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Relationship Between Amphetamine and Environmentally Induced Stereotypies in Pigs

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TERLOUW, E. M. C., A. B. LAWRENCE AND A. W. ILLIUS. *Relationship between amphetamine and environmentally induced stereotypies in pigs.* PHARMACOL BIOCHEM BEHAV **43**(2) 347-355, 1992.—The study investigated the relationship between the behavioural response to a standard dose of amphetamine and environmentally induced stereotypies in pigs. There were large individual differences in the frequency of amphetamine-induced stereotypies and time spent in locomotion. In addition, these two measures tended to be negatively correlated to each other, indicating that they were competitive. Levels of amphetamine stereotypies were negatively correlated with those of chain manipulation and drinking after a period of 50 and 100 days of physical restraint and food restriction; levels of locomotion were positively correlated with levels of chain manipulation after 100 days of restraint and restrictive feeding. These results suggest that pigs differ in their predisposition to develop environmentally induced stereotypies, and that this is related to catecholaminergic systems in the brain. In an amphetamine test performed after the period of restraint and restrictive feeding, amphetamine stereotypies were generally higher than in the first test but behaviour was no longer correlated to previous levels of environmentally induced stereotypies. The qualitative differences between the two forms of stereotypy, their negative rather than positive correlation, and the lack of correlation between environment-dependent stereotypies and stereotypies in the second amphetamine test suggests a complex relationship between these two forms of stereotypies. The increased amphetamine sensitivity in the second amphetamine test may reflect the effect of stress on central catecholaminergic systems.

Pigs Stereotypies Amphetamine Arousal Individual differences Excessive drinking Chain manipulation

STEREOTYPIES are behaviour patterns that are repetitive, invariant, and have no apparent goal (34,43). They often develop in wild animals in captivity, such as zoo animals, as well as in farm animals under intensive husbandry conditions (39,43). Food-restricted closely confined sows can perform a variety of stereotypic activities such as bar biting, manipulation of the tether chain, vacuum chewing, and excessive drinking (5,17,47,58,60). Environmentally induced stereotypies are believed to be the expression of high levels of arousal caused by an inadequate environment (18,43). Although the exact neural mechanisms underlying development of environmentally induced stereotypies is not known, a large body of data suggests that stress may alter brain dopamine utilisation (3, 4,13,22,37), and parallels have been drawn between environment- and dopamine agonist-induced stereotypies (1,18). Evidence for this hypothesis is still contradictory. In a recent study on pigs (57), amphetamine- or apomorphine-induced behaviour patterns had clear qualitative differences from stereotypies developed under restricted feeding and housing conditions, but both dopamine agonists did, however, increase behavioural activation in a general sense. Also, the observations that dopamine agonists facilitated performance of stereotypies in chimpanzees and pigeons (8,26), and that haloperidol selectively reduces levels of environment-induced stereotypy in pigeons, monkeys, voles, and sows (26,33,35,61), as well as of dopamine agonist-induced stereotypies (42), are consistent with this hypothesis.

Both rats and mice show individual differences in their response to dopamine agonists, and these differences have been related to differences in organisation of the dopamine systems (40,46,50). Furthermore, these individual differences were correlated with differences in behavioural response to environmental challenge (7,40,41,44). Pigs have also been found to differ in their behavioural response to dopamine

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agonists (57). Furthermore, when kept in similar conditions of restrictive housing and feeding pigs show large individual differences in type and level of stereotypy (5,47,58,60).

The present study was designed to test whether differences in amphetamine responsiveness are correlated to the tendency to develop chain manipulation or increased drinking under restrictive housing and feeding conditions. In addition, we assessed changes in pigs' sensitivity to amphetamine after the period of restrictive housing and feeding conditions.

METHOD

Experimental Protocol

Animals and housing. Subjects were 15 nulliparous pregnant female pigs (Landrace × Large White; Cotswold Pig Development Co. Ltd., UK), aged 9 months and weighing on average 160 kg (range: 145–180 kg). They had no previous experience of restrictive housing and were kept in a group in a large, strawed pen prior to experimentation. One week prior to the first amphetamine test, food had been restricted to 2.5 kg/day of a standard sow concentrate food in pelleted form, delivered once daily at 0800 h.

