Pharmacology Biochemistry and Behavior, Vol. 64, No. 1, pp. 53–57, 1999

0091-3057/99/$–see front matter

ELSEVIER

PII S0091-3057(99)00091-X

Rapid Effects of Estrogen or Progesterone on the Amphetamine-Induced Increase in Striatal Dopamine Are Enhanced by Estrogen Priming: A Microdialysis Study

JILL B. BECKER*‡ AND CHARLES N. RUDICK*

*Psychology Department, ‡Reproductive Sciences Program and Neuroscience Program,
The University of Michigan, Ann Arbor, MI 48109

Received 28 August 1998; Revised 3 February 1999; Accepted 15 February 1999

BECKER, J. B. AND C. N. RUDICK. *Rapid effects of estrogen or progesterone on the amphetamine-induced increase in striatal dopamine are enhanced by estrogen priming: A microdialysis study.* PHARMACOL BIOCHEM BEHAV **64**(1) 53–57, 1999.—There are estrous cycle-dependent differences in amphetamine-stimulated behaviors and striatal dopamine (DA) release; intact female rats exhibit a greater behavioral response to amphetamine on estrus than on other days of the cycle. Following ovariectomy amphetamine-induced behavior is attenuated, as is the striatal DA response to amphetamine in vitro. Repeated estrogen treatment in ovariectomized rats reinstates both of these responses to a level comparable to estrous females. In addition, 30 min after a single treatment with a physiological dose of estrogen there is enhanced amphetamine-induced behavior and increased amphetamine-induced striatal DA detected during microdialysis. This experiment was conducted to determine whether the acute effect of estradiol and the effect of repeated exposure to estrogen are functionally related. We report here that prior treatment with estrogen (three daily treatments of 5 μg estradiol benzoate) results in a significant enhancement of the effect of acute estrogen (5 μg estradiol benzoate) or progesterone (500 μg) on amphetamine-induced striatal DA release and stereotyped behaviors. Both the peak response and the duration of the response are greater in estrogen-primed animals treated with estrogen or progesterone 30 min prior to amphetamine, than in all other groups. Either prior treatment with estrogen (last dose 24 h before) or a single acute injection of estrogen result in an enhanced peak response to amphetamine, with no effect on the duration of amphetamine-induced striatal DA release. Treatment with progesterone in animals not primed with estrogen was not different from treatment with oil vehicle. These results demonstrate that there are both acute and long-term effects of estrogen on the striatum that underlie the dynamic changes in stimulated DA release and amphetamine-induced behaviors during the reproductive cycle. © 1999 Elsevier Science Inc.

Estrogen Progesterone Stereotyped behavior Dopamine Amphetamine Striatum

THE gonadal hormones, estrogen and progesterone, modulate behavioral and neurochemical indices of activity in the striatum [e.g., 1,4,7,15,16,20,24,26,30,32,41]. During estrus, amphetamine (AMPH)-induced striatal dopamine (DA) release is enhanced relative to other days of the estrous cycle (6–8) as is striatal DA metabolism and basal striatal extracellular DA (31,42), while striatal DA uptake sites are highest on the morning of proestrus (37). There is also estrous cycle-dependent variation is striatal DA receptor binding (14,35). Behaviorally, female rats show a greater response to striatal DA activation during estrus (6–12 h after the surges of estrogen and progesterone) than 24 h later on diestrus 1 (6,8,33,39). Female

Requests for reprints should be addressed to Jill B. Becker, Psychology Department, Biopsychology Area, 525 East University, Ann Arbor, MI 48109-1109.

rats also make fewer foot placement errors on estrus, compared with diestrus 1 or early proestrus, when traversing a suspended beam (9).

Ovariectomy attenuates striatal DA release and behaviors thought to be mediated by the striatal DA system (4,5,7,38). When ovariectomized (OVX) rats are treated for 3 days with estrogen, subsequent administration of either estrogen or progesterone enhances stimulated striatal DA release (4,5,7). Estrogen priming is necessary for progesterone to enhance stimulated striatal DA release in vitro (24). These effects of estrogen and progesterone occur coincident with an enhanced behavioral response to AMPH. Thus, relative to periods of low circulating hormones, during behavioral estrus or after repeated estrogen treatment, female rats exhibit greater rotational behavior and more intense stereotyped behavior (4–6,8).

