive action of ethanol on interneurons (see Introduction for references), the results indicate that ethanol has a more prominent depressive action in the hippocampus on projectional pyramidal and granular neurons (L units) than on the short-axon non-pyramidal interneurons (M units). Thus the results support the proposition (Alexandrov *et al.* 1990b) that the behavioural specialization, and not the morphological type of a unit, is the main determinant of the influence of ethanol.

As to the effect of ethanol on the frequency parameters of the discharge of neurons there is variability in different brain areas, including the hippocampus (Klemm 1979, Grupp & Perlanski 1979, Zornetzer *et al.* 1982); e.g. an increase or decrease of frequency of activity of given units or a different influence on closely spaced units. It was not clear 'how these cells differ in ways other than their sensitivity to ethanol' (Zornetzer *et al.* 1982, p. 107). On the basis of the present results we can explain such variability by the following factors:

(1) The effect on the frequency parameters depends on the *behavioural specialization* of the units.

(2) When recording multiple unit activity (MUA) we may have, after ethanol, *involvement of new units* (M units) in subserving of behaviour; therefore, variable amplitudes of MUA may be obtained (Klemm *et al.* 1976).

(3) Because the *sensitivity of the different phases of the activity* of the given unit may be *different* (cf. influence of ethanol on background and activation; see also Alexandrov *et al.* 1991), the influence of ethanol on the same unit may vary in different experimental conditions.

We suggested earlier that background activity may be at least partly explained by an inter-relation between the given unit and units which belong to other systems (Alexandrov *et al.* 1990 b), its decrease indicating a decrease of the intersystemic relations. The present results support this position, as ethanol (1) depressed irregularly appearing activity of slow, non-involved units which were probably L units related to *other* environments and behaviours; (2) depressed, in Dg, such L units which are presumably involved in subserving not only food-acquisition behaviour, but also *other* acts, manifesting by their activity 'relations' between different behaviours, and (3) depressed ripples which presumably reflect the functioning of interneuronal relations, mediated through the Schaffer collaterals and associational fibres of hilar cells (Buzsaki, 1986).

Thus the injection of ethanol leads to a decrease in a number of certain L units which are active in behaviour, but not to a decrease of their activation if they maintain their relation to phases of behaviour. On the contrary, the markedness of their activation may even increase. Furthermore, the process of coordination of systems (intersystemic relations) attaining such behaviour is depressed.

When comparing the present results with those obtained by us for the limbic cortex, we conclude that in both the hippocampus and

limbic cortex ethanol selectively depresses the activity of L units, especially 'place' units and 'pedal' units.

The depression of the activity of L units probably leads to a general decrease in the number of active units both in the limbic cortex and CA1 of the hippocampus. An increase in the number of M units, relative in the limbic cortex, appeared in Dg as an absolute increase which led to an increase in the general number of active neurons.

However, the influence of ethanol on the pattern of specialization of units is smaller in the hippocampus, in contrast to the limbic cortex, in which we observed no significant change in the relative size of groups of L and M units after injection of ethanol. On the other hand, the direction of ethanol influence on frequency parameters of the discharges were similar in both structures, but more pronounced in the hippocampus. In the limbic cortex we found (unpublished data) no differences in the activation frequency of L and M groups of units after ethanol. In other respects the direction of ethanol influence on frequency parameters was similar in both structures.

In the motor cortex we also observed, after ethanol, a decrease of background frequency and an increase in the a/b ratio but no change in the pattern of specialization of units, similar as in the limbic structures. Therefore, the pattern of behavioural specialization seems to be a more sensitive indicator of differences in the sensitivity of units of different brain areas to acute influence of ethanol than the frequency parameters of the discharges.

The present study was supported by The Finnish Foundation For Alcohol Studies.

REFERENCES

ALEXANDROV, YU.I. 1989. *Psychophysiological Significance of the Activity of Central and Peripheral Neurons in Behavior*. Science Press, Moscow (in Russian).

ALEXANDROV, YU.I., GRICHENKO, YU. V. & JÄRVILEHTO, T. 1990a. Change in the pattern of behavioural specialization of neurons in the motor cortex of the rabbit following lesion of the visual cortex. *Acta Physiol Scand* 139, 371–385.

ALEXANDROV, YU.I., GRICHENKO, YU.V., LAUKKA, S., JÄRVILEHTO, T., MAZ, V. N. & SVETLAJEV, I.A. 1990b. Acute effect of ethanol on the pattern of behavioural specialization of neurons in the limbic cortex of the freely moving rabbit. *Acta Physiol Scand* 140, 257–268.

