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The timing of schedule-induced behavior

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Abstract

Schedule-induced drinking (SID) is a case of learning in the absence of explicit response-reinforcer contingency, characterized by accumulative excessive drinking following successive intermittent food pellet deliveries. Two experiments with rats were conducted to examine whether it was possible to displace SID to later than the post-pellet moment within inter-food intervals. In Experiment 1, SID was established under a fixed time (FT) 30-s food schedule. This was followed by a phase in which unsignaled lick-contingent delays were enforced during the initial seconds of the inter-food interval. Subsequently, a second FT 30-s baseline was reintroduced, followed by a phase of signaled lick-contingent delays. Results indicated that lick-contingent delays were ineffective in displacing SID. Instead, the signal produced a marking effect that increased licking. In Experiment 2, during the acquisition phase, water access was restricted during the initial 5, 10, or 20 s of the inter-food interval, followed by an FT 30-s schedule with water available. In the second phase, only the FT 30-s schedule was implemented to determine if the onset of drinking had been displaced by prior experience. These two phases were then repeated. Results showed that SID occurred during water accessibility periods. Displacement of SID was achieved, demonstrating similarities between induced and more explicit operant behavior. The findings are discussed in terms of how timing might result from a combination of reinforcement and induction.

Key words: schedule-induced drinking, response-reinforcer contingency, delayed reinforcement, marking, timing, rats.

The timing of schedule-induced behavior

Schedule-induced behaviors are those that occur under intermittent reinforcement schedules, manifest at excessive rates despite lacking contingency with reinforcer delivery, and, relevant to this manuscript, have a specific temporal distribution within inter-reinforcement intervals (Falk, 1961, 1971; Pellón, 1990; Pellón et al., 2020; Roper, 1981; Timberlake, 1982; Wetherington & Brownstein, 1982). Schedule-induced behaviors tend to occur at the start of the inter-reinforcement intervals, right after the delivery of the reinforcer (e.g., schedule-induced drinking; see Álvarez et al., 2016; Fuentes-Verdugo et al., 2023; López-Tolsa & Pellón, 2021), or half-way the interval (e.g., schedule-induced wheel-running; see Gutiérrez-Ferre & Pellón, 2019; Segal, 1969).

Schedule-induced drinking (SID) is the most extensively studied schedule-induced behavior, given that it is reliably induced when mildly food-deprived rats are exposed to intermittent food delivery with water available in the operant chambers (e.g., Falk, 1971; López-Tolsa & Pellón, 2021; Pellón, 1990). SID usually occurs in the first 10-20 s after food delivery, regardless of the length of the inter-reinforcement interval, and shows an inverted-U shape distribution, stopping after some more or less fixed time has passed through the interval. The absence of contingency between SID and reinforcer occurrence, along with its specific location within the interval, led Falk (e.g., 1966b), and also Staddon (1977; see also Staddon & Simmelhag, 1971), to categorize SID and other schedule-induced behaviors as a separate class from operant behavior, initially termed adjunctive (Falk, 1971).

Numerous studies have explored schedule-induced behaviors since the first reports in the literature, but however have highlighted similarities between operant and induced behaviors, suggesting that both types are modified by their consequences, modulated by the same variables affecting operant behavior, and maintained by reinforcement (Pellón, 2004; see Wetherington, 1982). This led Killeen and Pellón (2013) to propose that all kinds of behavior can be reinforced through temporal

proximity with the reinforcer, even in the absence of a explicit contingency (Killeen, 2023; Killeen & Pellón, 2013; Skinner, 1948).

Killeen and Pellón (2013) proposed the model of competing traces, which states that each behavior has a temporal window (i.e., “a trace”) during which it can be reinforced, with different kinds of behavior showing dominance above others in different parts of the inter-reinforcement intervals (Pellón & Pérez-Padilla, 2013), so that behaviors with a shorter trace occur closer to next reinforcer (e.g., lever-pressing) and behaviors with a longer trace occur earlier in the interval (e.g., spout-licking). This would explain why SID is reinforced despite being temporally distant to the reinforcer and having a specific time location. This view, then, considers SID and other induced behaviors as operants. Furthermore, induced behaviors are considered to be acquired as part of a pattern where each behavior is chained to and reinforced by the next one (Killeen, 2023; López-Tolsa & Pellón, 2025; Ruiz et al., 2016).

A complementary approach considers that the reinforcer exerts both prospective and retrospective effects, inducing future behaviors, and reinforcing previous ones (López-Tolsa, 2019; López-Tolsa & Pellón, 2021, 2025). If SID is sensitive to the inducing effect of reinforcers, it would account for why it initially occurs at the post-reinforcement time instead of as a pre-reinforcement event. Likewise, Cowie et al. (2011, 2017) suggest that food presentations act as a discriminative stimulus signaling the future arrival of food, rather than as a reinforcer.

Even though SID normally occurs at the beginning of the inter-reinforcement intervals, it is likely being reinforced by the next delivery of food. There is plenty of evidence that SID is as sensitive to the same environmental contingencies as putative operant behaviors (Álvarez et al., 2016; Bond et al., 1973; Falk, 1966a; Lamas & Pellón, 1995a, 1995b, 1997; Patterson & Boakes, 2012; Pellón & Blackman, 1987, 1991; Pellón & Castilla, 2000). For example, SID can be reduced by punishment (e.g., Pellón & Blackman, 1987) and this reduction be modulated by food related parameters

(e.g., Lamas & Pellón, 1995b), or it can be enhanced by reinforcement (Álvarez et al, 2016) and be depended on reinforcer parameters as well (Castilla & Pellón, 2013).

Despite the many similarities between schedule-induced behaviors such as SID and operant behaviors as indicated above, SID develops at the same post-pellet location regardless of the duration of the inter-reinforcement interval (Íbias & Pellón, 2011; López-Tolsa & Pellón, 2021), unlike operant lever pressing (López-Tolsa & Pellón, 2021). This rigid time location of licking independent of inter-reinforcement interval length does not seems to fit with the proportional position of operant behavior in relation to reinforcer occurrence when reinforcement frequency changes, thus posing a challenge to the general account of schedule-induced behavior as operant.

The scalar timing property of operant behavior on time-base intervals (Matell & Portugal, 2007; Rakitin et al., 1998), referred to as an increase of a response standard deviation proportional to the interval length (Gibbon, 1977), has not therefore been yet observed on SID (López-Tolsa & Pellón, 2021).