The acute administration of estrogen to OVX rats also induces a rapid increase in AMPH-induced striatal DA release, 30 min later, as detected by in vivo microdialysis (3,11). In addition, estrogen rapidly induces an increase in striatal DA turnover (19) and downregulates D_2 class DA receptors (1). These effects are thought to be due to a direct effect of estrogen on the striatum, as physiological concentrations of estrogen in vitro rapidly enhance AMPH- or K^+-induced striatal release (2), and interfere in vitro with the GTP-induced affinity shift of D_2 DA receptors (36).

This experiment was conducted to directly compare the effects of acute estrogen treatment with the effects of repeated estrogen treatments on AMPH-induced DA in dialysate and stereotyped behavior. We also directly compare the effects of estrogen vs. progesterone with and without estrogen priming. We find that there are both acute and long-term effects of estrogen on the striatal DA response to AMPH, but that the acute effects of progesterone require estrogen priming.

METHOD

Adult female Sprague–Dawley rats weighing 175–200 g (Reproductive Science Program, University of Michigan, Ann Arbor) were maintained on a 14L:10D cycle with free access to food and water. They were housed two to three animals per cage until stereotaxic surgery, after which they were housed individually. All procedures were carried out using a protocol approved by the University of Michigan Care and Use of Animal Committee.

The rats were ovariectomized (OVX) under methoxyflurane anesthesia using sterile/aseptic conditions. Vaginal smears were taken for 10 days post-OVX and animals that continued to have cornified cells in the vaginal epithelium were eliminated from the study. At least 2 weeks after OVX, rats were anesthetized using sodium pentobarbital and guide cannulae (8 mm long; 25 gauge extrathin wall) were implanted bilaterally, 1 mm ventral to the top of the skull. Both cannulae were aimed for the dorsolateral striatum with coordinates from bregma, skull flat: anterior 0.2 and lateral 3.5. The cannulae were fixed into place using dental acrylic, and a stylet (8.5 mm) was inserted into each to prevent occlusion. Guide cannulae were implanted bilaterally to minimize loss of animals from the study. Only one set of data points was used for each animal. If both sites were confirmed to be appropriate by histology, and both probes functioned normally on the day of dialysis (the two sides were tested at the same time), the mean values of the two sides were used for that animal. If only one probe met the criteria, data from that one side was used for the analysis.

Dialysis probes were constructed based on the design described previously (40). The dialysis fiber was a semipermeable membrane with a molecular cutoff of 6000 and outer diameter of 0.25 mm (Spectrum Medical Industries, Los Angeles, CA). The probes were tested for recovery in vitro prior to the experiment. During recovery, a Ringer's solution (145 mM $NaCl_2$, 2.7 mM KCl, 1.2 mM $CaCL_2$, 1.0 mM $MgCl_2$, 0.25 mM ascorbic acid; pH = 7.3) was pumped through the probe at a flow rate of 1.5 μl/min. A solution of Ringers containing also 200 ng/ml of DA, homovanillic acid (HVA), and dihydroxyphenylacetic acid (DOPAC) was warmed to 37°C and the probe was placed into the solution for 1 h. Samples were collected at 15-min intervals. Recovery was calculated as the percent of each compound collected from the probe, relative to the amount in the solution after warming to 37°C. Only probes that recovered between 16 and 20% were used in dialysis. Twelve to 18 h before the beginning of an experiment, dialysis probes were inserted through the guide cannulae to a depth of 6.25 mm ventral to the skull. The Ringer's were pumped through the probes at a constant rate of 1.5 μl/min using a Harvard Apparatus pump (Holliston, MA). On the day of dialysis, samples were collected at 15-min intervals, and DA concentrations were assayed by high-performance liquid chromatography with electrochemical detection (6). DA concentrations were corrected for recovery as determined for each probe prior to the day of dialysis (amount of DA was divided by the % recovery and multiplied by 100).

