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Reinforcing and timing properties of water in the schedule-induced drinking situation

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ABSTRACT

A series of recent studies from our laboratory have added to the preceding literature on the potential role of water (in addition to food) as a positive reinforcer in the schedule-induced drinking situation, thus suggesting that adjunctive behaviors might have motivational properties that make their engagement a preferable alternative. It has also been suggested that adjunctive behaviors serve as a behavioral clock that helps organisms to estimate time, making their engagement motivational, so that they enable more accurate time adjustment under temporal schedules. Here, we review some of these experiments on conditioned reinforcement and concurrent chains, as well as on temporal learning. Data presented in this article suggest that adjunctive behaviors may be a part of the behavior patterns maintained by reinforcement, thus serving towards a better performance in temporal tasks.

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1. On adjunctive behavior and its nature

In 1961, Falk published a report in which he submitted rats to a conventional operant lever-pressing training to obtain food according to a variable interval (VI) schedule with a concurrently available bottle filled with water in the conditioning chambers. Animals pressed the lever as expected according to the VI schedule, but also drank excessive amounts of water, which was surprising given that the rats were not thirsty (they were just mildly hungry) and that no contingency had been arranged between drinking and the delivery of food. Drinking was limited to the moments immediately following the delivery of food and lever presses in anticipation of next feeding. Falk initially termed this behavioral phenomenon as "psychogenic polydipsia" (latter schedule-induced polydipsia—SIP) and theorized that it was an example of a wider behavioral category of what he termed as adjunctive (Falk, 1971; see Falk, 1977; Falk and Kupfer, 1998, for further theoretical analysis).

SIP (aka schedule-induced drinking—SID) is a robust behavioral phenomenon that has been observed under different intermittent food reinforcement schedules and animal species. Furthermore, several patterns of adjunctive behaviors have been reported, such as attacking, running, defecation, pica or the self-administration

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of drugs of abuse (see reviews by Falk, 1971; Pellón, 1990; Wetherington, 1982).

Staddon (1977) proposed a motivational account of *adjunctive* behavior (identified here with *schedule induction*, though differences between both terms are significant: see Pellón, 1990; Roper, 1981) by which there were two different motivational states related to distinct temporal moments of an intermittent reinforcement schedule, one strongly linked to the imminent delivery of the reinforcer (*terminal*—e.g., lever pressing) and the other to its absence (*interim*—e.g., drinking). The motivational terms in Staddon's account can be translated to a Pavlovian analysis (e.g., Lashley and Rosellini, 1980), such that adjunctive behavior would be limited to the periods of the reinforcement schedule related to the absence of the reinforcer (S−) and the operant behavior to the periods of high reinforcement probability (S+).

The validity of the conceptual framework offered by Staddon is nowadays disputable (see Killeen and Pellón, 2013) because there is a good number of observations that note that adjunctive behavior is not always produced at moments of low probability of reinforcement (e.g., Corfield-Sumner et al., 1977; Killeen, 1975; Minor, 1987) and it has been observed in portions of the inter-reinforcement interval related to the next obtainment of the reinforcer (e.g., Ávila and Bruner, 1994; Gilbert, 1974; López-Crespo et al., 2004).

As it is not easy to identify a stimulus (unconditioned or conditioned) capable of eliciting adjunctive behavior (see, however, Wetherington, 1982), alternative approaches have focused on the nature of adjunctive behavior as an operant behavior (the most recent by Killeen and Pellón, 2013; but see also Clark, 1962; Moran and Rudolph, 1980; Patterson and Boakes, 2012).

For a behavior to be considered as operant, it should fulfill three requisites (cf. Skinner, 1937): (i) be modifiable by its consequences; (ii) be modulated by the variables known to affect operant behavior; (iii) be maintained by reinforcement. These three requisites are fulfilled by what we know about adjunctive behavior. For example, the amount of SID (i) is increased or decreased by reinforcement or punishment respectively (e.g., Pellón and Blackman, 1987; Reberg, 1980), (ii) depends on the level of the animals' hunger and on the frequency, magnitude and quality of food (e.g., Falk, 1967; Reid and Dale, 1983; Roper and Nieto, 1979; Rosellini and Lashley, 1982), and (iii) can be maintained by reinforcement that is delayed in relation to the occurrence of the behavior (Álvarez et al., 2016).