Experimental procedure. After the first amphetamine test, pigs were kept in a group in the large pen for approximately 1 week before being moved to a housing system, where they were physically restrained and subjected to food restriction. The restraint period was interrupted after 50 days for parturition, which took place in individual stalls. Previous observations have shown that environmentally induced stereotypies are much reduced during the parturition period (56). Approximately 40 days from the start of the parturition phase, pigs were reintroduced to the restrictive housing and feeding conditions. Fifty days after reintroduction, pigs were subjected to a second amphetamine test.

Body weight and backfat thickness were recorded prior to each amphetamine test and prior to the second period of restrictive housing and feeding. Ultrasonic backfat measurements were taken at 6 cm from the middleline at the level of the last rib.

Amphetamine test. Three days before the first amphetamine test, pigs were moved to climate-controlled rooms (6 × 3.60 m; 20°C), each containing four individual pens (2.3 × 1.8 m). Pigs were not allowed access to bedding material. Feeding took place at 0800 h (2.5 kg/day). Pigs were moved to the test room on the night before the test to allow them to habituate to the test pen. The protocol for the second amphetamine test was identical except pigs were weighed and moved to the test pen directly from the restrictive housing system on the night before the test.

The test pens were the same used in a previous series of amphetamine tests (57). They consisted of three climate-controlled rooms, identical to each other and to the rooms with the home pens. Each contained a U-shaped pen, in which the observer distinguished five separate areas (see Fig. 1). There were no lines on the floor and the observer recognized the boundaries by cues on the walls. There were no manipulable objects such as chains, as in another study it was found that amphetamine does not induce oral manipulative activities (57). Observations (0900–1600 h) took place via two large viewing windows on one side. White noise was used to camouflage outside disturbances. At 1030 h pigs were injected subcutaneously with 0.7 mg/kg *d*-amphetamine sulphate (Sigma Chemical Co., Dorset, UK) in 4 ml saline while being restrained by a rope tightened around the upper jaw. The dose

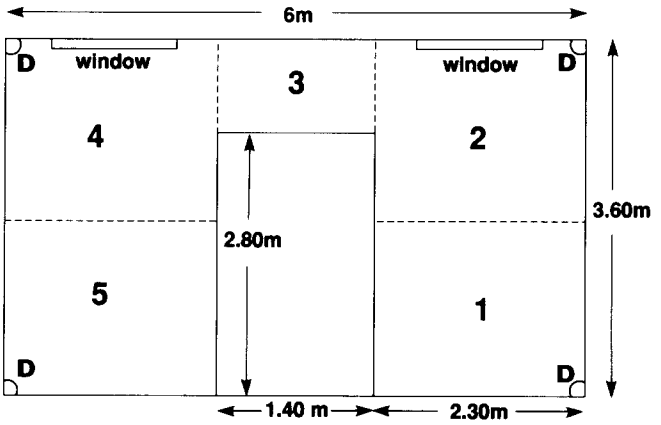

FIG. 1. Spatial arrangement of the pen used in the amphetamine test. D, drinking bowl.

was chosen based upon previously determined dose-response relationships such that both locomotion and amphetamine-induced jerking movements were likely to be induced (57). Six additional pigs of similar age and background were injected with 4 ml saline as controls in the first amphetamine test.

The observations consisted of a 1-min focal observation every 10 min (0900–1400 h) or every 30 min (1430–1600 h). They were recorded on a portable Epson X-20 computer using a data collection program (19).

Activities were classified into 5 behavioural categories:

1. *Amphetamine-induced stereotypies* [AMPH SS; see (57)]: As different elements of AMPH SS were previously found to be related to different neurological substrates (21,31), the following three subcategories were recorded separately: a) movements of the head; b) nonlocomotory movements of the hind legs (stepping); and c) chewing movements of the mouth. Head movements consisted of clearly visible up- and downward and sideways movements, stepping of repeated lifting of the hind legs [see also (57)], and mouth movements of an opening and closing of the jaws. A bout of AMPH SS was defined as an occurrence of a subcategory with an interval ≤ 1 s or a mixture of subcategories of AMPH SS. The occurrence of each bout of head, leg, and jaw movements was recorded. Different subcategories occurring within the same bout of AMPH SS were recorded separately. The frequency of AMPH SS was expressed as the total of the frequencies of the AMPH SS subcategories.
2. *Locomotion*: Frequency and proportion of time spent in forward locomotory activity, including running, and non-forward locomotory activity (backward locomotion and rotation around the hind legs) were recorded separately. In addition, crossings to a new floor area was recorded.
3. *Nosing and rooting of objects*: The proportion of time spent in nose contact with any object (wall, floor, bars, water trough) in the pen.
4. *Standing alert*: The proportion of time spent standing, with open eyes, but without performing any overt activity.
5. *Other activities*: Proportion of time spent in any activities other than those mentioned above.