At least 1 week after guide cannulae implantation, animals were primed with 5 μg estradiol benzoate (EB primed) in 0.1 ml peanut oil (SC) or peanut oil (0.1 ml; OIL primed), at 72, 48, and 24 h prior to dialysis. This dose of EB has been determined to produce serum concentrations of estradiol comparable to the physiological peak of estradiol during estrus (10,27). On the day of dialysis, six to eight baseline samples were taken at 15-min intervals to determine basal DA release. After baseline was determined to be stable, the animals received either 5 μg of EB, 500 μg progesterone (P), or oil. Groups: EB primed + EB (n = 7); EB primed + OIL (n = 8); OIL primed + EB (n = 9); OIL primed + OIL (n = 8); EB primed + P (n = 8); or OIL primed + P (n = 8). Thirty minutes later all animals received 2.5 mg/kg AMPH. Following AMPH administration, the animal's behavior was videotaped, and stereotyped head and forelimb movements were each counted during bins at 7.5-min intervals [coinciding with the dialysis collection intervals; (11)]. A subgroup of each group of the P-treated rats received P 4–5 h prior to AMPH (EB primed + P, n = 5; OIL primed + P, n = 3). Statistical comparisons by analysis of variance (ANOVA) indicated there was no effect of the time of P treatment (30 min vs. 4–5 h) on either the neurochemical or behavioral response to AMPH, and so the OIL-primed + P group and the EB-primed + P group each contain some animals that received P 30 min prior to AMPH, and others that received P 4–5 h before AMPH.

After dialysis, the rats received a lethal dose of sodium pentobarbital and were perfused with 0.9% saline followed by 10% formalin. The brains were removed, sectioned at 40 μm, and stained with cresyl violet to determine the position of the probe in the brain. Data from animals with probe placement outside of dorsolateral striatum were eliminated from the study. The numbers above indicated the final number of animals included in the analysis; six animals were eliminated due to probe placement.

Statistical analyses of behavioral and neurochemical data were performed using repeated-measures analysis of variance (ANOVA) with Bonferroni/Dunn post hoc group compari-

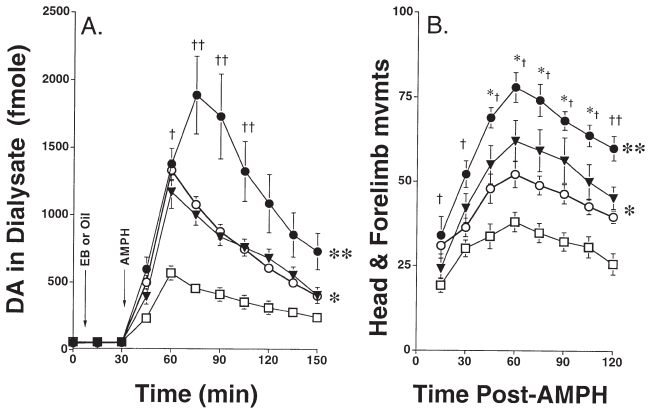

FIG. 1. (A) The effect of EB with or without EB priming on the AMPH-induced (2.5 mg/kg) increase in DA in dialysate from dorsolateral striatum. DA concentrations are expressed in fmol/15 min sample (mean ± SEM). Basal extracellular DA concentrations (fmol/15 min; mean ± SEM)—EB-primed + EB: 49.5 ± 7.4; OIL primed + EB: 50.1 ± 5.9; EB primed + OIL: 46.7 ± 4.0; OIL primed + OIL: 57.2 ± 10.3. (B) The effect of EB with or without EB priming on AMPH-induced stereotyped behaviors (head and forelimb movements) made in a 30-s sample time taken every 7.5 min. The sum of two observations were used for each 15-min interval (mean ± SEM). Closed circles: EB primed + EB, $n = 7$; open circles: OIL primed + EB, $n = 9$; closed triangles: EB primed + OIL, $n = 8$; open squares: OIL primed + OIL, $n = 8$. **Rats that received EB-PRIMED + EB showed significantly greater AMPH-induced DA in dialysate and greater stereotypy than all EB-treated groups for the entire 2-h period of sample collection (overall ANOVA; $p < 0.05$). *EB-PRIMED + OIL and OIL-PRIMED + EB groups showed a greater increase ($p < 0.05$) in AMPH-induced DA in dialysate and greater stereotypy than did the OIL PRIMED + OIL. †On individual time point comparisons EB PRIMED + EB > OIL PRIMED + OIL ($p < 0.05$). ††On individual time point comparisons EB PRIMED + EB > OIL PRIMED + OIL, OIL PRIMED + EB, and EB PRIMED + OIL ($p < 0.05$) and EB PRIMED + OIL and OIL PRIMED + EB > OIL PRIMED + OIL ($p < 0.05$). ‡On individual time point comparisons EB PRIMED + EB > OIL PRIMED + OIL and OIL PRIMED + EB ($p < 0.05$).

