



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

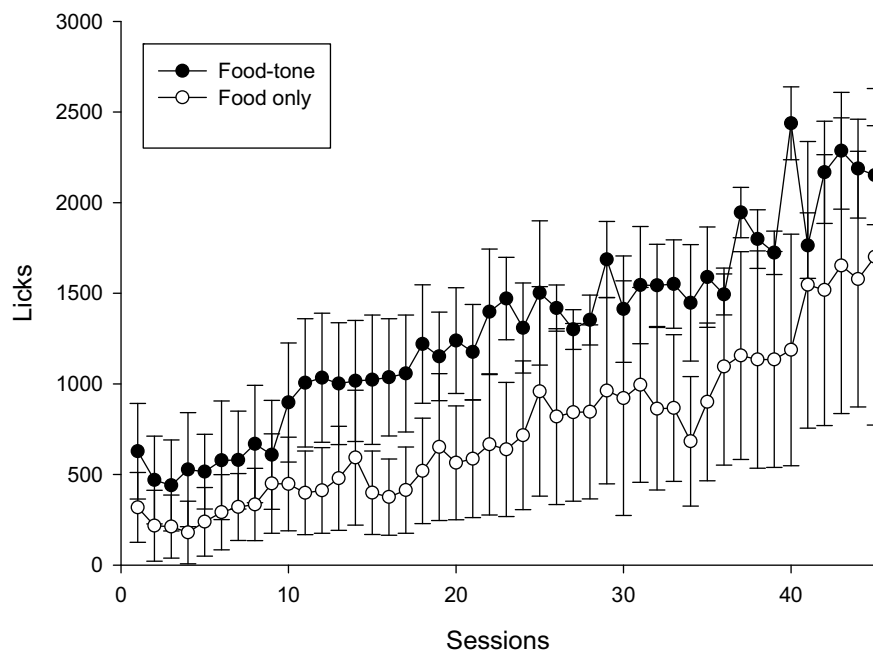


Fig. 1. Mean number of licks across the acquisition sessions for the rats that received food-tone pairings (filled circles) and the rats that received food only (open circles) at the end of each inter-food interval. Vertical bars show standard error of the mean.

supports water as a reinforcer only shows that SID has sufficient motivational properties to maintain an arbitrary response to produce water, as Falk (1966) suggested many years ago and as was mentioned before in Section 1. Moreover, the reinforcing properties of water described above could be controlled by its temporal relationship with food, instead of having reinforcing properties itself. Furthermore, data from our laboratory (Íbías and Pellón, 2014) have shown non-constant daily water consumption when animals were submitted to SID procedures, suggesting that induction and reinforcement of drinking results in raising overall daily intake of water.

2.1. Schedule-induced drinking and the role of food in establishing conditioned reinforcement

A possibility exists that water may acquire some reinforcing properties by virtue of its continuous association with food in the SID situation, thus deriving its reinforcing properties through a conditioned reinforcement process. An important function of food as a primary reinforcer of drinking in the SID procedure could hence be its role in establishing any arbitrary stimulus as a conditioned reinforcer of this behavior. The purpose of Experiment 1 was to test the role of food in establishing a neutral stimulus as a conditioned reinforcer of licking in the SID procedure (see Ruiz et al., 2016, for a more complete presentation).

Eight experimentally-naïve male Wistar rats were used; they were maintained by food deprivation at 85% of their free-feeding weights. All rats were exposed to a fixed time (FT) 30-s food delivery schedule by which a single pellet of food was delivered at regular 30-s intervals regardless of the rats' behavior, with each food pellet, in this case, paired with a 0.5-s tone signal for half of the animals (Food-tone group) but not for the other half (Food-only group). For all rats, a water bottle was available during the experimental sessions and each lick to the spout was followed by the same tone signal that was paired with the food in the food-tone rats. Fig. 1 shows the average (and the standard error of the mean) of the frequency of licks throughout the entire 45 sessions of acquisition for the groups of subjects that received food-tone pairings or food

only. The frequency of licks increased for all rats along the 30-min sessions of acquisition, although it was always higher for the rats that received food-tone pairings than for the rats that received food only.

After completion of SID acquisition, the role of the tone as a reinforcer of a new response (i.e., button pressing) was tested in a 30-min session. For all rats, the presentation of food, water and the tone for food or water, were suspended completely; however, each button-press resulted in the presentation of the tone signal. Fig. 2 shows the mean number of button-presses (and the standard error of the mean) in each sub-interval of 30-s in which the session of acquisition was divided. A higher frequency of button-presses was found for the subjects of the food-tone group in comparison to the rats of the food-only group, especially in the first half of the session.

The results of Experiment 1 showed that, on average, the frequency of licks during acquisition for the rats that received food-tone pairings was a bit higher than for the food-only rats, and that the signal functioned as a conditioned reinforcer. These results are consistent with findings showing that food acts as a primary reinforcer of induced drinking (Killeen and Pellón, 2013) and raises the possibility that the reinforcing value that the water (and the stimuli related to it) might have on the behavior it produces could be due to its relationship with food delivery. However, it is possible that the slightly higher acquisition of licking in the food-signal rats could be due to a suppressant effect of the signal on the licking of food-only rats, despite the signal being a conditioned reinforcer for the food-signal group. This possibility is supported by the little drinking induced in food-only rats under circumstances that normally induce higher levels of behavior (e.g., Íbías and Pellón, 2011).