The apparent lack of the scalar timing property in SID in relation to the time of food occurrence might be related to its early occurrence within inter-reinforcement intervals, separated from food delivery. The goal of the current series of experiments was to examine whether SID can be displaced within inter-food intervals (i.e., to occur at different moments of the interval than it's it beginning; see López-Crespo et al, 2004), and that if such a displacement could then lead to the observation of the scalar property. To achieve the displacement of SID, two experiments with different procedural manipulations were conducted. In Experiment 1, signaled and unsignaled lick-contingent food delays were enforced during the initial portion of the inter-food intervals. In Experiment 2, water access was restricted during the initial portion of the intervals to prevent drinking during that period. Unlike previous studies employing similar manipulations, the present study also analyzed the temporal distribution of SID.

Experiment 1

Previous experiments have shown that SID is reduced when unsignaled lick-contingent delays are implemented during acquisition (Hawkins et al., 1972; Lamas & Pellón, 1995a, 1997; Moran & Rudolph, 1980; Pellón & Blackman, 1991; Segal & Oden, 1969). However, once SID is established, the implementation of lick-contingent delays as punishment were initially shown less effective in reducing its occurrence (Falk, 1964, cited in Segal & Oden, 1969; Flory & Lickfett, 1974; Hawkins et al., 1972), although evidence of such a reduction has been systematically reported thereafter (Lamas & Pellón, 1995b; Pellón & Blackman, 1987; Pellón & Castilla, 2000). Adding a signal to the lick-contingent delays has occasionally enhanced the punitive effect (Pellón & Blackman, 1987) whereas in other instances it has produced an increase in SID (Moran & Rudolph, 1980). Pellón and Blackman (1991) found that signaled lick-contingent delays initially increased licking (during the first 20 sessions) but then decreased it, so it remains to be clarified whether this increase is a transitory effect or a persistent change in the response pattern. See Table A1 in the Appendix for a more detailed description summarizing previous experiments involving lick-contingent delays on the acquisition and maintenance of SID.

Using a different strategy, Reberg (1980) studied the effect of employing a positive or negative contingency (drink-food vs. no drink-food contingencies) for an extra food presentation during the first six seconds of a fixed time (FT) 30 s food schedule, and then reverting it on another experimental phase. He observed that rats that were exposed to the positive contingency first maintained excessive drinking during the phase in which the negative contingency was implemented, whereas rats initially exposed to the negative contingency displayed low drinking rates during the first segment, followed by an increase in drinking once the positive contingency was implemented.

To sum up, a negative lick-food contingency during acquisition (e.g., a delay or the omission of an extra reinforcer) may function as punishment of SID (Hawkins et al.,

1972; Lamas & Pellón, 1995a, 1997; Moran & Rudolph, 1980; Pellón & Blackman, 1991; Reberg, 1980; Segal & Oden, 1969), but there is still controversy about the effects of using a signaled lick-contingent delay instead of an unsignaled one. It would be helpful to compare the effects of signaled and unsignaled delays once SID has been developed, to determine whether they enhance the punitive effect or lead to an increase in drinking rates (cf. Pellón & Blackman, 1987).

Considering the aforementioned information, the objective of Experiment 1 was to test whether SID could be shifted after its acquisition using lick-contingent delays, both unsignaled and signaled, during the initial part of the inter-food interval to demonstrate if SID is sensitive to lick-contingent delays at this period of the interval. The following outcomes were expected: a) SID would be displaced toward the end of the inter-food interval due to a punishment effect at the beginning of the interval caused by the contingent food delays; b) this displacement would occur only if animals are submitted to lick-food delays, not as a simple consequence of lengthening the duration of the inter-food interval; and c) the scalar timing of licking would just be observed once drinking will be displaced from its initial occurrence after food delivery.

Method

Subjects

Subjects were 50 experimentally-naïve male Wistar rats obtained from Charles River Laboratories (Lyon, France), and that were 11 weeks old at the beginning of the experiment. Their weights were gradually reduced to about 80-85% of their individual free-feeding bodyweights, which were 295 grams on average (range: 267-330 grams) at their arrival to the laboratory. During the 10-day period of weight adjustment, rats were handled daily (i.e., gently held and manipulated by the experimenters) to habituate them to human contact. The handling of all subjects took about 1 hour. Rats were housed in groups of four, except for two cages of three rats each, and access to water was always available in the home cages throughout the experiment. Home-cages were made of transparent Plexiglas and measured 19 cm x 35 cm x 55 cm. The

room where they were housed was environmentally controlled (22ºC and 55% relative humidity) with a 12-hour light-dark cycle (lights on at 8:00 a.m.). Rats were weighed daily at approximately the same hour before the experiment and were fed about 30 minutes after the end of each session. Animal care procedures were in accordance with the European Union Council Directive 2010/63, the Spanish Royal Decree 53/ 2013, and with the authorization of the Community of Madrid (ref. PROEX 077/18) and the ethics committee of UNED.

Apparatus

Ten Letica LI-836 (customized by Cibertec, Madrid, Spain) 29 cm x 24.5 cm x 35.5 cm conditioning chambers were used to conduct the experimental sessions. They were enclosed in sound attenuating boxes, and a fan located on one of the walls provided ambient noise of 70-75 dB that served to mask external noise. The boxes were also equipped with a small observation window at the front that remained closed during experimental sessions. In the conditioning chambers, the front panel was made of aluminum, the left panel of transparent Plexiglas, and the remaining panels were made of black Plexiglas. The floor consisted of a 16-bar stainless steel metal grid. The food tray was located in the center of the front panel, at 3.5 cm above the floor, with one retractable lever on each side and a 3-W round lamp above each lever. The levers and the lights above them were not used during the experiment, so they remained retracted and turned off, respectively. Behind the wall, a dispenser delivered 45 mg sweet (sucrose based, unflavored) food pellets (Bio-Serv, Frenchtown, NJ, USA) into the food tray. In the right wall, a 3.2 cm x 3.9 cm aperture could be found, 20 cm apart from the front wall and 7 cm above the floor. Through this aperture it was possible by licking to access the spout of a bottle of water, which was placed behind the wall. Licks were recorded by the closure of an electrical circuit between the spout and the metal bars of the floor, so that each time the animals licked the spout, the circuit closed, and a lick was registered. The chambers were also equipped with a small speaker on the upper right side of the front panel, 25 cm above the floor. The speaker was

programmed to produce a tone of 2500 Hz that was 10 dB higher than the ambient noise of each chamber (80-85 dB). The houselight (25-W light) was located behind the front panel and provided indirect light for the whole chamber during the experiment. Chambers were controlled with a MED-PC application using a Microsoft Windows XP environment.