Development of Environmentally Induced Stereotypies

The restrictive housing treatment was designed to be similar to the standard dry-sow accommodation known to induce

stereotypies and took place in a 8 × 8-m climate-controlled room (20 ± 2°C) containing two rows of nine 70-cm wide stalls with vertical bars, facing each other on either side of a passage. Each stall had a metal trough fitted at the front with a nipple drinker in one corner. Pigs were tethered to a front corner of the stall with a neck tether and a 65-cm chain. In a corner of each stall, an extra chain was attached, forming a 10-cm loop that was easily accessible to the pig. Feeding took place at 0845 h (2.5 kg/day); animal care took place between 0900–0930 h. Water was available continuously. No daylight could penetrate the room and lights were on between 0845–2100 h.

Behavioural Recording

An automatic recording system was used to monitor chain manipulation and drinking [see (60) for details]. Briefly, a strip of piezo electric wire (Quantalec Ltd., Witney, Oxon, UK) was attached to the extra chain, and this electrically registered movements of the chain. This information was stored by digital counters and read by a BBC Master microcomputer. All pigs preferred manipulating the extra chain to the tether chain.

Manipulation of the drinker generated electric pulses in a water flow meter (Farnell Electral Co., Leeds, UK) that were stored and read as above. The amount of water recorded as taken from the drinker was corrected for the water remaining in the troughs every 24-h period. With one exception, water left in the trough was low (< 1.5 l/day).

The computerised data logging system recorded time spent in chain activity and amount of water drunk over 10-min intervals. Behavioural recordings were made on four 24-h periods during the last 2 weeks of the first and second periods of 50 days of restrictive housing. The automatically recorded measures have been found to correlate to observed chain activity and drinking (60).

Statistical Analysis

Average daily values of time spent in chain activity and amount of water drunk for the first and second periods of restrictive feeding and housing were calculated for each individual as the means of 24-h periods at 50 and 100 days of restrictive feeding and housing.

The analyses of the amphetamine test were performed on angular transformations of the proportion of time spent in each of the behavioural categories and on logarithmic transformation of frequency of occurrence of amphetamine-induced stereotypies and locomotion to correct for skewedness. Square root transformations were used for levels of chain manipulation and drinking, as their values were less strongly skewed. An analysis of variance (ANOVA) with nested structures for pig, test, and time of observation and two factors (test and time of observation) was used to analyse postinjection time effects and effect of long-term experience of restrictive housing. Increased levels of standing would be expected to be accompanied by proportional increases in activities usually performed while standing. To analyse whether changes in behaviour were specifically induced by amphetamine or were relative to increased levels of standing, the ANOVA was repeated fitting levels of standing as a covariate. Effects of amphetamine were compared to saline-injected controls (test 1) by an ANOVA with nested structures for pig, treatment, and time of observation and two factors (treatment and time of observation). Where significant effects were identified, the least significant difference (LSD) test has been used to locate significant differences between means.

In addition, average frequency and/or proportion of time spent was calculated for each behavioural category over the preinjection period and 0.5- and 1.5-h postinjection periods. Correlation coefficients across tests and periods within tests were calculated. Finally, correlation coefficients were calculated between levels of chain activity and drinking during the first and second periods of restrictive feeding and housing and time spent in locomotion and frequency of amphetamine-induced stereotypies during the two amphetamine tests.

RESULTS

Amphetamine Tests

There were large individual differences in the amount of AMPH SS and locomotion induced by amphetamine. In general, administration of amphetamine was followed by a rigid and motionless standing of the pig that lasted for the duration of occurrence of AMPH SS. This rigid standing was regularly interrupted by the occurrence of other activities. AMPH SS occurred soon after administration of amphetamine (Fig. 2A). There was a strong time effect, with highest levels of AMPH SS between 30 and 90 min after administration of amphetamine, after which levels gradually decreased over the remaining 4-h observation period, $F(33, 462) = 23.3$, $p < 0.001$ (Fig. 2A). The three subcategories of AMPH SS tended to occur together as shown by positive correlations between these activities (Table 1). Individuals were consistent in their response within tests, as shown by strong positive correlations between different test periods (e.g., $r = 0.86$, $p < 0.01$, for the first vs. second 1.5-h postinjection period of test 1).

