SHUTTLE-BOX MEMORY FACILITATION BY POST-TRAINING INTRACRANIAL SELF-STIMULATION: DIFFERENTIAL EFFECTS IN RATS WITH HIGH AND LOW BASIC CONDITIONING LEVELS.

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ABSTRACT

Rats were trained in a two-way active avoidance task (one massed acquisition session of 50 trials) immediately followed by a lateral hypothalamic intracranial self-stimulation (ICSS) treatment. The effects of this ICSS treatment upon retention at different times (24-hours, 7, 15 or 60-days) were studied in independent groups of subjects. Each one of these four groups of subjects was compared with a non-treated one (Control group). All groups of subjects (Control and ICSS) showed a higher performance on the retention session than on the acquisition session. In the Control subjects, the higher retention performances were observed in the 7-days and 15-days groups. However, the ICSS treatment facilitated the 24-hours retention compared to its Control group, allowing the treated subjects to achieve the same level of performance on the 24-hours retention session than that achieved by the non-treated (Control) animals at the 7-days retention test. At the 24-hours retention session, ICSS also increased the percentage of subjects that achieved an established learning criterion and decreased the number of trials to reach it. Clear differences related to the initial level of conditioning (acquisition session) were also observed in the 24-hours groups. That is, the facilitatory ICSS effect was stronger in the subjects with a low level of conditioning and weaker in those with a high level. It is concluded that post-training ICSS accelerates memory consolidation, and may equalize the performance of poor and good learners.

INTRODUCTION

Evidence from several studies indicates that intracranial self-stimulation (ICSS) in the lateral hypothalamus (LH) can modulate learning and memory consolidation processes (aversive and appetitive classical conditioning: Coulombe and White, 1980; 1982a; sensory preconditioning: Coulombe and White, 1982b; appetitive operant conditioning: Major and White, 1978). Experiments from our laboratory (Segura, Capdevila, Martí and Morgado, 1988; Segura, Portell and Morgado, 1991) have shown that post-training LH-ICSS can also improve the acquisition of a distributed two-way active avoidance conditioning (shuttle-box), in rats. This facilitatory effect is sustained over long periods (10 and 31 days). Our results also indicate that the number of ICSS trains and the intensity of the administered current are critical parameters in the facilitatory effect. There is a lineal and positive relationship between the level of the learning improvement produced by the ICSS treatment and those ICSS parameters. In our conditions, 2500 trains of ICSS at 100% of the optimum intensity (see Segura et al, 1988) produced the highest facilitatory effect.

The present experiment has been designed to improve our knowledge about the facilitatory effect of post-training ICSS upon two-way active avoidance retention. Four different retention times (24-hours, 7, 15 and 60-days), in independent groups of rats, are now tested. Because the training characteristics of our previous experiments (a distributed paradigm consisting of 5 acquisition sessions, one per day, 10 trials each) do not allow us to differentiate between the basic processes of acquisition and retention, the latter being the main objective of the present work, a massed training (50 trials) has now been chosen. In this way, we avoid the problems of distinguishing between the long usual periods (24-hours) of retention between sessions in distributed conditioning and the long periods of post-training retention necessary for testing the ICSS effects upon memory consolidation. The massed paradigm also allows to observe the effects of the treatment at different intervals without interference of repeating

experience sessions (as it occurs in a distributed paradigm). Furthermore, the massed paradigm makes possible to study the efficacy of the ICSS facilitatory treatment in relation to the basic level of conditioning of the rats, measured as the number of avoidances in the single acquisition session. This experiment is designed as another preliminary stage to investigate the neural pathways involved in learning and memory facilitation by post-training ICSS. We think that a better knowledge of the temporal evolution of the facilitatory process might help us to establish hypotheses about its neurophysiological nature.

METHODS

Subjects

One hundred forty-nine naive male Wistar rats, obtained from our laboratory breeding stock, with a mean age of 90.29 days (SD=4.14) at the beginning of the experiment and a mean weight of 430.5 g (SD=50.14) at the time of surgery, were used.