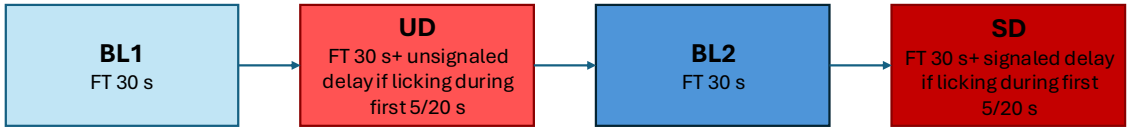
Procedure

The experiment consisted of four phases: 1) Baseline, 2) Unsignaled Delay, 3) Return to Baseline, and 4) Signaled Delay (see Figure 1). An FT 30 s schedule was implemented throughout the experiment, so a food pellet was delivered every 30 s regardless of the subjects' behavior, except during the delay phases, when food pellets could be delivered later (see details below). Before the beginning of each experimental session, the bottles were filled with fresh tap water and mounted behind the right wall. Water bottles were always available during experimental sessions, so rats were able to develop SID during inter-food intervals. Houselights were turned on at the beginning of the experimental session and turned off at the end. Sessions lasted 30 trials (at least 15 min) and were conducted daily between 12:00 and 14:00 hours.

Upon completion of the first phase (baseline), 32 of the initial 50 rats were assigned to one of four groups (n = 8 per group)—consisting of two experimental and two yoked-control groups—while the remaining 18 subjects were excluded for failing to meet the drinking criterion of at least 30 licks during the final session. Experimental and yoked-control subjects were paired according to their licking rates during this first phase, and these group assignments remained constant throughout the experiment. The four experimental phases are described in detail below.

Figure 1

Outline of the procedure followed in Experiment 1



Note. BL1 stands for Baseline; UD for Unsignaled Delays; BL2 for Return to Baseline; and SD for Signaled Delays.

Baseline (BL1). On the first phase, all rats underwent an FT 30 s food schedule. They had access to the food tray and the spout of the bottle of water during all experimental sessions. The goal here was for the rats to develop SID. This phase lasted 40 sessions.

Prior to the second phase, rats were assigned to one of four groups based on their drinking rates: two experimental groups, characterized by a maximum delay of either 5 s or 20 s, and two corresponding yoked-control groups. The 32 rats with more than 30 licks in the last session continued the experiment. The lowest rate of the selected rats was 0.03 licks/s, and the highest 2.65 licks/s, with an average of 0.88 licks/s. They were distributed following a pseudorandom selection into the two experimental groups and their corresponding yoked-control groups, to ensure similar rates among groups.

Unsignaled Delays (UD). During this phase, experimental subjects were exposed to lick-contingent delays intended to displace the onset of SID within inter-food intervals. For the EXP5 group, any lick occurring during the initial 5 s of each interval resulted in a delay of next food delivery; for the EXP20 group, this criterion applied to the initial 20 s. The duration of the delay was determined by the timing of the final lick within the specified period of each group: the time elapsed from the start of the interval to the last lick was added to the total duration of that interval for that specific subject. For example, if a rat from the EXP5 group made a lick in the 4th second, the

FT interval would be extended until second 34 (30 + 4) during that trial; or, if a rat from the EXP20 group made a lick in the 18th second, the FT would extend until the 48th (30 + 18) second in that trial. Each experimental rat had a yoked control rat, that received the food pellets at the same time as the experimental rats, regardless of their behavior. Delivery of food pellets to the yoked control groups (CON5 and CON20, respectively) depended therefore on the performance of the experimental subjects. This phase lasted 30 sessions.

Return to Baseline (BL2). During the third phase, baseline conditions were restored. The objective was to recover SID patterns under the initial conditions by reversing any behavioral changes produced by the lick-contingent delays. 10 sessions of an FT 30 s schedule without delays were conducted exactly in the same way as in the first phase (BL1). Fewer sessions were conducted during BL2, as SID had already been established and reached stability more rapidly.

Signaled Delays (SD). Finally, in the fourth phase, subjects were exposed to the same schedule as in the second phase, but the delays were accompanied by a tone. The objective in this phase was the same as in the UD phase, i.e. to displace SID via lick-contingent delays. The tone was added so that rats could discriminate better the initial period during which the action of licking would produce a delay. The tone was delivered as follows: it was presented contingent on licks emitted during the initial portion of the interval (the first 5 s for EXP5 and CON5, and the first 20 s for EXP20 and CON20), and its duration was synchronized with the contingent delay. If multiple licks occurred during the initial period, the delay duration was not cumulative; instead, each subsequent lick updated the duration to match the time elapsed from the start of the interval to that specific response. Consequently, both the added delay and the tone duration were determined by the timestamp of the final lick emitted within the 5-s or 20-s window. For example, if a rat in the EXP5 group licked at the 2nd and then at the 4th second, a 4-s delay was added to the FT 30-s schedule, and the tone remained active for the duration of that delay. This phase lasted 30 sessions.

Data Analysis

Data were analyzed only for subjects that maintained more than 100 licks per session during the final five sessions of each phase, excluding Phase 1. This excluded the following subjects from each group's graphs and analyses: S46 from CON5; S16 and S10 from EXP20; and S28 and S25 from CON20. Final group sizes went as follows: EXP5 (n=8), CON5 (n=7), EXP20 (n=6), and CON20 (n=6).

Licking rates and distribution of licks were recorded, and data from the last five sessions of each phase were analyzed. Response rates were calculated by dividing the total number of licks in a session by the duration (in seconds) of each experimental session. Additionally, licks were aggregated into 1-s bins to characterize the temporal distributions within the inter-food intervals. The MedPCPy package (Maldonado et al., 2023) was used on Python (Python Software Foundation, 2023) within PyCharm (JetBrains, n.d.) to perform initial data analysis and calculate the distribution of licks. Distributions were calculated per subject and session.

Individual distributions were calculated using the mean of the final five sessions per phase. Considering that SID shows an inverted-U shape, a Gaussian function was used to estimate the time (second with the highest licking) and width (standard deviation) of the peak of licking:

$$A \times \left(f(t, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \right),$$

where the free parameter *A* converts Gaussian probabilities (from 0 to 1) onto the same scale of individual response rates; *t* represents time (in seconds) from the beginning of the interval; μ is the time of the peak, the mean of the distribution which represents the second of the interval with the highest licking rate; and σ is the width of the peak, which corresponds to the standard deviation of the distribution, which represents the duration of the maximum licking rate moment during the interval. The Gaussian function was fitted to individual data using the nlmrt package (Nash, 2022) on R on RStudio (R Core Team, 2021; RStudio Team, 2020). The nlmrt package adjusts

non-linear functions by trying to find the minimum of the residual sum of squares. The starting values were A = 1000, t = 15 and σ = 5, with lower bounds of 100, 0.3 and 0.1, and upper bounds of 10000, 30, and 10, respectively for each parameter. The function was fitted adequately to most 5-session blocks (mean R^2 =0.92, range: 0.63-0.99; 98 cases out of 108 were over 0.8; see https://osf.io/v73jz/ for cases in which it was not successfully fitted).