Experiment 1 was carried out to explore the function of food as a primary reinforcer of drinking in the SID procedure and its role to establish any arbitrary stimulus as a conditioned reinforcer of this behavior. However, the results are not conclusive. In order to clarify the possibility that water may acquire conditioned reinforcement properties due to its relationship with food in the SID situation, two more experiments using concurrent-chains schedules were conducted.

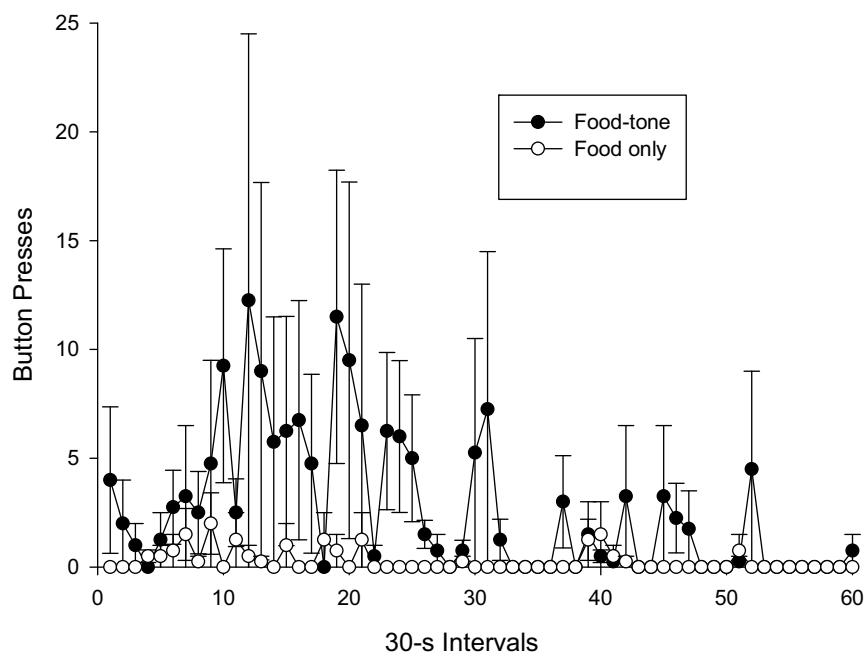


Fig. 2. Mean number of button presses through the session of establishment of a new response for the rats that had received food-tone pairings (filled circles) or food only (open circles) in the previous training. Vertical bars show standard error of the mean.

2.2. Schedule-induced drinking and its role as a conditioned reinforcer in concurrent-chains schedules of reinforcement

In Experiment 2, the reinforcing value of water was explored in a SID situation using concurrent-chains schedules of food delivery. Four food-deprived (85% of the free-feeding weights) and experimentally-naïve male Wistar rats were exposed to a concurrent-chains schedule with two terminal links that provided food pellets on identical FT 20-s schedules. Throughout several experimental phases, one terminal link provided the opportunity to drink in 100, 50 or 0% of the entries to this terminal link, whereas the other terminal link provided constant opportunity to drink (100%). For all rats, the first phase lasted 30 sessions and the next phases lasted 10 sessions each one, including a re-establishment of the 100/100% baseline conditions.

In the initial link, left and right nose pokes produced corresponding terminal links according to a concurrent VI 40-s VI 40-s. During the initial links, two lights above each button were activated. The progression of intervals was generated according to the series suggested by [Fleshler and Hoffman \(1962\)](#) and the procedure was arranged to produce an approximately equal number of left and right terminal-link entries independent of the number of responses in the left and right initial links ([Stubbs and Pliskoff, 1969](#)). The terminal links were signaled by two different frequencies of on and off lights above the corresponding buttons (0.5 s on, 0.5 s off; and 0.1 s on, 0.1 s off). The duration of the terminal links was fixed at 80 s, so that each terminal-link entry provided multiple food pellets per occasion. The sessions lasted 60 min or the time needed to repeat 30 initial- plus terminal-links cycles, whichever first occurred. The relation between left/right and terminal-link entries that provided constant opportunity to drink or only in a percentage of entries was counterbalanced between animals.

All rats developed SID in both terminal links, although water intake was dependent on the proportion of terminal links with an opportunity to drink. The right panel in [Fig. 3](#) shows the mean log ratio (and the standard error of the mean) of the total licks in the terminal link with variable percentage of opportunity to drink (L_{var}) relative to the total licks in the terminal link with constant

opportunity to drink (L_{100}) as a function of the changes in the percentage of terminal links with opportunity to drink.

On average, in the initial phase (100/100), there was a bias in the allocation of licks for the terminal link in which subsequently the opportunity to drink was manipulated. As the opportunity to drink was restricted to 50 and 0% of terminal links, licks were increasingly allocated to the terminal link with constant opportunity to drink. In the redetermination of 100/100's phase, a "regression" toward the baseline was found.

The left panel in [Fig. 3](#) shows the mean relative initial-link response rates for the last three sessions of each experimental phase (plus their standard errors): The log ratio of frequency of nose-pokes in the initial link that resulted in entries to the variable terminal link over the frequency of nose-pokes in the initial link that resulted in entries to the constant terminal link. Although there was a slight bias towards the initial link that resulted in entries to the variable terminal link, it was notable that the preference for this alternative changed systematically as a function of the changes in the percentage of the entries with opportunity to drink in the variable terminal link.