Electrode Implantation

Under sodium pentobarbital anaesthesia (50 mg/Kg, i.p.), each animal was implanted with a monopolar stainless steel electrode (130 μm) aimed at the LH, into the fibers of the medial forebrain bundle (MFB), according to the following stereotaxic coordinates: AP=-1.8 mm from bregma; L=2.0 mm (right hemisphere) and P=-8.5 mm, with the cranium surface as dorsal reference (Paxinos and Watson, 1986).

Procedure

Once the subjects (Ss) had recovered from surgery (7-days), they were taught to self-stimulate by pressing a lever in a conventional Skinner box (25x20x20 cm). Electrical brain stimulation consisted of a 0.2 sec train of 50 Hz sinusoidal waves at intensities between 10 and 200 μA. ICSS behavior was shaped for each subject to establish the range of current intensities that would support responding on a continuous reinforcement schedule. Those animals in which the stimulation produced convulsive or other abnormal behavior were excluded from the experiment. On 3 consecutive days, rats were trained in ICSS to establish the optimum current intensity of ICSS (EOI sessions) (as described in Segura et al., 1988). The mean of the two current intensities that resulted in the highest response rate in each of the last two EOI sessions (partial optimal intensities) was considered as the optimum intensity (OI) of ICSS for each animal.

The conditioning paradigm consisted of a two-way active avoidance task (one session of 50 trials). Before the acquisition session, two adaptation sessions (10 min each) consisting of free ambulation in the shuttle-box (Lafayette Instruments, Co.) were given to familiarize the rats with the learning environment. Two days later, the Ss were submitted to one acquisition session of two-way active avoidance. Immediately before this session, they received a supplementary 10 minutes adaptation session. The conditioned stimulus was an 80 dB and 1 KHz tone of 10 s duration. The unconditioned stimulus was an 1 mA electrical footshock, presented for 30 s at maximum. The CS-US interval was a short delay conditioning procedure, where the US is presented immediately after the end of the CS. The trials followed a fixed interval schedule of 1 min. In addition to the number of avoidance responses made in each conditioning session and the response latencies (both measures considered as the level of performance), inter-trial crossings were also scored.

Before the two-way active avoidance acquisition session, rats were randomly distributed into 8 groups according to two independent variables: TREATMENT (ICSS or Control) and RETENTION TIME (24-hours, 7, 15 or 60-days). Four groups of Ss received an ICSS session (2500 trains at the 100% of their OI) immediately after the acquisition session: **24h-ICSS** (n=16), **7d-ICSS** (n=19), **15d-ICSS** (n=15) and **60d-ICSS** (n=14). The other four groups of Ss (Control groups) did not receive stimulation after the acquisition session: **24h-C** (n=14), **7d-C** (n=15), **15d-C** (n=16), and **60d-C** (n=13) groups. The Ss of these control groups were placed during 15 min in the ICSS box after the acquisition session, with the electrode clip connected but with the lever retracted.

To test the retention level of the learned response, the rats received one additional avoidance session (50 trials) 24-hours (24h-ICSS and 24h-C groups), 7-days (7d-ICSS and 7d-C groups), 15-days (15d-ICSS and 15d-C groups) or 60-days (60d-ICSS and 60d-C groups) after the acquisition session.

Histology

At the end of the experiment, histological analyses were performed to verify the location of the electrode. The rats were sacrificed with an overdose of sodium pentobarbital (i.p.). They were then perfused intracardially with 10% formalin in distilled water. The brains were removed, frozen and cut into 35 μm sections on a freezing stage microtome (Frigomobil, JOUNG). The tissue was stained with Cresyl violet and examined under a binocular microscope. Electrode tip locations were reconstructed on plates from the atlas of Paxinos and Watson (1986).

Data Analyses

The main analyses have been carried out considering the independent variables as qualitative (*treatment*: 2 categories, and *time of retention*: 4 categories) and the dependent variables as quantitative. Thus, mixed analyses of variance were performed, with their correspondent contrast analyses ("simple" or "repeated" for the between-group effect, and "polynomial" for the within-groups effect). A survival analysis (see Lawless, 1982 and Miller, 1981) was also made to analyze and compare the mean number of trials that each experimental group needed to reach a fixed learning criterion (5 consecutive avoidance responses).