Pigs were consistent in their initial response to amphetamine across the two tests, as average AMPH SS levels in the first 1.5 h postinjection in tests 1 and 2 were positively correlated, but not thereafter ($r = 0.55$, $p < 0.05$, and $r = 0.17$, NS, for the first and second 1.5-h postinjection periods, respectively). There was a significant difference between the two tests, $F(1, 14) = 16.6$, $p < 0.001$, with higher levels of AMPH SS throughout the second test (Fig. 2A). This was due to significantly higher levels of all three AMPH SS subcategories [$F(1, 14) = 10.9$, $p < 0.001$, $F(1, 14) = 17.5$, $p < 0.001$, and $F(1, 14) = 9.1$, $p < 0.01$, for head movements, chewing, and stepping, respectively). The difference between AMPH SS levels in the first and second tests was not correlated to AMPH SS levels in the first test (e.g., $r = -0.09$, NS, for the first 1.5-h postinjection period).

Postinjection proportions of time spent in locomotion were higher in amphetamine- than in saline-injected pigs, $F(1, 19) = 9.60$, $p < 0.01$. In both tests, amphetamine increased levels of locomotion during the second 1.5-h postinjection period compared to preinjection levels [e.g., first test, $F(1, 14) = 15.0$, $p < 0.01$]. They were also increased during the first 1.5-h postinjection period in the second test, $F(1, 11) = 6.38$, $p < 0.05$. However, in all cases these levels were increased only relative to an increased proportion of time spent standing, as fitting levels of standing as a covariate removed the effect [e.g., $F(1, 10) = 0.23$, NS, for pre- vs. postamphetamine values in test 2]. However, locomotion induced by amphetamine differed from spontaneous locomotion in several aspects. First, in addition to forward locomotion, backward locomotion and rotating around the hind legs occurred. Full rotation (360°) did not take place. Second, the occurrence of brief forward and nonforward locomotory bouts (≤ 1.5 s),

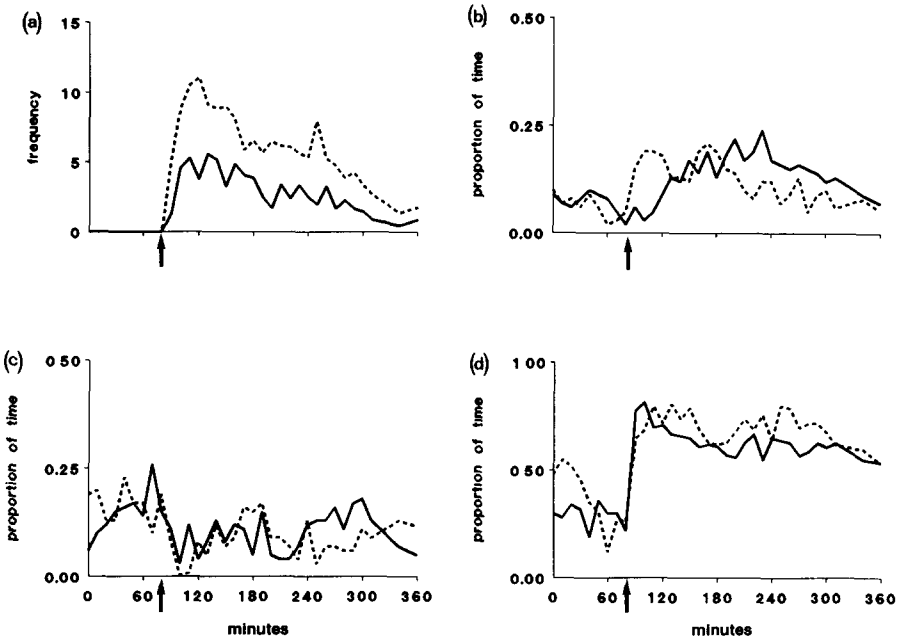

FIG. 2. Average levels of (a) AMPH SS; (b) forward locomotion; (c) nosing and rooting substrates; and (d) standing alert, before [(———), test 1] and after (---), test 2] 100 days of restrictive feeding and housing. The arrows indicate time of injection with 0.7 mg/kg amphetamine.

consisting of rigid walking, increased strongly after injection [$F(33, 462) = 2.35$, $p < 0.001$; e.g., test frequency/min: 0.01 ± 0.003 vs. 0.25 ± 0.02 for the preinjection period vs. the first 1.5-h postinjection period]. Nonforward locomotion occurred at low levels (e.g., 0.3% of the time in test 1). There was a significant overall time effect for forward locomotion with highest levels between 1.5 and 3 h postinjection, $F(33, 462) = 3.75$, $p < 0.001$, (Fig. 2B).