The quarter life (QL) was also calculated to determine the start of continuous licking during the interval. The quarter life represents the second of the interval in which the first quarter of the total of licks were made. It measures the beginning of a responding episode more consistently than post-reinforcement pause, which only measures the first response since the delivery of the reinforcer. QL was calculated individually for the last five sessions of each phase, using a macro in Excel.

Linear mixed-effects models (LMMs) were used to analyze possible relationships between the QL, peak, or width, with the independent variables of the study: group (EXP5, CON5, EXP20, CON20), delay (up to 5 or 20 seconds), belonging to the experimental group (yes or no), and phase (1, 2, 3 or 4). Additionally, random intercepts for subjects were included. LMMs were carried out on R. The packages used were psych (Revelle, 2023); nlmrt (Nash, 2022); readxl (Wickham et al., 2023) and xlsx (Dragulescu & Arendt, 2022). LMMs were chosen over other more classical statistical techniques because they allow to compare between- and within- subjects variance and offer more flexibility than ANOVA and for comparisons between groups with different number of subjects (Brown, 2021). For each analysis, the first step was to construct a null model (e.g., (Peak ~ (1|Subject)), to which more elaborated models were compared trough a likelihood ratio test to select the model that best fitted the data for each dependent variable (e.g., Peak ~ Phase*Delay + (1|Subject)). The best-fitting models were those with the highest significance. The best-fitting model for each variable is described in the Results section, and discarded models can be consulted in

the repository. Additional materials, including scripts, can be consulted at: https://osf.io/v73jz/.

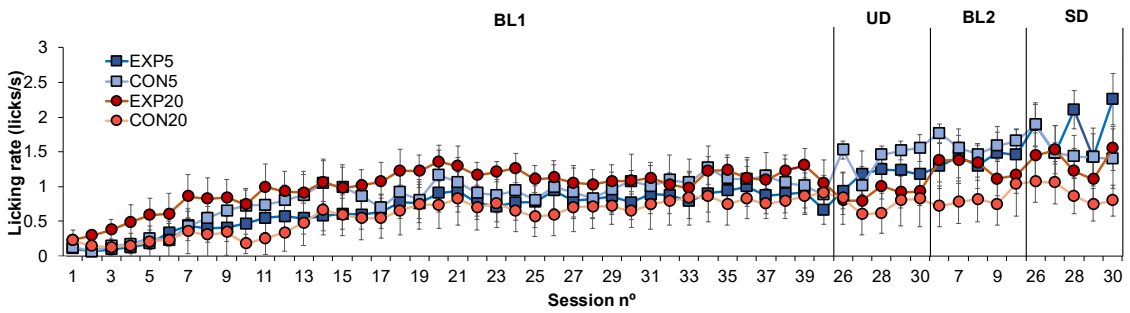
Results and Discussion

This experiment was designed to investigate whether it is possible to displace the moment of occurrence of SID once it had been acquired, by using unsignaled (phase 2) and signaled (phase 4) lick-contingent delays during early times at the start of inter-food intervals. Signaled delays were predicted to improve the rats' discrimination of which licks resulted in food delays.

Figure 2 depicts the acquisition of SID, measured in licks per second, during the different phases of the experiment for each group. Similar licking rates were observed for all groups during BL1 (0.83 to 1.16 licks/s). A difference between 5-s and 20-s delay groups occurred later during UD and SD phases. In general, higher response rates were observed during the SD phase. Rates were slightly higher for the CON5 group during UD and BL2 phases, but they were higher for EXP5 in the SD phase. On the other hand, rates for the EXP20 group were higher than for the CON20 during the whole procedure, with more pronounced differences during BL2 and SD phases. Contrary to the 5-s delay groups, the 20-s groups reduced their licking rates during UD.

Figure 2

Mean (± SD) rate of licks (licks/second) by session and group throughout Experiment 1



Note. Changes between phases are illustrated with black vertical lines. Blue squares represent the 5-s groups, and red circles the 20-s groups. Lighter colors indicate yoked-control groups, and darker ones the experimental groups. Phase names are presented above each phase session's results. BL1 = Baseline, UD = Unsignaled Delay, BL2 = Baseline 2, SD = Signaled Delay. Note that for UD, BL2 and SD, only the last 5 sessions are shown. Black vertical lines indicate standard error (SD) of the mean.

It is noteworthy that experimental subjects increased their licking when the tone was introduced, especially EXP5. Even though EXP20 increased their total number of licks, it did not increase its licking rate due to the lengthening of the interval. Similar results were observed in Moran and Rudolph (1980), who reported that the use of a tone for signaled delays increased SID acquisition, although not as efficiently as a light. Additionally, Schaal et al. (1992) found that unsignaled delays decreased key-pecking, while signaled delays maintained or caused lower decreases in response rates.

Pellón and Blackman's (1991) reported that the increase in licking under signaled delays was transitory (albeit in an acquisition but not in a maintenance study), with rates declining after the 20th session. In contrast, in this experiment, 30 sessions of signaled delays were conducted, and licking did not decrease. These discrepancies may be attributed to variations in the punishment contingencies employed across studies. In the present experiment, delays were capped at a maximum of 5 or 20 s, thereby limiting the punishment effect. In contrast, Pellón and Blackman (1991) employed a 10-s resetting delay; under such a contingency, each response during the delay restarted the timer, potentially extending the punishment period indefinitely and thus increasing its punitive effect. Although a marking effect may have also been present in Pellón and Blackman's (1991) study—initially enhancing drinking—the punitive effect of the 10-s resetting delays likely overshadowed the reinforcement process over time.

