



Research report

Decreased environmental complexity during development impairs habituation of reinforcer effectiveness of sensory stimuli



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ABSTRACT

Previous research has shown that rats reared in simple/impoverished environments demonstrate greater repetitive responding for sensory reinforcers (e.g., light onset). Moreover, the brains of these rats are abnormally developed, compared to brains of rats reared in more complex/enriched environments. Repetitive behaviors are commonly observed in individuals with developmental disorders. Some of these repetitive behaviors could be maintained by the reinforcing effects of the sensory stimulation that they produce. Therefore, rearing rats in impoverished conditions may provide an animal model for certain repetitive behaviors associated with developmental disorders. We hypothesize that in rats reared in simple/impoverished environments, the normal habituation process to sensory reinforcers is impaired, resulting in high levels of repetitive behaviors. We tested the hypothesis using an operant sensory reinforcement paradigm in rats reared in simple/impoverished (IC), standard laboratory (SC), and complex/enriched conditions (EC, treatments including postnatal handling and environmental enrichment). Results show that the within-session habituation of the reinforcer effectiveness of light onset was slower in the IC and SC rats than in the EC rats. A dishabituation challenge indicated that within-session decline of responses was due to habituation and not motor fatigue or sensory adaptation. In conclusion, rearing rats in simple/impoverished environments, and comparing them to rats reared in more complex/enriched environments, may constitute a useful approach for studying certain repetitive behaviors associated with developmental disorders.

1. Introduction

Restricted, repetitive, and stereotyped patterns of behaviors are commonly observed in developmental disorders, such as autism spectrum disorder (ASD) and stereotypic movement disorder (SMD) [1,2]. These behaviors are disruptive to learning and coping. It has been proposed that some of these behaviors could be maintained by sensory reinforcement – the sensory consequences produced by the behaviors [3]. Therefore, they are also called self-stimulatory behaviors in some literature [3–5], and the mechanism has been variously labeled as perceptual reinforcement [3], automatic reinforcement [6–8], or sensory reinforcement [9,10]. Altering sensory consequences or providing alternative reinforcers has been shown to reduce repetitive behaviors in children with developmental disorders [8,11,12].

Environmental factors are known to play an important role in modulating repetitive behaviors. Animals and humans raised in simple/

impoverished environments display more repetitive, stereotyped behaviors than those raised in more complex/enriched environments. For example, the repetitive pacing in zoo animals in their cages is attributed to the lack of normal environmental complexity [13]. Likewise, children raised in institutional settings without environmental complexity show greater frequencies of repetitive behaviors [14]. In contrast, exposure to complex environments, or environmental enrichment, can effectively ameliorate or prevent repetitive behaviors in zoo and lab animals [15–21]. Similarly, relatively complex foster-care environments can significantly reduce stereotypies in children with a history of institutional care [22].

We have suggested that repetitive behaviors maintained by sensory reinforcement are due to impaired habituation of reinforcer effectiveness of the sensory stimuli [23]. Habituation is the simplest form of learning, which allows organisms to cease to respond to irrelevant stimuli [24]. For example, in normal individuals, the reinforcing effects of

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irrelevant sensory stimuli generated by body rocking rapidly habituate. For individuals with developmental disorders or delays, habituation of the reinforcing effects of sensory stimuli generated by rocking may occur more slowly or perhaps not at all. Slow/impaired habituation to sensory stimuli may underlie the enhanced repetitive behaviors, which are reinforced and maintained by the sensory consequences they produce.

The goal of this present study was to demonstrate that rearing rats in simple/impooverished environments increased repetitive behaviors maintained by sensory reinforcers (*i.e.*, response-contingent light onset) in an operant paradigm. Furthermore, we hypothesize that the increase in repetitive behaviors is caused by impaired habituation of the reinforcer effectiveness of the sensory stimuli. Using an operant paradigm to investigate repetitive behaviors is different from other animal models of repetitive behaviors that assess general activity or utilize observational measures [21]. This approach allows us to specifically investigate how repetitive behaviors are maintained by sensory reinforcers. The reason why we used light onset as the sensory stimulus was that, unlike food or water, it is biologically unimportant. Repeated responding to such stimuli represents typical repetitive behaviors. The validity of this model is supported by the observation of an association between increases in sensitivity to sensory stimuli and repetitive behaviors in children with ASD and developmental delays [25–28].

Three different animal-rearing environments were used: im-pooverished (IC), standard laboratory (SC), and enriched conditions (EC). The EC condition was composed of two consecutive interventions, postnatal handling (pre-weaning) and environmental enrichment (post-weaning). They are widely used animal models to study prevention or intervention of various psychological disorders [21,29–41], and have been shown to exert additive beneficial effects when applied together [42–44]. Moreover, a test of dishabituation was used to provide evidence that the within-session decline in responding in rats was due to impaired habituation, not sensory adaptation or motor fatigue.