Individuals were consistent in their forward locomotory response within tests, as shown by correlations between different test periods ($r = 0.75$, $p < 0.01$ for the first vs. the second 1.5-h period postinjection). Average levels of forward locomotion did not differ between the two tests ($F(1, 14) = 0.58$, NS), and were positively correlated ($r = 0.64$; $p < 0.01$). In test 2, however, high levels of forward locomotion occurred earlier as shown by a test × time interaction, $F(33, 423) = 2.43$, $p < 0.001$ (Fig. 2B). Pigs that tended to show more forward locomotion in response to amphetamine also tended to show more forward locomotion in the preinjection period in test 1 ($r = 0.66$, $p < 0.05$) but not in test 2 ($r = 0.08$, NS), suggesting that behavioural differences may already have existed before amphetamine administration.

There was a significant time effect for nosing and rooting, $F(33, 462) = 1.84$, $p < 0.005$, with a sharp decline 20 min after injection (LSD): $p < 0.01$; Fig. 2C). Time spent nosing and rooting of substrates did not differ between the two tests, $F(1, 14) = 0.07$, NS. Time spent in nosing and rooting in the two tests were not correlated to each other (e.g., $r = -0.08$, NS, for the first 1.5-h postinjection periods).

There was a time effect for standing alert, $F(33, 885) = 10.99$, $p < 0.001$, with a strong increase in the behaviour immediately after injection with amphetamine (LSD: $p < 0.01$; Fig. 1D). Time spent standing alert was not different between the two tests, $F(1, 14) = 1.37$, NS, nor correlated (e.g., $r = 0.26$, NS for the first 1.5-h postinjection period).

Time spent in locomotion and frequency of AMPH SS were negatively correlated during the first 1.5 h postinjection ($r = -0.55$, $p < 0.05$, and $r = -0.73$, $p < 0.01$, for tests 1 and 2, respectively) but not during the second 1.5-h postinjection period ($r = 0.06$, NS and $r = -0.27$, NS for tests 1 and 2, respectively). AMPH SS tended to co-occur with standing alert, as shown by positive correlations between these behaviours (e.g., $r = 0.88$, $p < 0.01$, and $r = 0.82$, $p < 0.01$, in the first 1.5-h postinjection period in tests 1 and 2, respectively), in contrast to nosing and rooting, which was negatively correlated to AMPH SS (e.g., $r = -0.71$, $p < 0.01$, for the first 1.5-h postinjection period in test 1). Conversely, locomotion tended to be negatively correlated to standing with open eyes ($r = -0.43$, NS, and $r = -0.85$, $p < 0.01$, in the first 1.5-h postinjection period in tests 1 and 2, respectively).

TABLE 1

CORRELATIONS BETWEEN SUBCATEGORIES OF AMPH SS IN THE FIRST 1.5-h POSTINJECTION PERIOD

	Head	Step	Chew
Head	–		
Step	0.74*	–	
Mouth	0.96*	0.68*	–

Test 1. See text for analysis.
*$p < 0.01$.

Environmentally Induced Stereotypies

Levels of chain manipulation and drinking varied strongly between individuals in both periods of restrictive housing

(e.g., at 100 days: range = 5-275 min/day and 7-50 l/day for chain manipulation and water intake, respectively). Pigs were consistent in their behaviour, as average levels of chain activity and drinking measured during the first and second 50-day tether periods were positively correlated to each other ($r = 0.58$, $p < 0.05$, and $r = 0.90$, $p < 0.01$, for chain manipulation and drinking, respectively). While levels of chain manipulation did not differ between the two tether periods [155 ± 24 vs. 119 ± 24 min/day; $F(1, 14) = 2.1$, NS], drinking was significantly increased in the second tether period [17.4 ± 3.0 vs. 22.3 ± 3.9 l/day; $F(1, 12) = 16.0$, $p < 0.005$].