The results of Experiment 2 showed that manipulation of the opportunity to drink in the terminal links of a concurrent-chains schedule modulated the preference for one of two equivalent options in terms of food frequency, suggesting that water had an added value to food delivery. This finding is relevant in the context of previous research, because previous studies with similar procedures were not conclusive about the role of water as a determinant on choice between two schedules of food delivery (see [Cohen, 1975](#); [Heyman and Bouzas, 1980](#)). Cohen found that food-deprived rats allocated more time in one of two identical concurrent variable time (VT) schedules of food delivery, the schedule that provided opportunity to drink relative to the other schedule that only provided food. However, [Heyman and Bouzas \(1980\)](#) used a concurrent-chains schedule with identical schedules of food delivery in terminal links and found that rats allocated their initial-link responses equally between the two alternatives, although one of the two terminal links provided opportunity to drink and the other not. The results of Experiment 2 are consistent

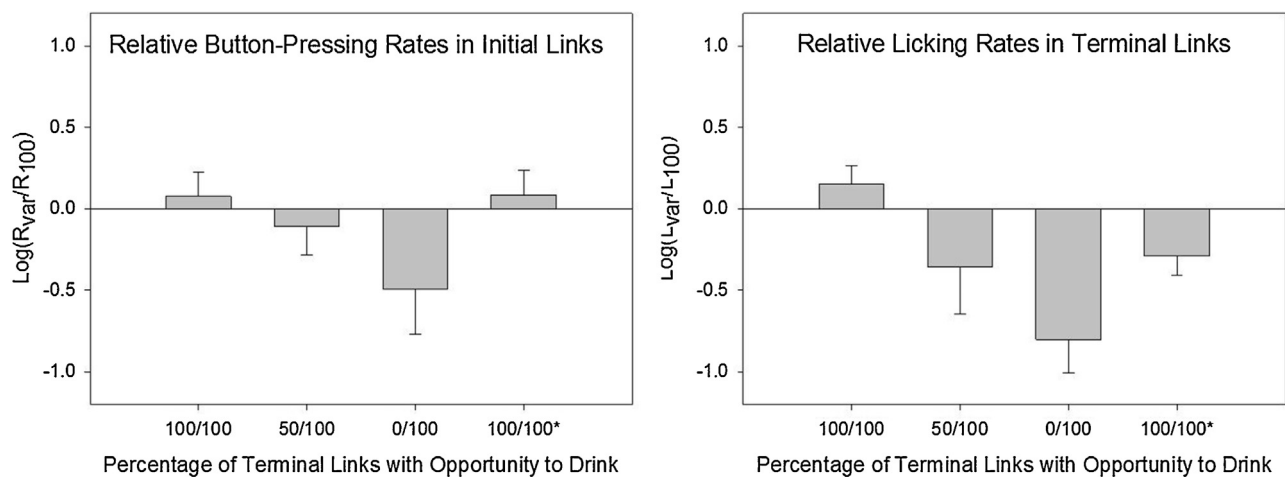


Fig. 3. Left panel: Mean relative button-pressing rates in the initial links for the last three sessions of each phase. Right panel: Mean relative licking rates in the terminal links for the last three sessions of each phase. The log ratios refer to frequency of responses in the chain with variable terminal link over frequency of responses in the constant terminal link. Vertical bars show standard error of the mean.

with Cohen's results, but the difference with Heyman and Bouzas' study raises the question about the consistency of the role of water as a reinforcer in choice procedures.

Experiment 3 attempted to clarify the reinforcing value of water in the SID procedure using concurrent-chains schedules of food delivery and varying the frequency of food delivery and opportunity to drink during the terminal links.

Eight experimentally naïve and food-deprived (at 85% of free-feeding weights) male Wistar rats were trained on a concurrent-chains schedule with terminal links that provided food pellets with different frequency (FT 10-s and FT 20-s). In a first phase, four rats had opportunity to drink during both terminal links (W group), but not the other four rats (NW group). In a second phase, FT 20-s terminal link provided opportunity to drink for all rats. Next, the first phase's conditions were re-established and then, in a fourth phase, FT 10-s terminal link provided opportunity to drink for all rats. The rest of procedural details were the same as in Experiment 2.

The right panel in Fig. 4 shows the mean log ratio (and the standard error of the mean) of the total licks in the terminal link with FT 10-s relative to the total licks in the terminal link with FT 20-s across the subsequent experimental phases for W and NW groups. Both groups allocated their licking equally in both terminal links when the two alternatives were accompanied with opportunity to drink (W group) or were not (NW group). When the opportunity to drink was restricted to the FT 20-s or to the FT 10-s, all rats allocated licking in the alternative with opportunity to drink.

The left panel in Fig. 4 shows the mean relative initial-link response rates for the last three sessions of each experimental phase, that is, the log ratio of frequency of nose-pokes in the initial link that resulted in entries to FT 10-s terminal-link over frequency of nose-pokes in the initial link that resulted in entries to FT 20-s terminal link. Throughout the experiment, all rats allocated button-pressing principally in the alternative that resulted in entries to FT 10-s terminal link, independently of the opportunity to drink in both alternatives (W group) or in neither (NW group), except when the opportunity to drink was provided only during FT 20-s terminal link.

Results from Experiment 3 were consistent with those from Experiment 2 regarding the utility of concurrent chains schedules of food delivery to study choice in a SID situation. The results of the two experiments globally show that choice responses in initial links were controlled by the frequencies of food delivery

in the terminal links, as well as by the probability of opportunity to drink.