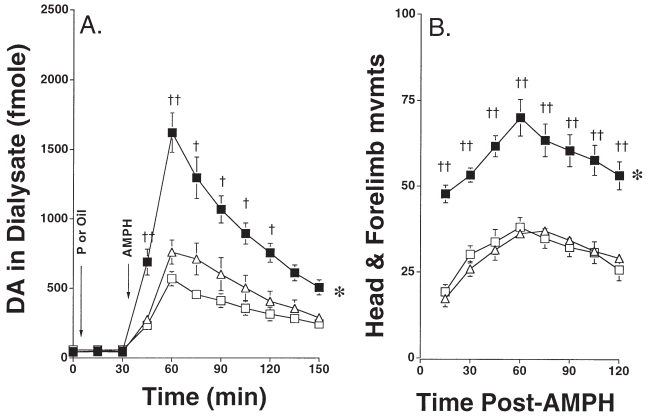

FIG. 2. (A) The effect of P treatment with or without estrogen priming on the AMPH-induced (2.5 mg/kg) increase in DA in dialysate from dorsolateral striatum. DA concentrations are expressed in fmol/15 min sample). Basal extracellular DA concentrations (fmol/15 min; mean ± SEM)—EB primed + P: 45.6 ± 1.7; OIL primed + P: 42.1 ± 3.2; OIL primed + OIL: 57.2 ± 10.3 (same data as Fig. 1). (B) The effect of P treatment with and without estrogen priming on AMPH-induced stereotyped behaviors (head and forelimb movements) made in a 30-s sample time taken every 7.5 min. The sum of two observations were used for each 15-min interval (mean ± SEM). Closed squares: EB primed + P, $n = 9$; open triangles: OIL primed + P, $n = 8$; open squares: OIL PRIMED + OIL, $n = 8$ (same data as in Fig. 1). *Rats that received EB PRIMED + P showed significantly greater AMPH-induced DA in dialysate and greater stereotypy than other groups depicted for the entire 2-h period of sample collection. †On individual time point comparisons EB PRIMED + P > OIL PRIMED + OIL ($p < 0.05$). ††On individual time point comparisons EB PRIMED + P > OIL PRIMED + OIL and OIL PRIMED + P ($p < 0.05$).

sons using Statview 4.5 for the Macintosh Computer. All six groups were compared in a single ANOVA for each of the measures (i.e., extracellular DA; head and forelimb movements), as rats from each of the groups were tested over the same time period in a random order.

RESULTS

In female rats primed with EB and receiving EB or P prior to AMPH, the AMPH-induced increase in extracellular striatal DA [main effect of group, $F(5, 42) = 12.609$, $p < 0.0001$; $p < 0.01$ in post hoc pair-wise comparisons] and stereotyped head and forelimb movements [main effect of group $F(5, 42) = 22.347$, $p < 0.0001$; $p < 0.05$ in post hoc pair-wise comparisons] were significantly greater than for all other groups (Figs. 1 and 2). On both measures there was a significant group × time interaction [DA, $F(35, 294) = 6.74$, $p < 0.0001$; stereotyped behaviors: $F(35, 294) = 2.38$, $p < 0.0001$] as the groups showed different patterns of change over time (Figs. 1 and 2). The AMPH-induced increase in DA in dialysate and stereotyped behavior, for both the EB-primed + OIL group and the OIL-primed + EB group, were significantly greater than the OIL-primed + OIL group or OIL-primed plus P group ($p < 0.05$). There were no significant differences in the stereotyped head and forelimb movements or in striatal DA concentrations in dialysate when the EB-primed + OIL group and the OIL-primed + EB group were compared (Fig. 1).