Levels of chain activity and drinking were not correlated to each other in either of the two periods ($r = -0.16$, NS and $r = 0.23$, NS for periods 1 and 2, respectively).

Relationships Between Environmentally and Amphetamine-Induced Stereotypies

Levels of AMPH SS in test 1 tended to be negatively correlated to drinking and chain manipulation in restraint after 50 and 100 days of restrictive housing and feeding (Table 2; see Fig. 3). Similar effects were found for the different AMPH SS subcategories (Table 3; Fig. 4A). These negative correlations were apparent immediately after injection (e.g., for correlations between AMPH SS and water intake at 100 days of tethering: $r = -0.69$; $p < 0.01$, $r = -0.50$, $p < 0.05$, $r = -0.55$, $p < 0.05$, $r = -0.55$, $p < 0.05$, for the first, second, third, and fourth $\frac{1}{2}$h postinjection, respectively).

Amphetamine-induced forward locomotion tended to be positively correlated to chain manipulation only after 100 days of restrictive housing and feeding (Table 2; Figs. 3 and 4B).

In amphetamine test 2, AMPH SS and amphetamine-induced forward locomotion were no longer correlated to drinking and chain manipulation after 50 or 100 days of restrictive housing and feeding (Table 2). The difference between AMPH SS levels in the first and second tests was not correlated to levels of chain manipulation and drinking during long-term restrictive feeding and housing ($r = -0.05$, NS, and $r = -0.07$, NS, for chain manipulation and drinking, respectively).

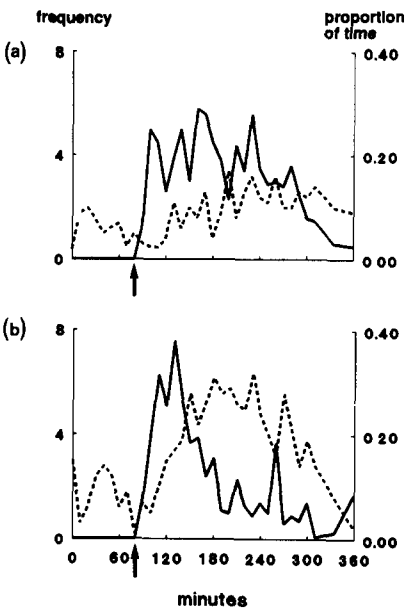

FIG. 3. Average levels of AMPH SS (——) and locomotion (---) in amphetamine test 1 for pigs that at 100 days of restrictive feeding and housing had developed levels of chain manipulation (a) below ($n = 8$) and (b) above ($n = 7$) the median. The arrow indicates time of injection. The initial high levels in graph (b) are caused by two outlyers.

Measures of body weight and backfat thickness were correlated across time (e.g., $r = 0.69$, $p < 0.05$, and $r = 0.54$, $p < 0.05$, respectively, for comparisons between the first and last measurements). In both tests, levels of amphetamine-induced locomotion were correlated to body weight but not to

TABLE 2

CORRELATIONS BETWEEN AMPH SS AND LOCOMOTION IN THE FIRST AND SECOND 1.5-h POSTINJECTION PERIODS AND CHAIN MANIPULATION AND DRINKING DURING RESTRICTIVE HOUSING AND FEEDING

		Drinking		Chain	
		50 days	100 days	50 days	100 days
Test 1					
AMPH SS	1st 1.5 h	−0.47*	−0.60†	−0.61†	−0.52†
	2nd 1.5h	−0.41	−0.48*	−0.69‡	−0.59†
Locomotion	1st 1.5 h	0.20	0.30	0.08	0.51†
	2nd 2.5 h	0.14	0.23	0.03	0.59†
Test 2					
AMPH SS	1st 1.5 h	−0.19	−0.41	−0.06	−0.41
	2nd 1.5 h	0.11	−0.09	0.17	−0.09
Locomotion	1st 1.5 h	0.04	0.17	−0.06	0.38
	2nd 1.5 h	0.11	0.07	−0.16	0.36

See text for analysis.
*$p < 0.10$.
†$p < 0.05$.
‡$p < 0.01$.