Killeen and Pellón (2013) (see also Pellón and Killeen, 2015) proposed that different classes of responses within temporal schedules are controlled by reinforcement in terms of delay gradients appropriate to each response. In the case of SID, it is normal that eating and drinking occur together, however drinking is proposed to be further strengthened by food occurring at the end of each inter-food interval since drinking appears to be memorable enough to sustain long reinforcement gradients (Pellón and Pérez-Padilla, 2013).

Contrary to reports on variables and manipulations affecting food, SID does not appear to be related to variables affecting drinking itself, such as the level of thirst or the nature of the liquid available (see Pellón, 1992). For example, SID does not appreciably vary as a function of water deprivation (e.g., Roper and Posadas-Andrews, 1981) or pre-experimental water preloads (e.g., Porter et al., 1978).

The relative insensitivity to manipulations affecting the motivational need of water could reflect the robustness of the phenomenon, suggesting that drinking itself could be reinforcing. Other data exists that might support this idea. For example, SID is relatively resistant to experimental manipulations that provoke antagonistic motivational states to drinking (see below) and it appears to be sufficiently reinforcing to sustain another behavior in order to have access to drink. Falk (1966) showed that SID even developed when rats had to press a lever to have access to water under ratios as high as 50 responses (without being water deprived) and which ran concurrently with a VI schedule of food reinforcement (see also Heyman and Bouzas, 1980).

If drinking in the SID situation is reinforcing, the poisoning of the liquid should show some resistance to suppress drinking as two opposite motivational tendencies are confronted. Roll et al. (1969) and Riley et al. (1980) have shown that animals exposed to X rays or injected with lithium chloride immediately after each SID session needed a relative high number of sessions before SID could be reduced, in contrast with the proven efficacy of such treatments with just one or two sessions in conventional taste aversion procedures (see Revusky and Garcia, 1970). Furthermore, when a taste aversion procedure was immediately effective in reducing SID, the duration of the effect was quite transient (Clarke and Westbrook, 1978; Riley et al., 1979). Finally, the resistance of SID to be reduced by these aversion procedures was higher after the behavior had been developed than in an acquisition experiment (Riley et al., 1979).

All of the above data may indicate that drinking in the SID situation is sufficiently reinforcing, thus conferring water the possibility of having primary reinforcer properties. Bruner and Ávila (2002) suggested an explanation in which SID is considered as an operant behavior controlled by operant contingencies between the water-producing response and water as its reinforcer. They carried out an experiment in which they found that food-deprived rats pressed a lever for water according to fixed interval (FI) schedules of different durations in a SID situation, and concluded that an indirect decrease in water intake when rats are food-deprived in the home-cages and re-establishment of water consumption when rats have access to food after food-deprivation (see Roca and Bruner, 2011) are the operations that enable water as the reinforcer of the behavior it produces (i.e., licks, button- or lever-presses) in the SID procedure. In other experiments, Bruner and collaborators found that manipulations of reinforcement parameters in the relation between water-producing response and water delivery (such as lick-to-water delay or lick-water contingency) resulted in effects similar to those found in operant behavior experiments (e.g., Ruiz and Bruner, 2008).

2. Conditioned reinforcement in the schedule-induced drinking procedure

The present series of studies were carried out in the context of the debate on the possibility of water having reinforcing properties in the SID procedure. Based on studies performed by Bruner and co-workers and briefly reviewed in Section 1 (e.g., Bruner and Ávila, 2002; Roca and Bruner, 2011), it is possible that water reinforces the behavior it produces and that parameter manipulations of the response-water relationship modulate the control over SID. For example, Ruiz and Bruner (2008) found that the rate of water-producing responses decreases as a function of lengthening the delay of water-reinforcement. Although this kind of result suggests that SID is not necessarily inconsistent with the established knowledge on conditioning theory, it raises a contest to other sets of studies in which it has been found that the drinking behavior is clearly controlled by its temporal relation with food at the end of the inter-food interval (cf. Killeen and Pellón, 2013). Hence, the motivational properties of water could not indicate self-reinforcing properties of drinking under the SID procedure because (as described above) the amount of drinking can be modulated by parameters related to the food schedule, and thus reflect environmental control.

According to the fact that a certain level of food deprivation and intermittent food delivery are necessary conditions to establish SID (see Falk, 1969, 1971), it could be suggested that food has a primary role over water in the procedure. Maybe the evidence that