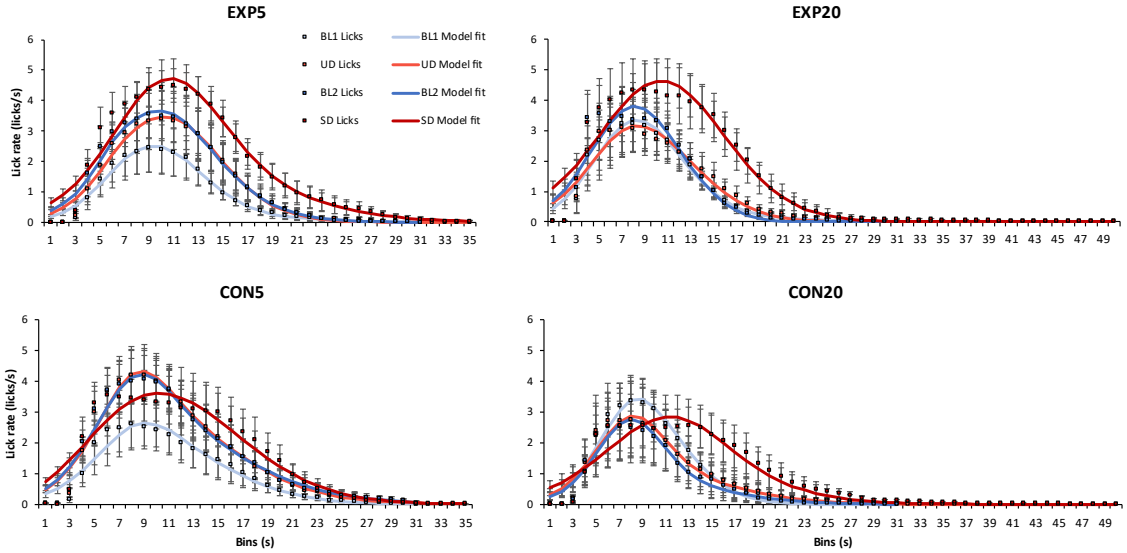
The increase in response rate during the signaled delay may be due to a marking effect of the tone, which implies that the introduction of a stimulus signaling the behaviors facilitates or increases the acquisition of the response (Moran & Rudolph, 1980). The marking effect has been observed in both schedule induced (Killeen & Pellón, 2013; Moran & Rudolph, 1980; Patterson & Boakes, 2012; Pellón et al., 2018) and traditional target operant behavior (Azzi et al., 1964; D'Amato et al., 1968; Lieberman et al., 1979; Williams et al., 1990).

Moreover, Moran and Rudolph (1980) commented that some lick-contingent delays may not be effective since some sensory stimulation such as a wet mouth may still be present when the reinforcer is delivered, considering that rats keep licking until about 20-25 s into the interval. Thus, the effect of the delay may then be the same as lengthening the interval, which would explain why EXP5 had a higher licking rate than EXP20 during UD and SD, since the interval was shorter for the former (EXP5 group). Also, the tone during signaled delays would be shorter for the 5 s group, facilitating rats to discriminate the licks causing the tone onset, and therefore increasing their licking.

Mean distributions of licks in each phase are displayed in Figure 3 (individual distributions can be consulted in Figure 1A in the Appendix). Distributions are presented using 1-s bins, and the corresponding mean of the fitted Gaussian curves for each group is shown in the graphs. The model was adequately fitted to the data of all groups and phases. Temporal distributions of licking during the signaled-delay phase differed from all other phases across all groups, characterized by a broader spread and a rightward shift of the peak towards the end of the interval. Furthermore, response rates reached their maximum during this phase for both experimental groups, whereas no such increase was observed in the yoked-control groups.

Figure 3

Distribution of licks and the fitted Gaussian curves throughout the inter-food intervals, for all phases of Experiment 1 and for each group independently



Note. Data from the four groups of Experiment 1 is shown. Top left: EXP5; top right: EXP20; bottom left: CON5; bottom right: CON20. Light blue symbols and lines regard the data from BL1 phase; light red for UD; dark blue for BL2; and dark red for SD. Data are represented by squares and the fitted curve by a continuous line. Black vertical lines indicate standard error of the mean.

Figure 3 illustrates that the introduction of the signal (SD) produced a clear effect; the distributions got taller and wider for both experimental groups, in line with the increase in response rates reported in Figure 2. This change in distribution during SD may allow for a better appreciation of the marking effect discussed above. Surprisingly, control groups also showed changes in the width of the distribution during the SD phase, which may be a lighter marking effect, since the tone was not made contingent to the control subjects' responses, but was mostly coincident with them (i.e. an experimental rat could start licking later in the interval than its yoked control, thus the tone would initiate when the former one started licking, not marking the control rat's previous licks). Additionally, the distributions in Figure 3 reveal that the introduction of lick-contingent

delays did not change the moment of occurrence of SID according to the duration of the delays introduced, contrary to what was expected. Since previous studies using lick-contingent delays did not report temporal distributions, no direct comparison can be made regarding this specific measure.

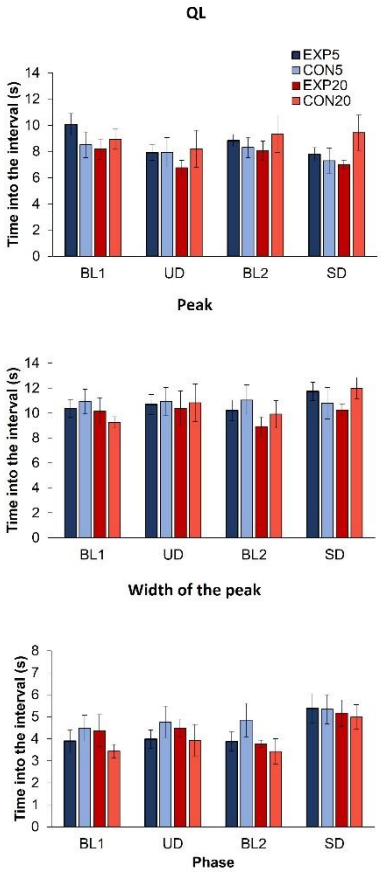
The quarter life, peak and width of the peak from all groups are included in Figure 4. The quarter life is the time into the interval when the first quarter of the responses took place, thus a shorter quarter life indicates that rats were licking at higher rates sooner into the interval. The best-fitting model for quarter life included phase (1, 2, 3 or 4) as fixed factor and random intercepts for subjects (QL ~ Phase + (1|Subject); $X^2_{(3)}$ = 14.594, p = 0.002). Results from the model confirm that rats started licking earlier during the delay phases, as the quarter life occurred 1.26 s earlier during phase UD than phase BL1 (t = -3.309, p = 0.001) and 1.14 s earlier during phase SD (t = -2.994, p = 0.004), but no other comparisons were significantly different (see Table A2 for further details).