Those rats showing an irregular acquisition (no avoidance responses in more than 3 blocks of 10 trials) were not included in the statistical analyses (3 in the 24h-ICSS group, 1 in the 24h-C group, 6 in the 7d-ICSS group, 2 in the 7d-C group, 2 in the 15d-ICSS group, 3 in the 15d-C and 1 in the 60d-ICSS).

RESULTS

The final sample consisted of 104 rats distributed into the eight groups described in the methods section. There were no statistical differences between groups in the body weight evolution along the experiment (MANOVA).

Acquisition of Active Avoidance Behavior

As expected, an analysis of variance for the entire sample did not show significant differences among groups in the total number of avoidance responses on the acquisition session. In order to study more accurately the evolution of the conditioning acquisition, we considered this session as being composed of five blocks of ten trials each. We observed that acquisition functions were also similar for all the groups (the interaction *block x group* effect of the MANOVA was not statistically significant). With respect to the evolution of learning throughout the five blocks of this session, the within-groups MANOVA pointed out that, in all the groups, the more important improvements in learning were observed on the four first blocks [1^{st} to 2^{nd} block: $F_{(1,96)}=58.29$ $p<0.001$; 2^{nd} to 3^{th} block: $F_{(1,96)}=88.59$ $p<0.001$; 3^{th} to 4^{th} block: $F_{(1,96)}=5.64$ $p=0.02$], and that there was a learning stabilization on the last two blocks (no differences were found between 4^{th} and 5^{th} blocks). The analyses of response latencies confirmed all the results obtained with avoidance responses. Thus, we can conclude that all the groups reached the same learning level on the acquisition session, a critical condition to be able to study the effects of the ICSS treatment upon different retention times.

Retention of Active Avoidance Behavior

a) Effects of ICSS treatment in each of the different retention sessions.

Figure 1 depicts the mean avoidances shown by ICSS and Control groups on the acquisition and retention sessions (24-hours, 7, 15, and 60-days). The retention performance

was better than the acquisition one in all the 8 groups of Ss [avoidances increment: $F_{(1,96)}$=201.25, p<0.001; response latencies decrement: $F_{(1,96)}$=206.85, p<0.001]. However, on the 24-hours retention session such increment in the performance level was higher in ICSS than in Control group, that is, the treatment facilitated the 24-hours retention. In fact, the MANOVA already showed that the decrement of the response latencies observed on the 24-hours retention test was higher in the ICSS group than in the Control one [$F_{(1,96)}$=7.91, p=0.006]. Moreover, the level of performance achieved on the 24-hours retention session by the ICSS group was higher than that of the Control group [avoidances: $F_{(1,24)}$=5.34, p=0.030; response latencies: $F_{(1,24)}$=8.18, p=0.009]. Furthermore, as we can observe in Figure 2, considering the 24-hours retention session as composed of five consecutive blocks of ten trials each, the facilitatory effect of the ICSS treatment was observed along the five blocks of the retention session.

This facilitatory effect of the ICSS treatment on the 24-hours retention session was also confirmed by a survival analysis, which pointed out significant differences between ICSS and Control groups [χ^2=4.118; fd=1; p=0.042]. As shown in Figure 3, all Ss of the ICSS group achieved an established learning criterion (5 or more consecutive avoidance responses), whereas only 75 percent of the Control group reached it. Moreover, the ICSS group achieved this established criterion faster than the Control one, as shown by the fact that 75 percent of ICSS animals reached the criterion in a mean of just 16,25 trials, whereas the control animals needed more than twice this quantity of trials (33,75).

No statistical differences were found between ICSS and Control groups on the 7, 15 or 60-days retention tests.

b) Longitudinal analyses.