ALEXANDROV, YU.I., GRINCHENKO, YU.V., LAUKKA, S., JÄRVILEHTO, T. & MAZ, V.N. 1991. Acute effects of ethanol on unit activity in the motor cortex of freely moving rabbits: comparison with the limbic cortex. *Acta Physiol Scand* 142, 429–435.

BREESE, C.R., HAMPSON, R.E. & DEADWYLER, S.A. 1989. Hippocampal place cells: stereotype and plasticity. *J Neurosci* 9, 1097–1111.

BUZSAKI, G. 1986. Hippocampal sharp waves: their origin and significance. *Brain Res* 398, 242–252.

FOSTER, T.C., CASTRO, C.A. & MCNAUGHTON, B.L. 1989. Spatial selectivity of rat hippocampal neurons: dependence on preparedness for movement. *Science* 244, 1580–1582.

FOX, S.E. & RANCK, J.B. 1975. Localization and anatomical identification of theta and complex spike cells in dorsal hippocampal formation of rats. *Exp Neurol* 49, 299–313.

GRUPP, L.P. & PERLANSKI, E. 1979. Ethanol-induced changes in the spontaneous activity of single units in the hippocampus of the awake rat: dose–response study. *Neuropharmacology* 18, 63–70.

KANAMORI, N. 1986. Hippocampal minispindle wave in the cat: the different distribution of two types of waves. *Neurosci Res* 4, 152–156.

KLEMM, W.R. 1979. Effects of ethanol on nerve impulse activity. In: E. Majchrowicz, E.P. Noble (eds), *Biochemistry and Pharmacology of Ethanol*, vol. 2, pp. 243–267. Plenum Publishing Corporation.

KLEMM, W.R., MALLARI, C.G., DREYFUS, L.R., FISKE, J.C., FORNEY, E. & MIKESKA, J.A. 1976. Ethanol-induced regional and dose–response differences in multiple-unit activity in rabbits. *Psychopharmacology (Berlin)* 49, 235–244.

MCBRIDE, R.L. & KLEMM, W.R. 1968. Stereotaxic atlas of rabbit brain based on the rapid method of photography of frozen, unstained sections. *Comm Behav Biol* A2, 179–215.

O'KEEFE, J. & DOSTROVSKY, J. 1971. The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely moving rat. *Brain Res* 34, 171–175.

O'KEEFE, J. 1976. Place units in the hippocampus of the freely moving rat. *Exp Neurol* 51, 78–109.

O'KEEFE, J. 1979. A review of the hippocampal place cells. *Prog Neurobiol* 13, 419–439.

RANCK, J.R. 1973. Studies on single neurons in dorsal hippocampal formation and septum in unrestrained rats. Part I. Behavioral correlates and firing repertoires. *Exp Neurol* 41, 461–531.

SINCLAIR, B.R., SETO, M.G. & BLAND, B.M. 1982. Q-cells in CA1 and dentate layers of hippocampal formation: relations to slow-wave activity and motor behaviour in the freely moving rabbit. *J Neurophysiol* 48, 1214–1225.

SPEAKMAN, A. & O'KEEFE, J. 1990. Hippocampal complex spike cells do not change their place fields if the goal is moved within a cue controlled environment. *European J Neurosci* 2, 544–555.

THOMPSON, L.T. & BEST, P.J. 1989. Place cells and silent cells in the hippocampus of freely-behaving rats. *J Neurosci* 9, 2382–2390.

WESTPHAL, K.P., KUNZ, G.B., BECHINGER, D., DIEKMAN, V. & KORNHUBER, H.H. 1990. Enhancement of theta activity before voluntary movements may reflect limbic activation. In: *Epilepsy* (Surg Pathophysiol, Clin Symptomatol, Med Treatm, Patient Selec and Surg Techn), p. 52.

WHISHAW, I.Q. 1976. The effect of ethanol and atropine on EEG and behaviour in the rabbit. *Psychopharmacology (Berlin)* 48, 83–90.

WIENER, S.I., PAUL, C.A. & EICHENBAUM, H. 1989. Spatial and behavioural correlates of hippocampal neuronal activity. *J Neurosci* 9, 2737–2763.

ZORNETZER, S.F., WALKER, D.W., HUNTER, B.E. & ABRAHAM, W.C. 1982. Neurophysiological changes produced by ethanol. In: Ethanol and Health Monograph N2. *Biomedical Processes and Consequences of Ethanol use*, pp. 95–128. US Government Printing Office, Washington, D.C.