The main purpose of Experiments 2 and 3 was to clarify the role of water as a secondary reinforcer relative to the role of food as primary reinforcer. However, the property of water to allocate preference for the alternative that provides better opportunity to drink does not seem to be derived from its function as primary or secondary reinforcer. In studies on choice, it is common that the frequency of conditioned reinforcers do not affect the control of choice exercised by primary reinforcer rates (Shahan et al., 2006). This questions the role of water as a conditioned reinforcer; however, its role as a primary reinforcer is not clear either. Choice in concurrent chains seemed to be guided more by food than by water in the terminal links. Maybe the role of the opportunity to drink during the inter-food intervals in the procedures of SID is a different one from its role as secondary/primary reinforcer; it could be something more fundamental, such as that engagement in drinking facilitates the temporal control of behavior during inter-food intervals (see Killeen and Fetterman, 1988).

The hypothesis that adjunctive behavior might be related to temporal control has been considered previously (see Harper and Bizo, 2000; Killeen et al., 1997). Lejeune and co-workers (Lejeune et al., 2006; Richelle and Lejeune, 1980) proposed that behaviors that are not usually measured could contribute to temporal estimation in a sort of collateral behavioral chain, preceding one another until the occurrence of the reinforcer, as a behavioral clock. Killeen and Fetterman (1988) proposed something similar with their Behavioural Theory of Timing (BeT), in which they suggested that organisms use adjunctive behavior as a key to estimate time, considering not individual behaviors but behavioral states as keys for the organisms, pointing out that the response that animals will be executing at the time of the delivery of the reinforcer will be strengthened. On the other hand, taking into account the fact that the behavior of organisms occurs continuously, it is feasible that, in certain circumstances, some responses will be controlled explicitly by a reinforcer but this does not preclude the relevance of the "non-reinforced" behaviors into the "behavior stream" controlled by subsequent reinforcers (see Schoenfeld and Farmer, 1970). In that sense, Machado and Keen (1999) have pointed out that behaviors observed during temporal stimuli (that can also be understood as inter-reinforcement time), constitute 'the' behavioral clock, and not only represent or are the expression of an internal clock. In the

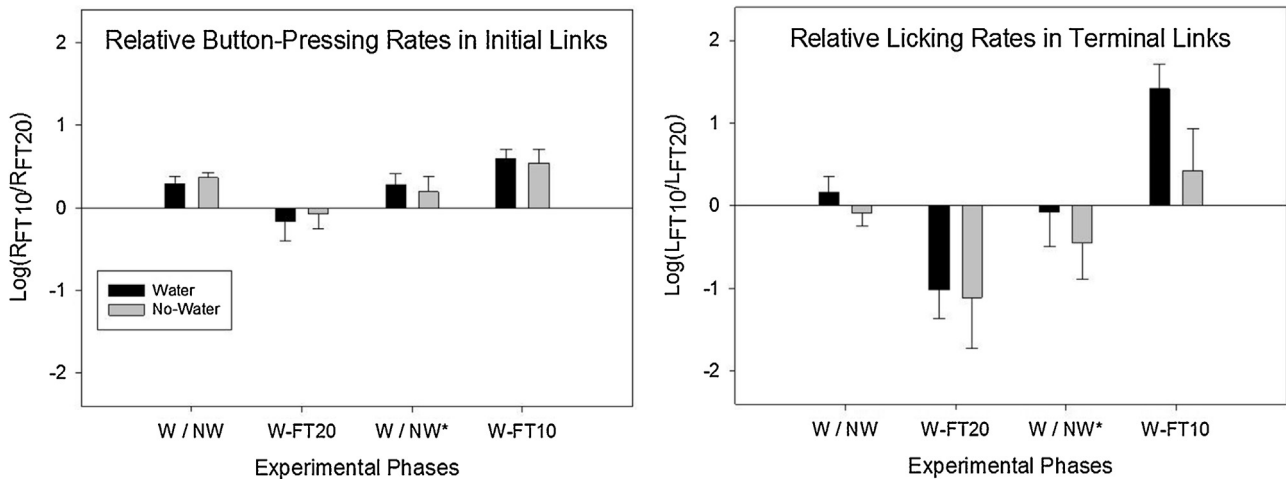


Fig. 4. Left panel: Mean relative button-pressing rates in the initial links for the last three sessions of each phase. Right panel: Mean relative licking rates in the terminal links for the last three sessions of each phase. The log ratio refers to frequency of responses in the chain with FT 10-s in the terminal link over frequency of responses in the FT 20-s terminal link. Vertical bars show standard error of the mean.

following experiments, the role of SID in the temporal control of behavior was explored.

3. Scheduled-induced drinking and temporal learning

As noted above, it has been suggested that adjunctive behaviors serve as time estimation, working as a behavioral clock that helps organisms in temporal tasks, although this hypothesis has not been tested thoroughly.

Segal and Holloway (1963) carried out an experiment where they found that rats exposed to a differential reinforcement of low rate (DRL) food schedule and that had the opportunity to engage in SID, developed a stable pattern of behavior which consisted in an uninterrupted period of drinking, a lever press followed by a food pellet and then drinking again. They concluded that this pattern of behavior helped rats to estimate time; however they didn't incorporate appropriate control measures.

In order to assess whether SID (and other adjunctive behaviors) works as a behavioral clock, it is important to evaluate the effect of engaging in SID during temporal learning tasks. López (2012) indicated that temporal learning could be divided in two different types: temporal learning per se and behavioral adaptation to temporal regularities in the environment. The first category includes estimation and discrimination of time, whereas the second includes behavioral regulation and temporal control.