Concerning the performance on the retention session tested 24 hours, 7, 15 or 60 days after the acquisition session (see Figure 1), significant differences were found among Control groups [avoidances: $F_{(3,96)}$=2.73, p=0.0048; response latencies: $F_{(3,96}$=4.47, p=0.006]. The results pointed out that the retention performance seems to spontaneously increase as time goes by. The

level of retention seems better 7 days than 24 hours after the acquisition, is sustained after 15 days and shows a tendency to decrease 60 days after the acquisition session. The MANOVA confirmed these results, showing that the increment in the number of avoidances on the corresponding retention session, compared to the respective acquisition one, was significantly higher on the 7-days test than on the 24-hours and 60-days retention tests [simple-contrast: $F_{(1,48)}$=7.66, p=0.008; $F_{(1,48)}$=4.43 p=0.04, respectively], and that the decrement of the response latencies was higher on the 7, 15 and 60-days retention tests than on the 24-hours retention test [simple-contrast: $F_{(1,48)}$=15.02, p<0.001; $F_{(1,48)}$=7.61 p=0.008 and $F_{(1,48)}$=4.53 p=0.039, respectively]. Moreover, the mean response latencies on the retention session were significantly lower on the 7 and 15-days retention tests than on the 24-hours retention test [simple-contrast: $F_{(1,48)}$= 4.37, p=0.042; $F_{(1,48)}$=4.62 p=0.037, respectively].

In contrast, no significant differences were found among the four retention sessions in the ICSS groups (see Figure 1), that is, ICSS treatment seemed to nullify the differences observed over time in normal conditions (Control groups).

c) Individual Differences.

Another interesting result was that on the 24-hours retention test the ICSS treatment decreased the within group performance variability compared to the control group [Snedecor: avoidances F=6,052 > $F_{(12,12,0.01)}$ =4.16; response latencies F=7,02 > $F_{(12,12,0.01)}$ =4.16]. This result suggested the possibility that ICSS would not affect all the subjects in a similar way. To test this possibility, each of the two previous 24-hours retention groups (24h-ICSS and 24h-C) were subdivided into two subgroups of subjects according to their performance on the acquisition session. Those animals that achieved a level of acquisition higher than the mean (24h-C: n=9; 24h-ICSS: n=8) comprised the high-level acquisition subgroups (HA). Animals that showed an acquisition level lower than the mean (24h-C: n=4; 24h-ICSS: n=5) comprised the low-level acquisition subgroups (LA). As expected, no statistical differences were found on the acquisition session between ICSS and Control groups into neither HA nor LA subgroups of subjects.

The above reported ICSS facilitatory effect upon the 24-hours retention test depended on the initial acquisition level of the subjects. As it can be observed in Figure 4, the ICSS treatment seemed to be effective only in the LA subjects. A MANOVA showed that, while the HA subjects, in both ICSS and Control groups, showed a significant improvement of performance between acquisition and retention [Control: avoidances: $F_{(1,11)}$=17,84; p=0.001; response latencies: $F_{(1,11)}$=8,21; p=0.015; ICSS: avoidances: $F_{(1,11)}$=21,62; p=0.001; response latencies: $F_{(1,11)}$=21,49; p=0.001], LA subjects only showed such improvement when they had received ICSS treatment [ICSS: avoidances: $F_{(1,11)}$=63,45; p<0.001; latencies: $F_{(1,11)}$=54,69; p<0.001]. These results suggest that the ICSS treatment might equalize the performances of the LA and HA subjects on the 24-hours retention test. Moreover, as is shown in Figure 5, where some previous data are presented in a different way, no statistical differences were observed in the performance between LA-ICSS subjects on the 24-hours test and LA-Control subjects on the 7-days test. Thus, in the LA subjects, the ICSS treatment had the same effect than the passage of a long time after training, that is, it allowed the Ss of this group to reach on the 24-hours retention test the same performance level that 1) they would achieve after a period of 7 days without treatment, or 2) HA Control subjects achieved on the 24-hours retention test.

Did the treatment also affect the HA subjects? Yes. In spite that the MANOVA did not detect significant effects of ICSS treatment upon HA subjects, a survival analysis showed that HA subjects treated with ICSS reached the learning criterion faster than HA control subjects [χ^2 =4.331; fd=1; p=0.0374].

ICSS Behavior and Shuttle-Box Locomotor Activity

During the shaping session, twenty-seven rats had to be excluded of the experiment because of aversive or stereotyped behavior induced by the intracranial electrical stimulation.