The peak is the second of the interval with the highest licking rate. Similar to the quarter life, the best-fitting LMM included phase (1, 2, 3 or 4) as fixed factor and random intercepts for subjects (Peak ~ Phase + (1|Subject); $X^2_{(3)}$ = 10.929, p = 0.012). Particularly, the peak occurred 0.99 s later during the SD phase, compared to BL1 (t = 2.639, p = 0.010), but no other comparisons were significantly different (see Table A3). However, visual inspection of distributions in Figure 3 shows that the peak occurred later during the UD phase, compared to BL1 as well.

The width of the peak was measured as the standard deviation of the Gaussian curve and is a measure of the time of duration of continuous drinking. Similar to the previous measures, the best-fitting LMM analysis for the width included phase (1, 2, 3 or 4) as fixed effect and random intercepts for subjects (Width ~ Phase + (1|Subject); $X^2_{(3)}$ = 28.121, p = 0.000). The model suggests no differences between groups. The width of the peak was 1.19 s larger in the SD phase, compared to BL1 (t = 4.789, p = 0.000), with no other significant differences (see Table A4).

Figure 4

Mean QL (quarter life), time of the peak, and width of the peak, by group and phase of Experiment 1



Note. QL is displayed in the upper row, the peak in the middle row, and the width of the peak in the lower row. EXP5 and CON5 are represented in blue color, and EXP20 and CON20 in red color. Dark color is for experimental groups and light one for yoked control groups. Phases are in order from left to right and allow comparisons between experimental groups and their yoked controls, as they are in pairs. Black vertical lines indicate standard error of the mean.

Overall, these analyses reveal that licking began earlier during the unsignaled and signaled delay phases, contrary to what was originally expected, and that there was

a delay in the maximum response rate and an increase in the duration of continuous licking during the SD phase, without significant differences between groups. However, the results indicate no signs of clear SID displacement, nor do they support evidence for the scalar property, which was the main goal of the experiment. Two factors may account for the lack of displacement observed: a lack of discrimination of the contingency, or a persistence of the distribution of licking, despite the change in the contingencies.

Regarding the lack of discrimination, none of the previous studies in Table A1 used a similar method of introducing delays, since in this experiment they just occurred if subjects licked at the first seconds of the interval, but in previous studies delays were in effect throughout the entire interval (e.g., Pellón & Blackman, 1987). The lack of displacement observed in the distributions (Figure 3) along with the increase (EXP5) or stabilization (EXP20) of the licking rate (Figure 2) during the signaled phase (SD) suggests then that subjects were not sensitive to the contingency established between their licks and the delays.

Another plausible explanation is that the previously learned distribution persisted despite the change in the contingencies that originally established it. As observed by Reberg (1980), rats exposed to a positive contingency between licking and reinforcement that is subsequently reversed to a negative contingency may fail to adjust their induced drinking to the latter condition. In the present experiment, although no formal contingency was programmed between licking and food delivery, the resulting behavioral effect may be functionally equivalent to the persistence reported by Reberg (1980). Also, López-Tolsa et al. (2026), found that adding a phase removing access to water for 30 sessions after SID had been acquired, resulted in less SID in a posterior phase with water access in comparison to a group which had not experienced the water removal. Both previous experiments highlight the importance of previous history and the sensitivity to new contingencies in SID, which may relate to the static distribution (previous history) and the increase in licking rate (new contingencies).

In summary, despite the lack of displacement and scalarity, these results suggest a shared phenomenon, the marking effect, between operant and induced behavior. This adds evidence to the consideration of schedule-induced behaviors as operants. Moreover, one of the primary hypotheses—that delays would suppress SID at the beginning of the interval—was not supported by the data. This suggests that alternative procedures are required to effectively displace SID and achieve the study's main objective. Consequently, a different procedure was employed in Experiment 2.

Experiment 2

The aim of Experiment 2 was to further explore the conditions that facilitate the displacement of SID to a later portion of the inter-reinforcement interval. In Experiment 1, a procedure involving response-contingent food delays failed to produce the expected displacement; therefore, a different approach was implemented in which access to water was physically restricted during the same post-reinforcement periods as in the previous experiment.

Several studies have employed procedures that restricted access to water to displace SID within inter-reinforcement intervals (see Table A5 for details). In these experiments the time of water availability was limited to a certain period within the interval, preventing rats from accessing the waterspout, thus allowing to observe SID at different moments within the interval. Although a considerable number of studies have employed water-restriction procedures, they present several limitations: small sample sizes, manipulation of SID only after acquisition (with the exception of Daniel & King, 1975), an absence of reporting temporal distributions, and a lack of comparison with control groups under unconstrained drinking conditions.

In order to overcome these potential limitations, López-Crespo et al. (2004) conducted a study to observe the acquisition of SID in moments different to the beginning of the inter-food interval. They used sample sizes of $n \geq 7$ and reported response distributions. They observed that SID was successfully acquired in the first

and second half of an FT 30 s interval (Experiment 1) and in the different third parts of an FT 90 s interval (Experiment 2). They also displaced SID distributions in both schedules for control groups in a latter phase. These controls had free access to water during the whole interval, but a phase was added where water availability was restricted to the last period of the interval, and SID was maintained.

Ávila and Bruner (1994) restricted water access to different 16 s periods within an FI 128 s food reinforcement schedule, observing that licking was effectively confined to those specific periods. Drinking increased as the 16-s access periods occurred in closer temporal proximity to next food delivery. Consequently, water consumption followed a positively accelerated function towards the end of the 128-s interval, consistent with patterns observed in operant behavior restricted to specific periods in pigeons (Bruner, 1981; Dews, 1966; Farmer & Schoenfeld, 1966a, 1966b). These results also align with Killeen and Pellón's (2013) vision of delayed reinforcement, as SID seems to be gradually more reinforced as the reinforcer delivery comes closer, being this the most plausible explanation.

In light of the aforementioned findings and the results of Experiment 1, the objective of Experiment 2 was to displace SID within inter-food intervals by restricting water access during the initial portion of the intervals. Additionally, the duration of such impediment time will be manipulated to compare how different interval durations affect SID development. Three main findings were expected with this procedure: (a) the onset of SID would be postponed due to the restricted water access; (b) licking would be organized around water availability—or a signal correlated with it; and (c) shifts in the rate and temporal location of licking would become more pronounced as the delay between food delivery and water availability increased.