It is not clear yet if organisms use the same strategies in tasks that require different types of temporal learning, so it is necessary to evaluate the impact of SID in tasks that require different types of temporal learning. In the context of the present manuscript, we present data collected with two temporal tasks: an FI schedule, which provides information about behavioral adaptation to temporal regularities, and a temporal discrimination task, which provides information about temporal learning per se.

3.1. Schedule-induced drinking and temporal learning in a fixed interval schedule

An FI schedule is a great example of a task in which organisms need to learn temporal regularities of the environment in order to adapt their behavior to them. Although organisms exposed to this schedule only need to emit a response at the end of the interval to receive the reinforcer, they develop a characteristic pattern of responses (*scallop*) that consists of a pause after the reinforcement followed by an accelerated response rate until the next

reinforcement (Ferster and Skinner, 1957; López and Menez, 2012). It is worth noting that this characteristic FI pattern results from averaging all inter-reinforcement intervals in a session and normally from a group of animals (e.g., Baron and Leinenweber, 1994). Data obtained from exposing organisms to FI schedules have usually been analyzed in steady-state conditions after many training sessions, but in order to understand temporal learning, it is important to examine the learning process and the variables affecting it (see López, 2012).

The next experiment (Experiment 4) was designed to assess whether having the opportunity to engage in SID improves behavioral adaptation to temporal regularities, hence improving temporal learning in FI schedules.

Six male Wistar rats were food-deprived to maintain them between 80 and 85% of their free-feeding weights, and were exposed to a FI 30-s food reinforcement schedule, 60 trials per session, during 30 sessions. Rats were divided in those that had access to water (W) in the conditioning chambers, thus having the opportunity to engage in SID (W group) and those that did not (NW group).

There are many measures to assess temporal adjustment in FI schedules, such as the post-reinforcement pause (PRP) and the quarter life (QL), which were calculated in this study. The PRP is the time elapsed since the beginning of the interval (just after the delivery of the previous reinforcer) and the first lever press emitted by the animal, and the QL is the time during which the subject completes the first fourth of the total lever presses emitted in an interval. The performance of rats is considered to be better adjusted as the PRP and QL are longer, because that indicates the subjects are starting to press the lever later in the interval. Both measures were calculated from the data of each individual inter-reinforcement interval and then averaged over the entire session. Since the goal of Experiment 4 was to evaluate temporal learning, all sessions were analyzed and reported.

Fig. 5 shows mean PRP data during all 30 sessions of the experiment. Throughout the sessions, animals from the W group had longer PRPs, showing a higher value than NW rats as early as session 1. The small difference observed at the start of the experiment was magnified as training progressed, since rats in the W group increased PRP duration throughout the sessions whereas the NW group remained fairly constant.

Fig. 6 displays mean QL data. As it happened to PRP, it can be seen that the W group had a larger QL than the NW group throughout the sessions of the experiment, starting with small differences that

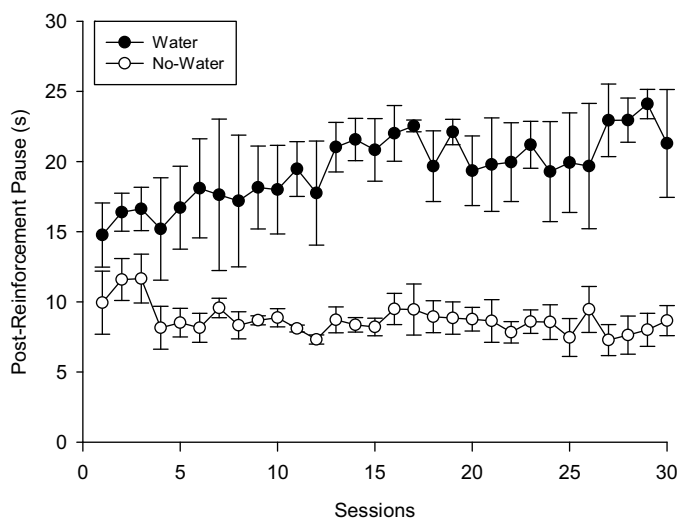


Fig. 5. Mean post-reinforcement pause duration throughout all experimental sessions for rats that had access to water (filled circles) and did not have access to water (open circles). Vertical bars show standard error of the mean.

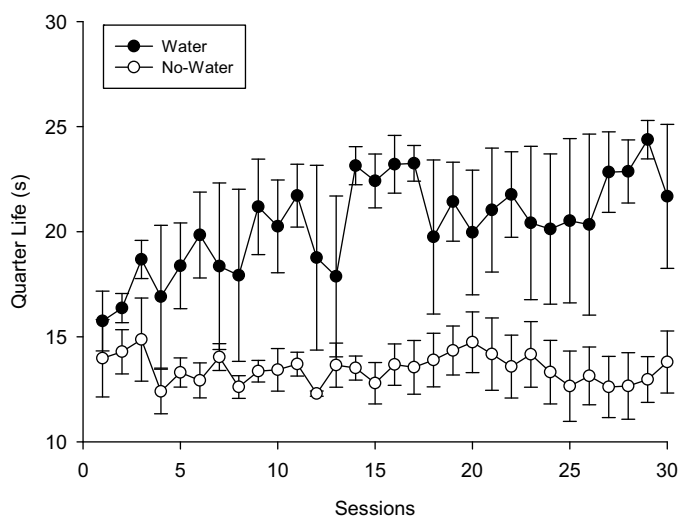


Fig. 6. Mean quarter life duration for all experimental sessions of W group rats (filled circles) and NW group rats (open circles). Vertical bars show standard error of the mean.

were increased as training progressed. This was due to a steady increase in QL in W rats and the no-change registered for NW rats.