Although some significant differences between groups were found regarding the different parameters of ICSS (OI values, and ICSS rates in both EOI and treatment sessions), correlational analyses showed that no one of such variables was related to the level of

conditioning achieved in the acquisition or retention sessions. The mean values of these ICSS variables and the results of the MANOVA between the experimental groups are summarized in Table 1.

Concerning the activity level in the shuttle-box, an analysis of variance did not detect any statistical differences between groups in the number of crossings performed during the 3 shuttle-box adaptation sessions. With reference to the number of inter-trial crossings made in the retention session no effects of the treatment variable were observed. However, statistical differences were found depending on the retention time variable [$F_{(3,96)}$=5.97, p=0.001]. Specifically, the 24-hours retention groups showed a lower activity level than the 7 and 15-days retention groups [$F_{(1,100)}$=5.76, p=0.018 and $F_{(1,100)}$=14.16, p<p=0.001, respectively] and the 60-days retention groups showed a lower activity level than the 7-days retention groups [$F_{(1,100)}$=10.45, p=0.002]. Nevertheless, these differences could not explain the observed variations in learning, since correlational analyses showed that the locomotor activity in shuttle-box was never related to the level of conditioning.

Histology

All electrodes were implanted into brain sites between -1.40 mm and -2.30 mm antero-posterior coordinates with reference to bregma (Paxinos and Watson, 1986). Most of the Ss whose electrode was outside the LH-MFB but that showed regular ICSS rates (6 of the 24h-C group; 2 of the 7d-ICSS group, 2 of the 7d-C group, 3 of the 15d-C group, 2 of the 60d-ICSS group and 5 of the 60d-C group) had their electrode tips in the following brain regions: fornix, ansa lenticularis and the region in the zona incerta above the MFB. Statistical analyses (T-tests) showed that it does not seem to exist any relationship between the histological location of the electrode and either the activity in the shuttle-box (both during adaptation and learning sessions) or the OI values for each subject. MFB stimulation seemed to generate higher ICSS rates than the rewarding stimulation of other brain sites [$F_{(1,85)}$=9.74, p=0.002]. Finally, the electrode

location was not related, either, to the number of avoidances performed during acquisition and retention sessions.

DISCUSSION

The results of the present experiment showed that post-training ICSS facilitated the 24-hours retention of a massed two-way active avoidance conditioning. On the 24-hours retention test the treated animals achieved a performance level higher than that of their controls, and similar to the high and asymptotic performance achieved by the non-treated animals (Control group) on the 7-days retention test. That is, apparently the ICSS treatment reduced the post-training time necessary to reach the maximum spontaneous performance level. The 24-hours ICSS facilitatory effect was also pointed out by the fact that the treatment increased the percentage of subjects that achieved an arbitrary learning criterium.

Our results also showed that the memory consolidation time of this conditioning was not the same for all the subjects. While a post-training period of only 24 hours was enough for HA rats (good learners) to reach a maximum performance level, a longer period (7 or more days) was required for LA rats (poor learners). However, the ICSS treatment nullified these differences affecting mainly the performance of the LA subjects, which showed the same level of performance than HA ones (with or without ICSS) on the 24-hours retention test.

The observed 24-hours facilitatory effect confirms our previous results with the same kind of conditioning but under different training conditions (Segura et al., 1988; 1991). They also agree with other results showing a facilitatory effect upon the 24-hours retention of other kinds of conditioning (Coulombe and White, 1980; 1982a; 1982b; Major and White, 1978).

The above mentioned performance differences between groups of subjects are probably attributable to the effect of ICSS treatment, but not to other variables such as intracranial electrode locations, appearance of convulsions or changes in locomotor activity, since no relation was found between these variables and the performance level in any group of Ss in any session.