Method

Subjects

Subjects were 24 naïve male Wistar rats (Charles River Laboratories, Lyon, France), approximately 12 weeks old at the start of the experiment. Their weights were

gradually reduced to about 78-83% of their individual free-feeding bodyweights, which was 329 grams in average (range 280-379 grams) on their arrival to the laboratory. This deprivation protocol was more stringent than in Experiment 1 to ensure the reinforcing efficacy of food delivery during experimental sessions, as several subjects had to be excluded from the previous experiment. Daily handling was conducted for 1 h during the initial weight-reduction week. Rats were housed in groups of four, with water available ad libitum in the home cages throughout the experiment. All other housing conditions were identical to those described in Experiment 1. Animal care procedures were in accordance with the European Union Council Directive 2010/63, the Spanish Royal Decree 53/ 2013, and with the authorization of the Community of Madrid (ref. PROEX 077/18) and the ethics committee of UNED.

Apparatus

Six conditioning chambers different than the ones used in Experiment 1, were used to conduct the experimental sessions. Chambers were 30 cm x 30 cm x 25 cm and were enclosed in sound-attenuating boxes. A fan located on one of the walls provided an ambient noise of 70-75 dB. The boxes were also equipped with a small observation window at the front that remained closed during experimental sessions. Regarding the conditioning chambers, their left panel was made of transparent Plexiglas, and their right, back and ceiling panels were made of black Plexiglas. The front panels had three modules. The center one was made of aluminum and contained a magazine, located 5 cm above the floor. Behind each front wall, a dispenser delivered 45 mg sweet (sucrose based, unflavored) food pellets (Bio-Serv, Frenchtown, NJ, USA) into a magazine. The other two modules in the front panel were made of black Plexiglas. Each lateral module had a round aperture (nose poke), 1.7 cm in diameter, positioned 7.5 cm above the floor and 5 cm from the lateral wall. Each time rats had inserted their noses into this aperture, a response would be recorded (albeit registered, no relevant results were extracted out of these measures). Inside the round aperture, there was a 4-W light that remained off during the procedure. Next to the

nose poke aperture, there was a rectangular opening (3 x 1.6 cm), placed 7 cm above the floor and 5.5 cm from the lateral wall. This opening provided access to the tip of a solenoid valve that delivered 0.15 ml of water per lick. Two signal lights (one red and one green, always operated simultaneously), each 1 cm in diameter, were located above the solenoid valve aperture. Only the left valve was operative during specific times. The floor consisted of a 16-bar stainless metal grid. Licks were recorded with the registration of the closure of an electrical circuit between the valve and the metal bars of the floor, so each time the animals licked the spout the circuit closed, and a lick was registered. A houselight was located behind each front panel, which provided light for the whole chamber during the experiment. The houselight consisted of an indirect 25-W light. Chambers were controlled with a MED-PC application using a Microsoft Windows XP environment.

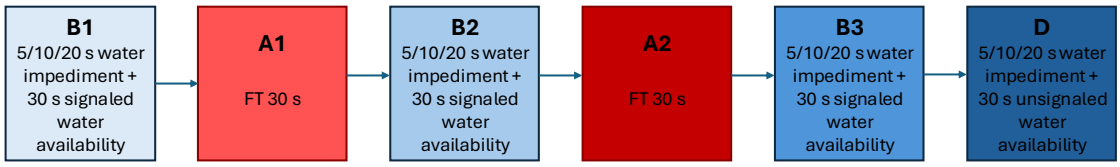
Procedure

The present experiment had a within-subject design, consisting of six phases (see Figure 5): B phases, in which water was impeded for a specific period and then water availability was signaled during 30 s ending with food delivery; A phases, in which a straight FT 30 s food schedule was implemented; and a D phase, in which water was impeded again for a specific period and then water was available but unsignalled during 30 s ending with food delivery. Rats therefore received food reinforcement under FT schedules, such that food was delivered at the programmed intervals regardless of the subjects' behavior. The water valve was available during specific periods, as will be described, allowing rats to develop SID during inter-food intervals. Before each experimental session began, the left valves were filled with fresh tap water. At the beginning of the sessions, houselights were turned on, and they were turned off at the end of the experimental session. Sessions lasted 30 trials (15 - 25 mins) and were conducted daily between 10:00 and 12:00 hours.

The distribution of subjects among the three groups was made randomly at the beginning of the experiment, and the three groups (n=8) remained the same until the end of the experiment. The phases of the experiment will be described next.

Figure 5

Outline of the procedure followed in Experiment 2



Note. B and D stands for phases with water impediment (signaled or unsignaled); A stands for phases without water impediment.

Phase B1: acquisition with restricted access to water. Rats were exposed to three different FT (35, 40 and 50 s) food schedules, according to their group. The objective of this phase was for rats to develop SID in different locations of the inter-food interval. To achieve this, access to water was impeded for the first 5, 10 or 20 s of the interval and then it was available for the remaining 30 s. Water availability was signaled with the lights above the valves. Thus, the schedules for each group were like this: FT35 was exposed to an FT 35 s with an initial 5 s impediment; FT40 to an FT 40 s with an initial 10 s impediment; and FT50 to an FT 50 s with an initial 20 s impediment. This phase lasted 30 sessions.

Phase A1: FT 30 s. All subjects were exposed to an FT 30 s of food pellet delivery, during which water was always available, and signaled in the same way as in B1. The objective of this phase was to verify if SID was displaced, according to the rats' previous experience, or occurred at the beginning of the interval in the absence of the impediment. This phase lasted 20 sessions.

Phase B2: reinstatement of restricted access to water. In the third phase, the conditions from phase B1 were replicated, and 10 sessions were conducted in exactly the same way.

Phase A2: FT 30 s. The conditions from phase A1 were replicated, and 10 sessions were run in the same way.

Phase B3: second reinstatement of restricted access to water. Ten sessions with identical conditions to B1 and B2 were conducted.

Phase D: unsignaled water availability. In this phase, the same conditions of water impediment from phases B were implemented, except that the lights above the valve remained off throughout the session. This phase lasted 10 sessions.

Data analysis

Only the data from subjects who met the criteria used in Experiment 1 (i.e., more than 100 clicks in the last five sessions of each phase) were analyzed. This excluded the following subjects from each group's graphs and analyses: S1, S5 and S8 from FT35; S1 from FT40 (just on phase B1 due to its lack of adjustment); and S1, S3 and S5 from FT50. The groups resulted in FT35 (n=5), FT40 (n=8), and FT50 (n=5). Data were analyzed in the same way as in Experiment 1, with some minor changes that will be detailed next.

