Acute and Subchronic Effects of Methylenedioxyamphetamine [(±)MDMA] on Locomotion and Serotonin Syndrome Behavior in the Rat

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SPANOS, L. J. AND B. K. YAMAMOTO. Acute and subchronic effects of methylenedioxyamphetamine [(±)MDMA] on locomotion and serotonin syndrome behavior in the rat. PHARMACOL BIOCHEM BEHAV 32(4) 835-840, 1989.—Specific behaviors comprising the serotonin syndrome (low body posture, forepaw treading, headweaving) and the autonomic signs of piloerection and salivation were determined and analyzed with locomotor activity in response to MDMA at three doses (2.5, 5.0, and 7.5 mg/kg). All behaviors were dose-responsive. Serotonin syndrome behaviors increased in both intensity and duration of response with increasing doses. In contrast, locomotion varied only in intensity. Subchronic injections, in the same group of animals, permitted an analysis of acute vs. subchronic effects on these same behaviors. Both the serotonin syndrome and locomotor behaviors were augmented on subsequent testing, indicating that, (±)MDMA, like amphetamine, is capable of producing behavioral sensitization.

3,4-Methylenedioxymethamphetamine (MDMA) Serotonin syndrome Hyperlocomotion

The increased street use of the amphetamine analog, 3,4-methylenedioxyamphetamine [(±)MDMA], has prompted an intensified effort to determine both the acute and subchronic neurochemical effects of this drug. Acute and chronic high doses of MDMA release [3H]serotonin (5-HT) (10,23), decrease tryptophan hydroxylase activity (28), and decrease 5-HT and 5HIAA tissue content in the striatum and limbic brain regions (21,28). The drug is also neurotoxic to serotonergic nerve terminals (1, 2, 16, 18, 21, 22, 28, 29). Overall, these acute and long-term effects of (±)MDMA on the serotonergic system are similar to those reported for parachloroamphetamine (13). The effects of MDMA on the dopaminergic system are less pronounced (10,28). However, in vitro (10) and in vivo studies (31) have shown that the drug stimulates release and elevates striatal tissue content of dopamine (23,28). Behaviorally, (±)MDMA appears similar to amphetamine and can produce amphetamine-like stimulant effects using a drug discrimination paradigm (4,5). Both (±)MDMA and d-amphetamine maintain self-injection behavior in baboons (8,14) and produce discriminative stimulus effects that are stereoselective in such a manner that the (+)isomer is more potent than the (−)isomer (20). These behavioral effects have led Lyon et al. (15) to propose that MDMA's mechanism of action is more similar to that of dopaminergically mediated amphetamine than to that of the serotonergically mediated hallucinogens. However, it is possible that the drug has a complex mechanism that involves both neurotransmitter systems.

Activation of the serotonergic and dopaminergic systems is differentially associated with specific behaviors. The serotonin syndrome, consisting of the low body posture, side-to-side head- weaving, lateral forepaw treading and the autonomic signs of piloerection and salivation, is a valid and reliable model of 5-HT mechanisms (9, 13, 26). In contrast, activation of the dopaminergic system has been associated with increased locomotion and stereotypical gnawing (19).

The present study utilized these models of the serotonin syndrome and hyperlocomotion to determine if the behavioral profile of MDMA action was consistent with serotonergic and/or dopaminergic activation. To date, there have been no published reports quantifying the motor effects of (±)MDMA. Therefore, the purpose of this study was to quantify, in a dose and time-dependent manner, the serotonin syndrome and locomotor activity following acute and subchronic low doses of (±)MDMA.

METHOD

Animals

Male Sprague-Dawley rats weighing 200–300 grams were used for this study. Rats were housed 4/cage in a temperature- (23 ± 1°C)

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and spaced 4 inches apart. These photocells were connected to a Commodore-64 computer programmed to monitor the pattern of beam interruption (Boja et al., in preparation). Consecutive on-time interruption of two beams registered one unit of activity. The computer was programmed to collect data in five-minute periods for the duration of the 120-minute test.

Serotonin Syndrome Behavior

The criteria for determining the presence of the serotonin syndrome were based on the following definitions: Forepaw treading—A pivoting movement resulting from lateral side-to-side stepping of the forepaws while the hindlimbs remain relatively stationary. Headweaving—Lateral side-to-side movements of the head with no net locomotion. Low body posture—Movement with the stomach nearly touching the floor of the cage and the hindlimbs abducted.