2. Methods

2.1. Animals and rearing conditions

Male Sprague-Dawley rats were bred in house. Briefly, male and virgin female breeders (Envigo, Indianapolis, IN, USA) were housed in pairs in breeding cages until mating plugs were found. Then females were singly housed in standard plastic cages until giving birth. The colony rooms were on a 12 h/12 h reverse light/dark cycle with light on during 7:00 p.m. – 7:00 a.m. All procedures were approved by the Institutional Animal Care and Use Committee of University at Buffalo, The State University of New York.

After birth, pups were culled to 10 (with ≤ 8 males) per litter. Litters were randomly assigned to the IC, SC, and EC groups and used in different projects. On average, 3.6 rats per litter were used in this study. Littermates, however, were not allocated to different groups due to application of the pre-weaning treatment (*i.e.*, postnatal handling).

Before weaning, each litter (pups and dam) in the IC and SC groups was housed in standard plastic cages (25 × 48 × 20 cm) and left undisturbed except for weekly cage changes. Pups in the EC group underwent a brief maternal separation (15 min) and handling procedure once daily during postnatal days (PDs) 2–20. The purpose of postnatal handling was to enhance maternal behavior, as a complementary enrichment procedure in the early developmental period [42,45].

Pups were weaned on PD 21, and only male rats were kept for the experiments. After weaning, rats in the IC group were singly housed in small metal hanging cages (17 × 24 × 20 cm), which were facing a wall without disturbance (no cage change). Rats in the SC group were housed in pairs in standard plastic cages and not disturbed except for weekly cage changes. Rats in the EC group were group housed (10 per cage) in a large 4-level pet cage (64 × 92 × 160 cm, Model: CG-71111, Drs. Foster & Smith, Rhinelander, WI, USA) with 30 small pet toys,

including pods, hideouts, ropes, and wheels (Drs. Forrest and Smith). The toys were relocated or changed daily to create novelty. The EC rats were transferred to temporary cages during toy reconfiguration, which typically took 15 min per day. All of the housing conditions were maintained until the completion of the experiments.

2.2. Apparatus

Twenty-four locally built experimental chambers, previously described in detail [46], were used for the operant procedure. Briefly, the left and right side walls each had one snout poke aperture. The test chamber was located inside of a sound-and-light attenuating box, with a wall-mounted fan that provided ventilation and masking noise. The reinforcer light used in the experiments was located on the ceiling, midway between the two snout poke apertures. Snout poke could cause onset of the light, which produced an illuminance of 68 lx, as measured from the center of the test chamber. Snout pokes were monitored with infrared photo sensors located in the snout poke apertures. The chambers were connected to a computer using the MED Associates (Fairfax, VT, USA) interface. The MED PC[®] programming language was used for programming of the experimental contingencies.

2.3. Procedure

Eight-week-old rats (IC: $n = 16$; SC: $n = 10$; EC: $n = 10$) underwent light-onset reinforcement training in the operant chambers. One poke aperture was randomly assigned as the “active” hole and the other the “inactive” hole. During the pre-exposure phase, rats underwent 10 continual daily 60-min test sessions in the unlit chambers. Snout pokes were recorded but had no programmed consequences. In the following light-onset phase, rats underwent sessions 11–20, in which snout poking into the active hole turned on the light for 5 s under a variable-interval 1-min schedule, while snout poking into the inactive hole had no programmed consequences. Because the response rate was very low in the last 42 min of the 60-min sessions, only the first 18 min of each session were analyzed. The 18 min were divided into six 3-min epochs for data analysis. All of the testing procedures were conducted during the dark phase of the light-dark cycle.

2.4. Dishabituation challenge

After the light-onset phase, the rats underwent a dishabituation challenge, during which a continuous loud (~ 90 dB) warbling sound (noise) produced by a Sonalert (Model: SC110, Mallory, Indianapolis, IN, USA) was presented from 31st to 36th min of the test session. The 60-min dishabituation test session was divided into ten 6-min epochs, and responses in each epoch were expressed as percentage of the responses in the first 6 min of the baseline sessions. Averages from two regular 60-min light-onset sessions just before the dishabituation challenge were used as baseline.

2.5. Data analysis

Responses were analyzed by averaging numbers of nose pokes to the active or inactive holes in the first 18 min of 2 consecutive sessions during both pre-exposure and light-onset reinforcement phases. The reinforcer effectiveness of light onset was measured by the proportional response to the active hole/total responses.

The within-session decline in responding (habituation) was quantified by two methods. The first method was area under the curve (AUC) measure. The procedure for computing AUC has been described in detail previously [47]. Briefly, nose pokes from each 3-min epoch were normalized to the maximal number of responses in an epoch (typically the first of the 6 epochs). Using the normalized values as *y*-coordinates, the six 3-min epochs that made up the 18-min observation period were partitioned into five trapezoid areas for computing the AUC measure.

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