In female rats primed with EB, and receiving P prior to AMPH, the AMPH-induced increase in striatal DA ($p < 0.05$) and stereotyped head and forelimb movements ($p < 0.05$) were significantly greater than for the group receiving P without EB-priming or the OIL control group (Fig. 2). There were no significant differences in stereotyped head and forelimb movements or in striatal DA concentrations in dialysate when the OIL-primed + OIL group and the OIL-primed plus P group were compared (Fig. 2).

The time course of the AMPH-induced increase in striatal DA also varied across groups (Fig. 1A). At 30 min post-AMPH the increase in DA was comparable for the EB-primed + EB group, the EB-primed + OIL group, and the OIL-primed + EB group, and all three groups were greater than the OIL-primed + OIL group ($p < 0.05$). At 45 min post-AMPH the DA in dialysate from the EB-primed + EB group continued to increase while in the EB-primed + OIL and OIL-primed + EB groups DA concentrations were already declining. Thus, 45–75 min post-AMPH the DA in dialysate from EB-primed + EB-treated animals was significantly greater than for the EB-primed + OIL, OIL-primed + EB or OIL-primed + OIL groups ($p < 0.05$). During the interval from 45–60 min post-AMPH, DA in dialysate from the EB-primed + EB group was also greater than that seen in the EB-primed + P group ($p < 0.05$; Fig. 1A vs. Fig. 2A). How-

ever, at 15 and 30 min post-AMPH the increase in DA was greater for the EB-primed + P group than for the OIL-primed + P group and the OIL-primed + OIL group ($p < 0.05$). At 45 min post-AMPH the DA in dialysate from the EB-primed + P group began to decline, and was significantly greater than the OIL-primed + OIL group ($p < 0.05$). At 45–105 min post-AMPH the DA in dialysate from EB-primed + P-treated animals continued to be greater than for OIL-primed + OIL groups ($p < 0.05$).

The time course of AMPH-induced stereotyped head and forelimb movements (Fig. 1B) mirrors the group differences in DA in dialysate (Fig. 1A). During the first 30 min after AMPH, the EB-primed + EB group exhibited greater stereotyped behaviors than did the OIL-primed + OIL group. During the intervals from 45–105-min post-AMPH, the EB-primed + EB group had significantly more stereotyped head and forelimb movements than did the OIL-primed + OIL group and the OIL-primed + EB group ($p < 0.05$). During the last 15-min interval, the EB-primed + EB group was significantly greater than the OIL-primed + OIL, OIL-primed + EB, and EB-primed + OIL groups ($p < 0.05$; Fig. 1B). Throughout the 120-min post-AMPH, the the EB-primed + P group exhibited greater stereotypy than did the OIL-primed + OIL group or the OIL-primed + P group ($p < 0.05$; Fig. 2B).

DISCUSSION

The results of the experiments reported illustrate that physiological doses of estrogen can have both rapid (<1 h) acute effects and long-term (>24 h) effects on the AMPH-induced increase in striatal DA and DA-mediated behaviors. Furthermore, the combined effect of repeated estrogen treatments and acute estrogen produces a greater effect on these measures than either acute or repeated treatments independently. Interestingly, repeated estrogen treatments also primes the striatum to be responsive to P, although P by itself is without effect on AMPH-induced DA in dialysate or AMPH-induced stereotyped behaviors. These results indicate that the dramatic changes in striatal DA responsiveness that occur during the estrous cycle are due to the combined effects of exposure to increasing serum estrogen concentrations during the 4-day estrous cycle and the acute effects of the surges of estrogen and progesterone that occur on the afternoon of proestrus.