Syndrome behavior was observed through a Plexiglas panel mounted in the wall of the sound-attenuated chamber. Behaviors were rated according to a scale adapted from Kutscher and Yamamoto (13): 0 = absent; 1 = occasional (the behavior was present for >30 seconds during the one-minute observation period); 2 = frequent (the behavior was present for >30 seconds during the one-minute observation period); and 3 = constant (the behavior was present for the entire one-minute observation period). Piloerection and salivation were rated as 0 = absent or 1 = present. Scores for each behavior were summed for each time period to produce a total serotonin syndrome score.

Procedure

Acute study. Twenty-four hours before testing, rats were moved from the animal colony to a quiet room and placed in plastic construction as the animals’ home cages were placed in a sound-attenuated chamber. Eight photocell beams were located along the sides of each cage at a height 2 inches above the floor and head and hindlimbs abducted. The criteria for determining the presence of the serotonin syndrome were based on the following definitions: Forepaw treading—A pivoting movement resulting from lateral side-to-side stepping of the forepaws while the hindlimbs remain relatively stationary. Headweaving—Lateral side-to-side movements of the head with no net locomotion. Low body posture—Movement with the stomach nearly touching the floor of the cage and the hindlimbs abducted. Syndrome behavior was observed through a Plexiglas panel mounted in the wall of the sound-attenuated chamber. Behaviors were rated according to a scale adapted from Kutscher and Yamamoto (13): 0 = absent; 1 = occasional (the behavior was present for >30 seconds during the one-minute observation period); 2 = frequent (the behavior was present for >30 seconds during the one-minute observation period); and 3 = constant (the behavior was present for the entire one-minute observation period). Piloerection and salivation were rated as 0 = absent or 1 = present. Scores for each behavior were summed for each time period to produce a total serotonin syndrome score.

procedure

Acute study. Twenty-four hours before testing, rats were moved from the animal colony to a quiet room and placed in activity cages. Four animals were tested per session. Each test was conducted between the hours of 10 a.m. - 12 p.m. On the day of testing, animals were injected with saline or with 2.5, 5.0, or 7.5 mg/kg of (±)-MDMA and monitored for locomotor activity for a
period of 120 minutes. Serotonin syndrome behavior was simultaneously rated by an observer who was blind to the treatment condition. Animals were rated for a 1-minute period every 5 minutes for the duration of the 120-minute test. After testing was completed, the animals were returned to their home cage in the animal colony.

**Chronic study.** The same group of animals were weighed and injected every other day with the test dose of (±)-MDMA or saline vehicle. Forty-eight hours after the sixth and twelfth injection (TEST 2 and TEST 3, respectively), animals were again tested as described above. To determine the effects of stress due to subchronic injections, separate groups of animals (n = 6) received saline injections and were placed in activity cages according to this same schedule but received MDMA (2.5, 5.0 or 7.5 mg/kg) forty-eight hours after the twelfth injection (TEST 3).

**RESULTS**

**Locomotor Behavior**

**Acute effects.** The dose-dependence of the locomotor response to an acute injection of MDMA was analyzed with a 1-way ANOVA using total mean activity scores. Figure 1 shows a significant dose effect for TEST 1 (F = 6.24, p < 0.01) and Fig. 2 illustrates the time course of locomotor activity. Between 5 and 25 minutes after injection, all animals showed an elevated activity score due to the stress of injection. From 25 minutes until the conclusion of the experiment (120 minutes), MDMA produced a dose-dependent hyperlocomotor response when compared to saline controls.

**Subchronic effects.** The effects of subchronic treatment on the locomotor response were analyzed with a 2-way ANOVA with repeated measures (Dose vs. Test) using the mean total activity scores for each animal. There was a significant dose-dependent enhancement of locomotor activity (F = 4.55, p < 0.05) from TEST 1 to TEST 3 (Fig. 1). Activity scores of animals subchronically injected with saline and administered MDMA on TEST 3 did not differ significantly from animals given a single acute injection of MDMA.