TABLE 3

CORRELATIONS BETWEEN DRINKING AND CHAIN MANIPULATION AFTER 50 AND 100 DAYS OF RESTRICTIVE HOUSING AND FEEDING AND SUBCATEGORIES OF AMPH SS (TEST 1)

	Drinking		Chain	
	50 days	100 days	50 days	100 days
First 1.5-h postinjection period				
Head	−0.35	−0.46*	−0.59†	−0.54†
Step	−0.39	−0.64†	−0.35	−0.26
Chew	−0.36	−0.43	−0.64†	−0.60†
Second 1.5-h postinjection period				
Head	−0.23	−0.34	−0.69‡	−0.67‡
Step	−0.08	−0.20	−0.54†	−0.15
Chew	−0.06	−0.08	−0.36	−0.26

See text for analysis.
*$p < 0.10$.
†$p < 0.05$.
‡$p < 0.01$.

backfat thickness (e.g., for test 1: $r = -0.54$, $p < 0.05$, and $r = -0.17$, NS, for body weight and backfat, respectively). Amphetamine stereotypies were not correlated to either body weight or backfat in either test (e.g., $r = 0.14$, NS, and $r = 0.002$, NS, for body weight and backfat, respectively).

DISCUSSION

The present study found that the behavioural response to amphetamine was correlated to chain manipulation and drinking during subsequent long-term restrictive housing and feeding. Furthermore, long-term restrictive housing and feeding increased subsequent amphetamine sensitivity, as expressed by levels of amphetamine stereotypies.

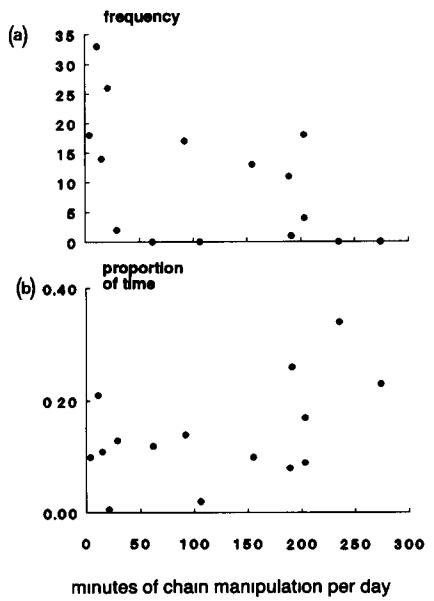

FIG. 4. Correlations between average levels of chain manipulation at day 100 of restrictive housing and feeding and average levels of: (a) stereotyped mouth movements ($r = -0.57$; $p < 0.05$) and (b) locomotion ($r = 0.54$; $p < 0.05$) in amphetamine test 1. Averages were based on 5 h postinjection.

Individual differences in behavioural response to both restrictive housing and feeding and to a standard dose of amphetamine were consistent over time and therefore appear to reflect fundamental differences in catecholaminergic and behavioural organization between individuals. First, individual levels of chain manipulation and drinking during long-term restrictive housing and feeding were positively correlated across the two 50-day periods despite an interruption of 40 days. Second, individual levels of amphetamine-induced stereotypies and locomotion correlated across the two amphetamine tests, which were separated by 140 days. Correlations cannot be accounted for by differences in metabolism of amphetamine as correlations were also found between chain manipulation and drinking and the initial response (30 min postinjection) to amphetamine. The results suggest therefore that pigs differ in their predisposition to develop environmentally induced stereotypies and that this predisposition is related to the catecholaminergic systems of the brain.

The present study confirms previous work (57) that locomotion in pigs is not specifically induced by amphetamine but rather is related to the generally increased levels of activity. However, amphetamine did affect locomotion as amphetamine-injected pigs showed an increased occurrence of nonforward locomotion and short bouts of locomotion. In addition, the negative correlation between amphetamine stereotypies and locomotion found in the present study indicates that the two behaviors were competitive, suggesting that increased locomotion does not occur due to inhibition by high levels of rigid standing and amphetamine stereotypies (38,51).