Several hypotheses could explain our results. Because in the present experiment the ICSS effect was only evident when the animals were tested 24 hours after the treatment (and not after longer periods: 7, 15 or 60-days), it is possible to suggest that the treatment had an anterograde facilitatory effect on the 24 hours performance/retrieval. However, several reasons argue against this possibility. First, it has been shown that when the ICSS treatment is administered between 1 and 4 hours after the training session, depending on the particular kind of conditioning, it loses its facilitatory effect upon 24-hours retention (Coulombe and White, 1980; 1982a; 1982b; and Major and White, 1978). Thus, a critical factor seems to be the contingency between the treatment and the previous conditioning session, but not the temporal proximity between the treatment and the next session. Second, our previous research showed that when several post-training ICSS treatment sessions are given to the rats in a distributed conditioning training, the facilitatory effect of ICSS is also observed in tests performed 10, 15 or 30 days after the last ICSS treatment session (Segura et al., 1991). Is it still possible to claim for an anterograde effect of ICSS so many days after the treatment?. It does not seem probable. In our experiment, the lack of ICSS effects upon long-term retention can be explained by the fact that, since the facilitatory effect seems to depend on the total number of ICSS trains administered (Segura et al., 1991), a single ICSS treatment session could have been insufficient to make evident this facilitatory effect at periods longer than 24 hours. Moreover, a ceiling effect, as a consequence of the massed training procedure used (50 trials), could also have masked the long term ICSS effect. In this sense, while on the 24-hours retention test (where the ICSS treatment had effect) the performance level of the non-treated animals was low (62%), on the remaining retention tests (where ICSS did not have any effect) the non-treated animals showed higher performance levels (7-days: 77.38% avoidance responses; 15-days: 77.23% and 60-days: 70.46%). These last values were similar to those of the ICSS facilitated 24-hours retention group (83.6%). Therefore, there are good reasons to question an anterograde effect, on the other hand not easy to explain, of the post-training ICSS upon the retention performance.

Another suggestion, following the interpretation of the Kamin effect (1959) for this kind of conditioning, is that the ICSS treatment might reduce the shock induced fear reactions (i.e. freezing) which could interfere with shuttle-box behavior shortly (24 hours) but not at later times (7 or more days) after training. This hypothesis could also explain our previous results showing long-term (10 or 30 days) performance facilitation with distributed avoidance training. That is, if the animals learn more during the training sessions because of a reduced fear reaction induced by the ICSS treatment, we might also expect a higher long-term retention of the conditioned response. Nevertheless, these explanations seem unlikely, since post-training ICSS treatment is also capable of improving the retention of appetitive conditioning, where aversive emotional behavior is considered to play a non-significant role (Coulombe and White, 1980). On the other hand, in our opinion, the retention level showed by non-treated subjects on the 24-hours session does not seem to correspond to a true Kamin effect, since: a) the Kamin effect is observed between 0 and 1 hour after the acquisition session, but not after 24 hours when the performance level seems to recover; b) our results do not show a decrease of performance on the 24-hours retention session compared to acquisition (even though we do not know what would happen on a 1-hour retention test); c) while in the original Kamin's experiment the animals reached a moderate acquisition level (25 trials), in our experiment all the groups showed a learning stabilization on the last trials of the acquisition session (animals received twice that quantity of trials).

Huston et al. (1977) showed that post-training reinforcing stimulation of the lateral hypothalamus improves retention of T-maze learning when given after errors only. In the present experiment the ICSS treatment had a greater effect on poor learners (that received more shocks during training). Therefore, a third way of explaining our results is to think that the ICSS treatment could have a greater effect on memory for aversive than for rewarding events. However, we do not believe in that possibility mainly because, as we have seen in our previous experiments (Segura et al. 1989, 1991), an identical ICSS treatment did not differentially facilitate the 24 hours retention of the first sessions (when the subjects performed the maximum

number of wrong responses and, therefore, received the maximum number of shocks) of a distributed shuttle-box paradigm. In fact, we observed the greater facilitation in the last conditioning sessions where most of the subjects received a low number of shocks.

In the same sense, it is also difficult to believe that in the present experiment the ICSS treatment, given immediately after the end of the unique massed conditioning session (and not contingently to errors performed in each trial, as Huston et al.), affected more the associations of the first trials (always with more shocks) than those of the last trials, where all the subjects, the poor learners enclosed, received a lower number of shocks. Anyway, the suggestion that ICSS treatment could have a greater effect for aversive than for rewarding events deserves been tested in new experiments.