**5-HT Syndrome Behavior**

**Acute effects.** Analysis using a 1-way ANOVA with repeated measures and the mean total scores of all behaviors comprising the serotonin syndrome (forepaw treading, headweaving, low body posture, piloerection and salivation), showed that acute MDMA administration increased syndrome behavior (Fig. 3) in a dose-dependent manner (F = 7.39, p < 0.01). Saline controls did not have a measurable response and therefore the data are not illustrated. Figure 4A, B, and C show a significant dose-dependent increase for forepaw treading (F = 4.76, p < 0.05) and low body posture (F = 6.71, p < 0.05), but not for headweaving. Time course analysis revealed that, of the separate behaviors comprising the syndrome, low body posture was the most frequently and intensely displayed component. A post hoc Dunnett test showed that this behavior contributed significantly to the total syndrome score (p < 0.05).

**Subchronic effects.** Subchronic treatment with MDMA increased the mean total score for serotonin behavior (Fig. 3) as a function of dose (F = 36.86, p < 0.01) and length of treatment (F = 4.81, p < 0.01). Alterations in the response for separate syndrome behaviors are shown in Fig. 4D, E, and F. For clarity, only the results from TEST 3 are illustrated, although TEST 2 was conducted in a similar detailed manner. Analysis of the separate syndrome behaviors revealed that the subchronic treatment paradigm does not affect each component of the syndrome equally. Low body posture was the only component that was potentiated by the lowest dose (2.5 mg/kg) in TEST 3 when compared to TEST 1. Subchronic treatment increased the intensity of all behaviors in a dose-dependent manner and differentially affected the time course of the individual behaviors (Test vs. time interaction, F = 15.79, p < 0.01: headweaving, F = 16.84, p < 0.01; low body posture, F = 26.58, p < 0.01).

Table 1 presents the results from the autonomic components of salivation and piloerection. Although there were dose-dependent increases in both salivation (F = 53.83, p < 0.001) and piloerection (F = 42.61, p < 0.001) these increases were not dose-responsive with subchronic treatment.

To determine the possibility that the stress of repeated injections alone contributed to the enhanced response seen with subchronic MDMA treatment, a separate group of controls received saline injections according to the same injection schedule as the MDMA-treated animals and then received MDMA for TEST 3 of the study. For both the serotonin syndrome and hyperlocomotion, there were no significant differences in the intensity or duration of response between this group (receiving saline subchronically and MDMA on TEST 3) and that of the acutely injected MDMA animals.

**DISCUSSION**

The present study illustrates that (±)-MDMA produces amphetamine-like hyperlocomotion as well as a "serotonin syndrome" consisting of forepaw treading, headweaving and low body pos-
ture and the autonomic signs of salivation and piloerection. These behaviors are concurrently displayed in a time- and dose-dependent manner and are augmented with subchronic treatment.

Analysis of the behavioral components contributing to the serotonin syndrome reveals that low body posture is the most reliable, and enduring component displayed in response to all doses of MDMA and that this behavior parallels the time course of the locomotor response. Additionally, subchronic MDMA treatment results in a differential enhancement of these specific behaviors. Likewise, examination of the autonomic components contributing to the syndrome reveals that subchronic treatment does not increase the frequency of piloerection and salivation in a dose-dependent manner. In fact, subchronic MDMA treatment produces a ceiling eﬀect for piloerection that may indicate the insensitivity of our scoring method for this component.

Previous studies have examined the relative contribution of the separate components comprising the serotonin syndrome and have found slight differences in the behavioral profile (6, 13). Kutscher and Yamamoto (13) found forepaw treading to be the most reliable indicator for 5-HT activation following p-chloroamphetamine (PCA), and Goodwin and Green (6) found low body posture to be the most robust component of the syndrome in response to 8-hydroxy-2-(di-n-propylamino)tetralin (8-OH-DPAT). Although both drugs are known to release serotonin in vitro. However, to date, no studies have been done with intact animals to determine the time course of this eﬀect. Future studies are needed to determine if there is a correlation between the syndrome behavior displayed with MDMA and its eﬀect of serotonin release.

Serotonin release is known to produce hyperactivity in rodents but recent studies indicate that this eﬀect is produced via catecholaminergic mechanisms (7). Although MDMA binds with low aﬃnity to dopaminergic receptors, this drug releases dopamine both in vitro (28), and in vivo (31). Interestingly, the time course of MDMA-induced dopamine release seen with in vivo voltam-
ACUTE AND SUBCHRONIC EFFECTS OF (±)MDMA