Either acute estrogen or repeated estrogen followed by 24-h withdrawal produces an enhancement in the peak of AMPH-induced DA in dialysate (see Fig. 1A). The combined treatment of repeated and acute estrogen results in an even greater, but delayed peak, and a broadening of the striatal DA response to AMPH. Thus, there is a greater effect of repeated and acute EB treatment. Acute actions are thought to be due to direct effects of estrogen on the striatum to increase DA turnover and enhance stimulated DA release (2,19,43). Prolonged or repeated estrogen treatments elevate serum prolactin, produce DA receptor supersensitivity, and can affect DA turnover. These DA receptor changes appear to be mediated both by indirect effects of estrogen on prolactin as well as through prolactin-independent effects of estrogen (12,13,14,17,18,28,29). During the estrous cycle, DA turnover increases during estrus and falls during proestrus (25). The resulting behavioral effects reported here are likely to be due to the combined effects of repeated EB and acute EB or P on striatal DA release, DA turnover, and DA receptor binding.

Interestingly, the hormone regimen given here has not been found to produce changes in DA receptor binding that would predict the behavioral results reported. Experiments using quantitative autoradiography to measure D_2 DA receptor binding find that 30 min after a single injection of EB, D_2 DA receptor binding is decreased. Furthermore, there was no effect of EB priming + P on D_2 DA receptor binding (1). Thus, changes in DA turnover and in AMPH-induced DA release following estrogen treatment are likely to be the primary cause of the behavioral effects reported.

The finding that in EB-primed rats, P enhances AMPH-induced DA in dialysate is consistent with previous reports that effects of P on striatal DA release in vitro are dependent on estrogen priming (20–24). Estrogen is thought to induce membrane receptors for progesterone in the striatum, which mediate this effect (34). Thus, during the estrous cycle when both estrogen and progesterone are present, estrogen is presumably acting at many sites both within the striatum and elsewhere to induce the cyclic changes in sensitivity to dopaminergic drugs that are seen [e.g., (2,6,8,9)].

The results reported here are important for our understanding of how estrogen affects stimulated striatal DA activity. The finding that there are combined effects of acute and repeated estrogen suggest that the timing of drug delivery may be important for the effectiveness of estrogenic drugs on sensorimotor functions. Given the high rate of use of hormone replacement therapy in postmenopausal women, and the incidence of Parkinson's Disease in an aging population, an improved understanding of the interactions among modes of estrogen treatment and basal ganglia function may eventually lead to more effective hormone replacement and drug treatment strategies for women.

ACKNOWLEDGEMENTS

This research was support by a grant from the National Science Foundation (BNS9514888).

REFERENCES

1. Bazzett, T. J.; Becker, J. B.: Sex differences in the rapid and acute effects of estrogen on striatal D2 dopamine receptor binding. Brain Res. 637:163–172; 1994.
2. Becker, J. B.: Direct effect of 17β-estradiol on striatum: Sex differences in dopamine release. Synapse 5:157–164; 1990.
3. Becker, J. B.: Estrogen rapidly potentiates amphetamine-induced striatal dopamine release and rotational behavior during microdialysis. Neurosci. Lett. 118:169–171; 1990.
4. Becker, J. B.; Beer, M. E.: The influence of estrogen on nigrostriatal dopamine activity: Behavioral and neurochemical evidence for both pre- and postsynaptic components. Behav. Brain Res. 19:27–33; 1986.
5. Becker, J. B.; Beer, M. E.; Robinson, E. E.: Striatal dopamine release stimulated by amphetamine or potassium: Influence of ovarian hormones and the light-dark cycle. Brain Res. 311: 157–160; 1984.
6. Becker, J. B.; Cha, J.: Estrous cycle-dependent variation in amphetamine-induced behaviors and striatal dopamine release assessed with microdialysis. Behav. Brain Res. 35:117–125; 1989.
7. Becker, J. B.; Ramirez, V. D.: Sex differences in the amphetamine stimulated release of catecholamines from rat striatal tissue in vitro. Brain Res. 204:361–372; 1980.
8. Becker, J. B.; Robinson, T. E.; Lorenz, K. A.: Sex differences and estrous cycle variations in amphetamine-elicited rotational behavior. Eur. J. Pharmacol. 80:65–72; 1982.
9. Becker, J. B.; Snyder, P. J.; Miller, M. M.; Westgate, S. A.; Jenu-