Longer PRP and QL in the W group are probably related to the acquisition and increment of drinking behavior. Both timing measures tended to increase during the first 15 sessions of the experiment, remaining then steady towards the last 15 sessions. Fig. 7 depicts that PRP, QL and licking rate had similar slopes during the first 15 sessions, showing that the more the subjects drunk, the longer PRP and QL were obtained.

These results show that engaging in SID allows rats to have what is considered a better performance on temporal tasks such as the FI, which requires a behavioral adaptation to temporal regularities in the environment. López and Menez (2005, 2012) have reported that previous experience in a schedule with temporal regularities (such as an FT) improves subsequent performance on FI schedules. Nevertheless, that effect is transitory because eventually, rats with different previous experiences will develop the same pattern of behavior (López and Menez, 2005).

It can be suggested that previous experience in schedules with temporal regularities improves performance on FI schedules

because organisms tend to acquire certain patterns of behaviors as a consequence of regular inter-reinforcement intervals (IRI), similarly to what was reported by Skinner (1948). Probably, subjects with previous experience in FT acquire a pattern of behavior that persists during FI sessions, while subjects with different histories (for example, a random interval schedule) have to learn that pattern once they started the FI experience, hence taking more time to learn it.

The behavioral trajectory to the typical FI response pattern includes a decrease in response rate during the first half of the IRI and an increase during the second half across sessions (Machado and Cevik, 1998). Since drinking water starts as a post-pellet behavior that tends to fill in most of the IRIs (e.g., Álvarez et al., 2016; Staddon and Ayres, 1975), its development provides an opportunity for rats to decrease the response rate of lever pressing at the beginning of the IRI, generating as a consequence a better-adjusted pattern of behavior.

Why is SID (and no other potential activity) the predominant behavior? Lucas et al. (1988) showed that organisms behave in a pre-organized way that includes patterns of behavior repeated in the IRIs. Specifically, in rats (and possibly in other mammals), that pattern includes food-handling, post-prandial focal-search, post-prandial drinking and other exploratory behaviors, and anticipatory focal-search. It is quite possible that during interval and time food schedules this pattern (or one very similar to this) is repeated during the IRI, ending with lever pressing and/or magazine approach and the delivery of food at the end of the interval, hence reinforcing not only the lever pressing but the whole pattern as well. Such situation has been previously described by Clark (1962), and is consistent with what Killeen and Pellón (2013); see also Pellón and Killeen, 2015) have proposed regarding reinforcement of SID and other adjunctive behaviors. The likelihood of behavior according to patterns pre-organized for a specific aim (e.g., Timberlake, 2001) and its strength by reinforcement, offers an account for why drinking in the SID procedure is a most likely behavior and how it increases with training. This is a plausible explanation given that when a contingency between SID and the delivery of food is established, animals tend to increase their licking rate, as would happen with any other operant behavior, but with a long time gap between instances of licking and food delivery (Álvarez et al., 2016; Reberg, 1980).

What happens to rats that have no access to water during the IRIs? They will probably develop patterns similar to those described above which do not include post-prandial drinking but other exploratory behaviors. Behaviors that do not have an immediate consequence (as it is the case for drinking after licking) are possibly more difficult to perform for most animals (as could be attacking without a conspecific or running without a wheel), thus it seems reasonable to assume that, under those circumstances, it will take longer to establish a specific pattern or it would not develop as strongly as when animals have an object to interact with. If they do not have water, they will probably engage in other behaviors in substitution. Evidence in favor of rats developing a pattern that comprises different behaviors that exclude drinking comes from studies in which rats are trained under intermittent food schedules without access to water; hence the subsequent acquisition of SID is retarded or prevented when water is made available in comparison to animals without such history (e.g., Tang et al., 1988; Toates, 1971).

3.2. Schedule-induced drinking and temporal learning in a discrimination task

The training phase of the Temporal Bisection Task (TBT) (Church and Deluty, 1971) is a good example of a procedure involving temporal learning per se, because organisms have to learn to