A fourth possibility, as we have suggested in previous works (Segura et al., 1988; 1991), is to explain our results in relation to memory consolidation processes. In the present experiment we have observed a spontaneous increase in performance over time, mainly in LA subjects, that is, the retention level of control animals was better 7 days than 24 hours after training, and it was sustained after 15 days. Other previous experiments also pointed out a natural tendency of the normal (non-treated) subjects to improve their performance over time, without any treatment or experience repetition (Huppert and Deutsch, 1969; Destrade and Cardo, 1974; Jaffard, Destrade, Soumireu-Mourat and Cardo, 1974; Segura et al., 1991). All these results support the Bloch's hypothesis (Bloch, 1970) suggesting that, even though the registration of new information is followed by a short period of processing, usually called the consolidation period, which requires a minimum level of arousal, true consolidation may occur later. Thus, how did the treatment improve the retention performance in the present experiment? Since post-training ICSS treatment allowed the subjects to reach at the 24 hours the same performance level that they could have achieved without treatment after a memory consolidation period of 7 days, the ICSS effect could lie in an acceleration of the consolidation period, that is, decreasing the time required to reach an asymptotic retention level. Because the facilitation of the 24-hours performance was mainly observed in the LA subjects, the ICSS speeding-up effect upon

consolidation process could depend on the initial acquisition level of each subject. As mentioned above, the ICSS treatment seems to equalize LA and HA performances at the 24-hours test, probably accelerating the consolidation process of those rats with a basic poor level of avoidances (LA rats). It seems then, that post-training ICSS treatment provides the LA subjects with something that HA subjects are already endowed of. ICSS could act making up for a deficiency of some systems related to memory formation, as for example those of arousal. In this sense, previous works have suggested that reinforcing brain stimulation improves learning by generating an unspecific or general activation of the central nervous system during a critical period for memory consolidation (Destrade and Jaffard, 1978; Segura et al., 1991). In contrast to this suggestion, Major and White (1978) showed that electrodes in certain brain sites produce vigorous self-stimulation but not post-training memory improving effect. Therefore, as Major and White (1980) suggest the facilitatory effect could depend on the activation of particular pathways, as those of the medial forebrain bundle related to the nigro-striatal system. Post-training general or specific arousal induced by the ICSS treatment could also explain the decreased number of trials that HA subjects required to reach the learning criterion at the 24-hours retention test. That is, although ICSS treatment was not able to increase significantly the performance in HA subjects because of a ceiling effect, it accelerated the within session learning (performance) of these subjects.

In conclusion, our results suggest that post-training ICSS treatment accelerates memory consolidation and may equalize the performance of poor and good learners.

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FIGURE LEGENDS

Figure 1: Mean avoidances and standard errors in the four retention sessions compared to those on the acquisition sessions in ICSS and Control groups. ICSS facilitated the retention only on the 24-hours test (as indicated, the mean avoidances in the 24h-ICSS group was higher than in the 24h-C group).

Figure 2: Mean avoidances in the 24h-ICSS and its respective Control groups in each of the blocks of the acquisition and the retention sessions. Both groups showed the same level of performance on the acquisition session. But ICSS had a facilitatory effect along the five blocks of the retention session. (Means and standard errors are depicted).

Figure 3: Survival curve of the 24-hours retention session comparing ICSS and Control groups. ICSS subjects achieved the learning criterion faster than control subjects. In addition, while 100 percent of the subjects in the ICSS group reached the criterion only 75% of the control subjects reached it.

Figure 4: Differential effects of ICSS in the 24-hours retention test depending on the initial acquisition level of the subjects. ICSS increased retention performance specially in low-acquisition level subjects. (Means and standard errors are depicted).

Figure 5: Comparative effects of the treatment upon retention of shuttle-box conditioning. ICSS equalized the performance of LA subjects on the 24h retention test (24h-ICSS) with 1) the one of LA Control subjects on the 7d retention test (7d-C) (the suggested acceleration of memory consolidation) and 2) the one of HA Control subjects on the 24h retention test (that is, the treatment equalized poors and good learners at 24 hours). (Means and standard errors are depicted).

Table 1: Mean values corresponding to different variables of the ICSS response: optimal intensity of stimulation (OI), response rate in both EOI and treatment sessions.