It is generally believed that the effects of amphetamine on behaviour are mainly mediated by increased dopamine release from the nerve terminals (27). Neurological studies based upon specific lesions and local administration of dopamine or dopamine agonists suggest that locomotion and amphetamine stereotypies depend upon different neurological substrates: Locomotion is believed to be dependent upon dopaminergic

mesolimbic projections to the nucleus accumbens and olfactory tubercle, while amphetamine stereotypies depend upon the dopaminergic nigrostriatal system (14–16,32,45). These data led to the suggestion that at transitory doses the amount of locomotion and stereotypy would reflect the balance between the nigrostriatal and mesolimbic systems (50). Thus, the present data would indicate that in pigs this balance predicts the individual's predisposition to develop chain manipulation and excessive drinking. However, in a study where Segal and Kuzcenski (50) found large individual differences in rats in amount of stereotypy and locomotion the neurochemical data did not support such a simple relationship, suggesting that other neurological structures are also involved (23,24,27).

Amphetamine stereotypies increase with dose (57), suggesting that at a standard dose higher levels of amphetamine stereotypies reflect increased amphetamine sensitivity. As environmentally induced stereotypies are believed to express an increased dopaminergic activity due to arousal (18,26), and haloperidol selectively reduces these stereotypies (33,61), a positive rather than negative correlation between amphetamine stereotypies and environmentally induced stereotypies would be expected. However, the effects of amphetamine are complex and may depend upon the autoreceptor/postsynaptic receptor balance and the size of the readily releasable pool of dopamine, as well as on its effect on dopamine synthesis and cellular vesicular function of dopamine (36). In addition, the activity of other systems, such as the acetylcholinergic and noradrenergic systems, may influence the behavioural output (6,27). Thus, an interpretation of the present results in functional terms is difficult at this stage. It may be of interest to note, however, that while stereotyped snout rubbing could be induced by apomorphine in piglets, snout rubbing induced by early weaning was accompanied by a decreased dopamine release in central dopaminergic systems (52,53). Similarly, stereotyping voles showed lower levels of apomorphine-induced stereotypies than nonstereotyping voles (Odberg, personal communication). Finally, there is some evidence that stereotypies are related to both dopaminergic and noradrenalinergic systems in the brain (26).

The lack of correlation between the behaviour in the second amphetamine test and chain manipulation and drinking confirms further the complexity of the systems involved. This lack of correlation and the general increase of amphetamine sensitivity suggest that factors other than behaviour have altered dopaminergic functioning over the course of the experiment. These factors may involve time effects or aspects related to the restrictive housing and feeding treatment. Pigs in the present study showed higher levels of amphetamine stereotypies than those used in a previous study (57). As in contrast to the previous study pigs used in the present study were both mature and food deprived, the separate effects of age and food deprivation cannot be assessed. From work on rats, it is well known, however, that food deprivation and other forms of stress, such as tail-pinch, immobilisation, and electric footshock, increase dopamine agonist responsiveness (2, 10–12, 20,29,30,48).

As food deprivation may influence amphetamine sensitivity in rats, and the development of chain manipulation and excessive drinking in sows also depends upon food deprivation (58), it could be argued that in the present study differences in energy status may be the basis of the correlation between amphetamine sensitivity and chain manipulation and drinking. However, although body weight was negatively correlated to amphetamine-induced locomotion backfat thickness was not. In addition, amphetamine-induced head, limb, and oral movements were also not correlated to body weight or backfat thickness. More direct physiological measurements of bodily energy status might have been correlated to amphetamine sensitivity. For example, in rats plasma glucose levels affect central catecholaminergic activity and are correlated to amphetamine sensitivity (28,49,55,62). A possible common basis for the effect of food deprivation on amphetamine sensitivity and the development of chain manipulation and drinking may therefore be the effect of food deprivation on central catecholaminergic activity (9,25,54).

Chain manipulation and drinking during restrictive housing and feeding conditions were not correlated to each other. As low levels of amphetamine stereotypies predicted high levels of chain manipulation and drinking, this may indicate that individuals are predisposed to develop both activities and that environmental factors determine the relative amounts of drinking and chain manipulation. However, on a behavioural level previous work found that pigs that were more dominant in a food competition test tended to develop higher levels of drinking under restrictive feeding and housing conditions (59).

In conclusion, amphetamine sensitivity as reflected by amphetamine stereotypies is negatively correlated to the tendency to develop environmentally induced stereotypies in pigs. The qualitative differences between these two forms of stereotypies, the negative, rather than positive, correlation, and the lack of correlation between environment-dependent stereotypies and stereotypies in the second amphetamine test suggest that the relationship between these two forms of stereotypies is a complex one. The increased amphetamine sensitivity after long-term restrictive housing and feeding may reflect the effect of stress on central dopaminergic systems.

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