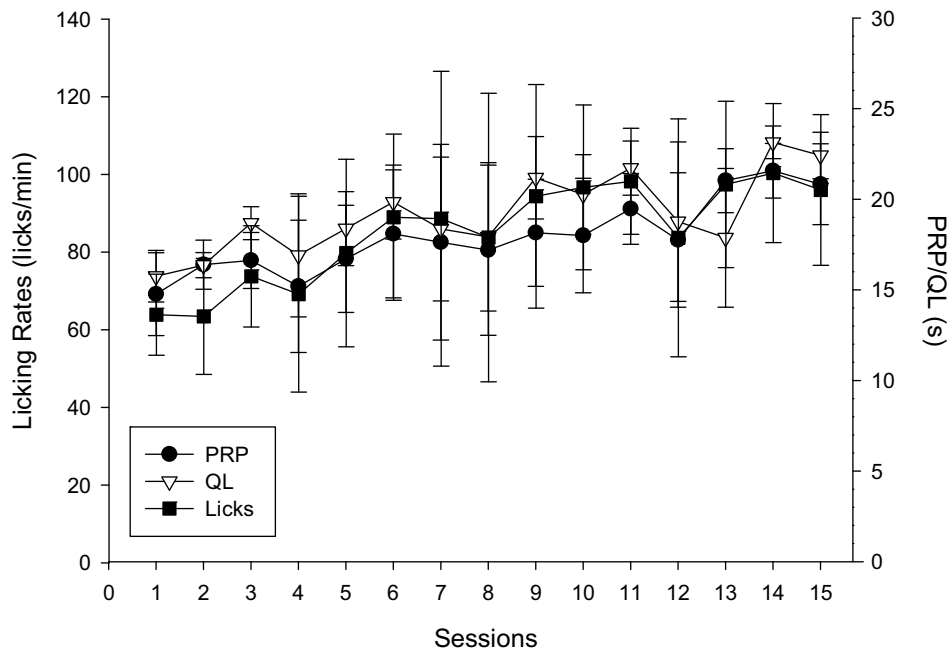


Fig. 7. Mean post-reinforcement pause – PRP – (circles), quarter life – QL – (triangles) and licking rate (squares) of the W group across the first 15 sessions of the experiment. Vertical bars show standard error of the mean.

discriminate between two stimuli that differ only in their durations. As with FI schedules, TBT has mostly – or even exclusively – been studied in steady state. In papers reporting TBT, data analyzed were usually the performance of rats during the testing phase, and little is known of the variables affecting (accelerating) the learning process.

The aim of Experiment 5 was to assess whether having the opportunity to engage in SID accelerated learning in this temporal discrimination task, therefore only the data from the training part of a TBT were analyzed.

Twelve experimentally-naïve and food deprived (at 80–85% of free-feeding weights) male Wistar rats were exposed to a procedure where they had to learn to discriminate between two stimuli of different duration (10- or 40-s lights), each associated with a lever in a standard operant conditioning chamber. The experimental sessions consisted of 40 trials with a 25-s inter-trial interval (ITI). Each trial occurred as follows: At the start, the lights of the chambers were turned on, and remained on for 10 or 40 s randomly, then the lights were turned off and the levers were inserted. If the rat pressed the lever associated with the appropriate stimulus duration (correct lever), a food pellet was delivered and the ITI began again; if it pressed the wrong lever, there was no food pellet and the ITI began immediately. This task continued until each subject achieved 80% correct responses for 3 consecutive sessions. After session 30, rats that had not reached the criterion in at least one session were given correction trials, which were similar to the normal trials described above with the exception that if the rat made a wrong response both levers were retracted and presented again, until the animal gave the correct response for that trial. As in Experiment 4, rats were divided in two groups: one that had access to a water bottle in the conditioning chamber throughout all sessions (W group), and another that did not have access to water in the conditioning chamber (NW group).

Fig. 8 shows that rats in the W group needed a mean of 27 sessions to achieve the criterion, while rats in the NW group needed a mean of 34 sessions. It should be noticed that there could be a greater difference between groups, because half of the subjects of the NW groups needed correction trials, meaning that they could

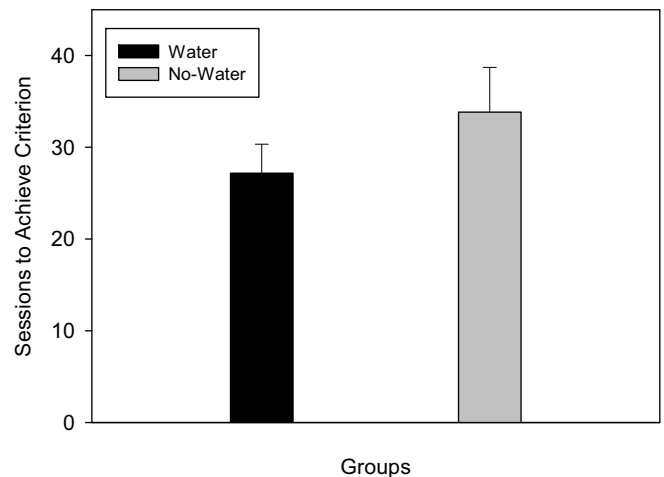


Fig. 8. Mean number of sessions needed to achieve the criterion by W rats (black bar) and NW rats (grey bar). Vertical bars show error of the mean.

Table 1
Number of sessions needed to achieve the criterion in three consecutive sessions.

W group		NW group	
Subject	Sessions	Subject	Sessions
S1	21	S2	32
S3	29	S4	19
S5	19	S6	24
S7	26	S8	53*
S9	41*	S10	38*
S11	27	S12	37*

(*) indicates that subject had correction trials.

have needed a lot more than 30 sessions to achieve the criterion without correction, specially S7 that needed 23 sessions with correction trials to achieve it; whereas only 1 rat in the W group needed correction trials (see Table 1).

It has been widely observed, but not usually reported, that rats' performance in a bisection temporal task consists on spending the

first part of the trial pawing or biting at the opening of the ‘short’ lever, until the signal ends and the lever is presented, changing to the ‘long’ lever at approximately the geometric mean of the two anchor durations, continuing to paw and/or bite the opening until the lever is inserted (Yin et al., 2016). Machado and Keen (1999) also reported that pigeons developed unique behavioral patterns that were acquired during training phase and that accounted for differences found in the psychometric functions in the test phase that could not be explained by other causes. Finally, Fetterman et al., (1998) showed that adjunctive responses might come to serve as discriminative stimuli in timing a 6- versus 12-s interval. Mouthing the dispenser and sniffing at the short lever were associated with pressing the short lever when the interval ended; moving to the long lever and sniffing it were associated with a long judgment.