wine, M. J.: The influence of estrous cycle and intrastriatal estradiol on sensorimotor performance in the female rat. Pharmacol. Biochem. Behav. 27:53–59; 1987.
10. Butcher, R. L.; Collins, W. E.; Fugo, N. W.: Plasma concentration of LH, FSH, prolactin, progesterone and estradiol-17beta throughout the 4-day estrous cycle of the rat. Endocrinology 94:1704–1708; 1974.
11. Castner, S. A.; Xiao, L.; Becker, J. B.: Sex differences in striatal dopamine: In vivo microdialysis and behavioral studies. Brain Res. 610:127–134; 1993.
12. Di Paolo, T.; Diagle, J.; Picard, V.; Barden, N.: Effect of acute and chronic 17 beta-estradiol treatment on serotonin and 5-hydroxyindole acetic acid content of discrete brain nuclei of ovariectomized rat. Exp. Brain Res. 51:73–76; 1983.
13. Di Paolo, T.; Dupont, A.; Daigle, M.: Effect of chronic estradiol treatment on dopamine concentrations in discrete brain nuclei of hypophysectomized female rats. Neurosci. Lett. 32:295–300; 1982.
14. Di Paolo, T.; Falardeau, P.; Morissette, M.: Striatal D-2 dopamine agonist binding sites fluctuate during the rat estrous cycle. Life Sci. 43:665–672; 1988.
15. Di Paolo, T.; Levesque, D.; Daigle, M.: A physiological dose of progesterone affects rat striatum biogenic amine metabolism. Eur. J. Pharmacol. 125:11–16; 1986.
16. Di Paolo, T.; Poyet, P.; Labrie, F.: Effect of chronic estradiol and haloperidol treatment on striatal dopamine receptors. Eur. J. Pharmacol. 73:105–106; 1981.
17. Di Paolo, T.; Poyet, P.; Labrie, F.: Effect of prolactin and estradiol on rat striatal dopamine receptors. Life Sci. 31:2921–2929; 1982.
18. Di Paolo, T.; Poyet, P.; Labrie, F.: Prolactin and estradiol increase striatal dopamine receptor density in intact, castrated and hypophysectomized rats. Prog. Neuropsychopharmacol. Biol. Psychiatry 6:377–382; 1982.
19. Di Paolo, T.; Rouillard, C.; Bedard, P.: 17 beta-Estradiol at a physiological dose acutely increases dopamine turnover in rat brain. Eur. J. Pharmacol. 117:197–203; 1985.
20. Dluzen, D. E.; Ramirez, V. D.: Bimodal effect of progesterone on in vitro dopamine function of the rat corpus striatum. Neuroendocrinology 39:149–155; 1984.
21. Dluzen, D. E.; Ramirez, V. D.: Progesterone effects upon dopamine release from the corpus striatum of female rats. I. Evidence for interneuronal control. Brain Res. 476:332–337; 1989.
22. Dluzen, D. E.; Ramirez, V. D.: Progesterone effects upon dopamine release from the corpus striatum of female rats. II. Evidence for a membrane site of action and the role of albumin. Brain Res. 476:338–344; 1989.
23. Dluzen, D. E.; Ramirez, V. D.: In vitro progesterone modulates amphetamine-stimulated dopamine release from the corpus striatum of castrated male rats treated with estrogen. Neuroendocrinology 52:517–520; 1990.
24. Dluzen, D. E.; Ramirez, V. D.: In vitro progesterone modulation of amphetamine-stimulated dopamine release from the corpus striatum of ovariectomized estrogen-treated female rats: Response characteristics. Brain Res. 517:117–122; 1990.
25. Fernandez-Ruiz, J. J.; Hernandez, M. L.; deMiguel, R.; Ramos, J. A.: Nigrostriatal and mesolimbic dopaminergic activities were modified throughout the ovarian cycle of female rats. J. Neural Transmi. 85:223–229; 1991.