Those patterns of behavior resemble the pattern observed in other temporal schedules, such as FI, during which the subject starts to press the lever after the delivery of the previous reinforcer and usually continues doing so until the next reinforcer is provided. It is possible that access to water provides an opportunity for rats to engage on a different pattern, where they ‘fill’ the IRI performing a measurable behavior, such as drinking, instead of pawing or biting the lever opening. This suggestion is consistent with the findings of Segal and Holloway (1963).

Is it really ‘temporal learning’ as López (2012) named it? Maybe ‘behavioral adaptation to temporal regularities of the environment’ is the *strategy* used by organisms to estimate or discriminate time; and apparently SID – and possibly other adjunctive behaviors – serve as a strategy to produce behavioral patterns that researchers perceive as a better performance in temporal tasks. Maybe there is no need to use different explanations to account for different aspects of the behavior of organisms; whether the reinforcer is explicitly contingent or not with the behavior, behavior is controlled by the environmental events (i.e., stimuli) throughout the passage of time. The use of different concepts to describe the behavior of organisms could be interpreted as if the organism could have the ‘capacity’ to use one or another psychological process to result in behavior of one or another type. Nevertheless, behavior is only what organisms do, and the contingencies of reinforcement in the environment will shape it to what we call ‘adaptation to the environment’ (see Skinner, 1981).

4. Some conclusions and reflections

The experiments described in this article aimed to investigate the reinforcing properties of SID, as it has been suggested that water in SID situations acts as a reinforcer (Bruner and Ávila, 2002). Furthermore, other authors have suggested that SID and other adjunctive behaviors could act as a behavioral clock (Killeen and Fetterman, 1988; Richelle and Lejeune, 1980), which could result in reinforcing for organisms in the sense of being able to predict when the reinforcer is going to be delivered.

Nevertheless, data presented here point at a different direction: There is no clear evidence of SID acting as a primary or secondary reinforcer (Section 2), but there is some evidence that SID is part of a behavioral pattern reinforced by the delivery of food (Section 3). Killeen and Pellón (2013) suggested that different behavior classes could be reinforced by the same reinforcer at the end of a schedule with temporal regularities (FT or FI). Furthermore, it is possible that behavior classes are not reinforced ‘separately’, but are reinforced as a whole pattern that fills IRIs, as Skinner (1948), Machado and Keen (1999) and others have pointed out. The conclusions derived from SID studies could be generalized to other adjunctive behaviors, however it is a matter of empirical investigation, and the differences in the environmental circumstances under which animals normally live should be taken into account

in order to better understand the origin and control of each one of these behaviors. For laboratory rats, home cages usually limit general activity due to their reduced size, which can be the establishing operation for an adjunctive behavior such as wheel-running to result in an effective reinforcer (e.g., Belke and Wagner, 2005). Nevertheless, wheel-running may also occur as a part of a whole pattern of behaviors between food reinforcers, if the opportunity to run is available amongst other behavior alternatives (cf. Killeen and Pellón, 2013).

The temporal structure of behavioral patterns can be shaped by their repeated exposure to reinforcement schedules of specific lengths, in such a way that behaviors related to the delivery of the reinforcer would be more powerfully conditioned and maintained (such as licking or lever-pressing under food reinforcement schedules) than those less correlated with reinforcement (Killeen et al., 1997). Therefore, if a particular behavior is no longer useful, in the sense that it does no longer correlate with the delivery of the reinforcer, it will probably be extinguished and replaced by another temporally-appropriate one (Haight and Killeen, 1991). Furthermore, although there is evidence that patterns of behavior during IRIs are often highly variable, this does not necessarily imply that they do not serve as temporal discriminative stimuli for other behaviors in the pattern, because even if they are topographically different, they can still be functionally equivalent (Harper and Bizo, 2000).

On the other hand, there is some evidence that adjunctive behavior during IRIs can be adapted to temporal regularities, although it may be not necessary for timing (Richelle and Lejeune, 1980). Furthermore, the fact that certain classes of behavior are correlated with a specific temporal focus does not mean that organisms use those behaviors to anticipate food delivery (Killeen et al., 1997). That is, every situation in which a food-related behavior occurs periodically does not imply that organisms are counting, the only fact that we can state is whether “our use of a clock helps us predict its behavior, or if its behavior predicts the reading on our clock” (Killeen et al., 1997, p. 80).

The role of reinforcement can be seen as an organizer of existent sequences of behavior, being behavior allocated within environmental constraints including time. In this respect, and following the arguments outlined here, one should expect that SID won’t really be time dependent in the sense of showing the scalar property (Gibbon, 1978) but would be dependent on inter-reinforcement interval length with a rather fixed temporal location immediately after the occurrence of the reinforcer (Flores and Pellón, 1997; Íbias and Pellón, 2011), thus explaining the functional characteristics of SID as related to food rather than water parameters.

Some previous studies on the comparative role of food and water as reinforcers are consistent about the finding that under similar motivational levels for food and water (i.e., food- and water-deprived, or not deprived at all), rats respond more to food than to water (Fallon et al., 1965; Hearst, 1961; for replication of this phenomenon with other animal species see Findley, 1962, for monkeys; Ploog and Zeigler, 1997, for pigeons; Thompson, 1964, for fighting cocks), and even more when they are just food deprived (Willis et al., 1974). Although water and food have a controlling effect on drinking behavior (licking or via an arbitrary response like button- or lever-pressing), it is evident that food-related variables have a principal role as establishing operations of the apparent function of water as a reinforcer, and their relevance as a behavioral strategy to facilitate temporal adaptation in between food reinforcers.

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