26. Gordon, J. H.: Modulation of apomorphine-induced stereotypy by estrogen: Time course and dose response. Brain Res. Bull 5:679–682; 1980.
27. Henderson, S. R.; Baker, C.; Fink, G.: Effect of oestradiol-17beta exposure on the spontaneous secretion of gonadotrophins in chronically gonadectomized rats. J. Endocrinol. 73:455–462; 1977.
28. Hruska, R. E.; Pitman, K. T.: Hypophysectomy reduces the haloperidol-induced changes in striatal dopamine receptor density. Eur. J. Pharmacol. 85:201–205; 1982.
29. Hruska, R. E.; Pitman, K. T.; Silbergeld, E. K.; Ludmer, L. M.: Prolactin increases the density of striatal dopamine receptors in normal and hypophysectomized male rats. Life Sci. 30:547–553; 1982.
30. Hruska, R. E.; Silbergeld, E. K.: Increased dopamine receptor sensitivity after estrogen treatment using the rat rotation model. Science 208:1466–1468; 1980.
31. Jori, A.; Cecchetti, G.: Homovannilic acid levels in rats striatum during the oestrus cycle. J. Endocrinol. 58:341–342; 1973.
32. Joyce, J. N.; Smith, R. L.; Van Hartesveldt, C.: Estradiol suppresses then enhances intracaudate dopamine-induced contralateral deviation. Eur. J. Pharmacol. 81:117–122; 1982.
33. Joyce, J. N.; Van Hartesveldt, C.: Estradiol application to one striatum produces postural deviation to systemic apomorphine. Pharmacol. Biochem. Behav. 20:575–581; 1984.
34. Ke, F. C.; Ramirez, V. D.: Binding of progesterone to nerve cell membranes of rat brain using progesterone conjugated to ^{125}I-bovine serum albumin as a ligand. J. Neurochem. 54:467–472; 1990.
35. Levesque, D.; Di Paolo, T.: Rapid conversion of high into low striatal D2-dopamine receptor agonist binding states after an acute physiological dose of 17 beta-estradiol. Neurosci. Lett. 88:113–118; 1988.
36. Levesque, D.; Di Paolo, T.: Modulation by estradiol and progesterone of the GTP effect on striatal D-2 dopamine receptors. Biochem. Pharmacol. 45:723–733; 1993.
37. Morissette, M.; Di, P. T.: Sex and estrous cycle variations of rat striatal dopamine uptake sites. Neuroendocrinology 58:16–22; 1993.
38. Robinson, T. E.; Camp, D. M.; Becker, J. B.: Gonadectomy attenuates turning behavior produced by electrical stimulation of the nigrostriatal dopamine system in female but not male rats. Neurosci. Lett. 23:203–208; 1981.
39. Robinson, T. E.; Camp, D. M.; Jacknow, D. S.; Becker, J. B.: Sex differences and estrous cycle dependent variation in rotational behavior elicited by electrical stimulation of the mesostriatal dopamine system. Behav. Brain Res. 6:273–287; 1982.
40. Robinson, T. E.; Whishaw, I. Q.: Normalization of extracellular dopamine in striatum following recovery from a partial unilateral 6-OHDA lesion of the substantia nigra: A microdialysis study in freely moving rats. Brain Res. 450:209–224; 1988.
41. Van Hartesveldt, C.; Cottrell, G. A.; Meyer, M. E.: Effects of intrastriatal hormones on the dorsal immobility response in male rats. Pharmacol. Biochem. Behav. 35:307–310; 1989.
42. Xiao, L.; Becker, J. B.: Quantitative microdialysis determination of extracellular striatal dopamine concentrations in male and female rats: Effects of estrous cycle and gonadectomy. Neurosci. Lett. 180:155–158; 1994.
43. Xiao, L.; Becker, J. B.: Effects of estrogen agonists on amphetamine-stimulated striatal dopamine release. Synapse 29:379–391; 1998.