When fitting the Gaussian curve (Equation 1) to calculate the peak and width of the distribution, different values were employed for t and σ in phases B and D, according to the interval duration, whereas for phases A the same values were used for all groups. Values were changed according to the interval duration. For group FT35, the starting values were A=1000, σ = 6 and t = 17, with lower bounds of 1, 0.12 and 0.35, and upper bounds of 10000, 12 and 35, respectively for each parameter. For group FT40, the starting values were A=1000, σ = 6,6 and t = 20, with lower bounds of 1, 0.13 and 0.4, and upper bounds of 10000, 13 and 40. Lastly, for FT50, the starting values were σ = 8,5 and t = 25, with lower bounds of 0.17 and 0.5, and upper bounds of 17 and 50. For phases A the starting value were σ = 5 and t = 15, with lower bounds

of 0.1 and 0.3, and upper bounds of 10 and 30. The function was fitted adequately to most 5-session blocks (mean R2 = 0.87, range 0.41-0.98; 90 cases out of 107 over 0.8; see https://osf.io/v73jz/ for cases in which it was not successfully fitted).

The QL was calculated in the same way as in Experiment 1. MMs were used to analyze if the dependent variables (QL, peak and width) were a function of the independent variables of the experiment, which were the group (FT35, FT40 and FT50), the delay (0, 5, 10 or 20 seconds), and the phase (1, 2, 3, 4, 5 or 6). Also, random intercepts for subjects were included. The best-fitting models are described in the Results section.

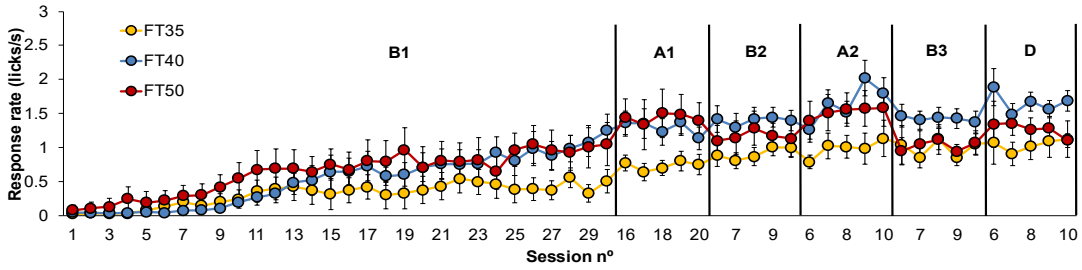
Results and Discussion

The goal of Experiment 2 was to determine whether restricting water access at the beginning of the inter-food intervals during the acquisition of SID could displace its temporal location. Furthermore, we examined whether this learned distribution would be maintained during a subsequent phase without water restriction. Three different restriction durations were employed to assess if SID could be acquired with an onset delayed from the preceding food delivery.

Changes in response rate for each group throughout the experiment are presented in Figure 6. Response rates of FT35 increased after B1 and A1, and then remained relatively stable for the rest of the phases; whereas FT40 and FT50 show rate increases from B1 to A1 and from B2 to A2, followed by a decrease in B3 and a slight increase in D. Overall, licking rates were higher in Phases A than in Phases B, suggesting similar levels of water consumption (i.e., the same number of licks delivered over shorter durations). This indicates that a higher reinforcement frequency (Phases A) resulted in an increase in licking proportional to the reduced interval length, compared to phases with lower reinforcement frequencies (Phases B and D), across all groups.

Figure 6

Mean (± SD) rate of licks (licks/second) by session and group throughout Experiment 2



Note. Changes between phases are illustrated with black vertical lines. Yellow circles indicate results for the 5-s restriction group (FT35), blue circles are used for the 10-s one (FT40), and red circles for the 20-s one (FT50). Phase names are presented at the top of each phase sessions' results. Note that for A1, B2, A2, B3 and D, only the last 5 sessions are shown. Black vertical lines indicate standard error (SD) of the mean.

Comparisons between groups showed that FT35, which had the highest reinforcement frequency (every 35 s), had the lowest licking rate during most phases; while FT40 was the group with the highest licking rate, but showing similar levels to FT50. During phases A, all groups had the shortest intervals of all and the highest levels of drinking, compared to previous phases, except for FT35, which stabilized for the last four phases. This could be due to response variability, since groups did not have many subjects, though certainly a negative relation between the interval length and drinking levels was expected, as reported in previous studies (e.g., Pellón & Castilla, 2000; Segal & Oden, 1969).

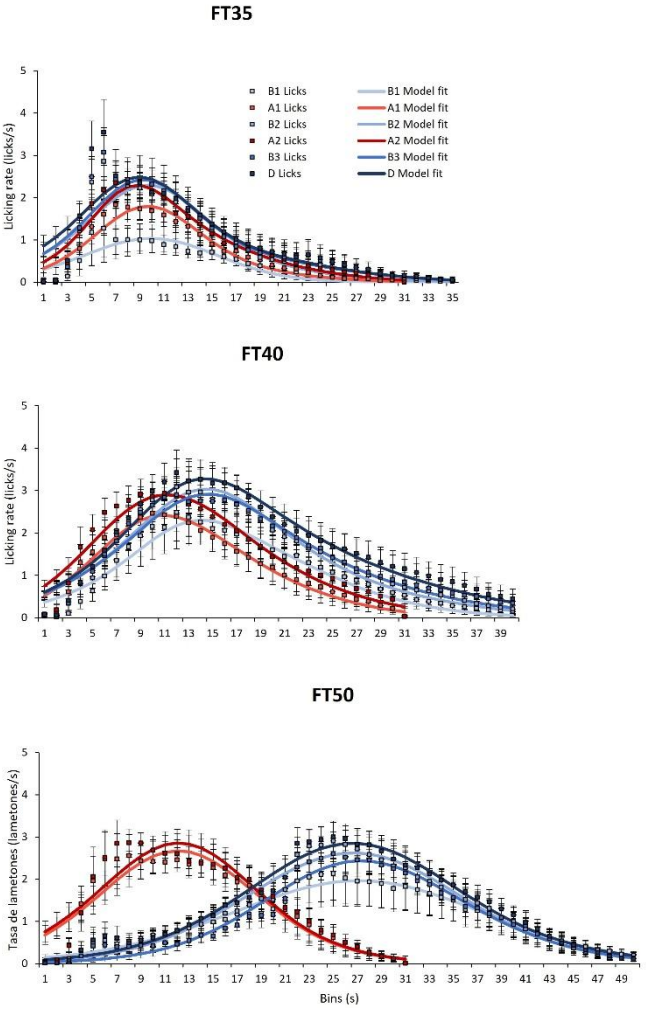
Mean distributions of licks and the mean fitted Gaussian curves by group are shown in Figure 7**.** All groups present a relatively good fit between the data and the corresponding model. The three groups displayed similar temporal distributions: licking occurred at the beginning of the interval during Phases A, characterized by an inverted U-shaped pattern. In contrast, licking was displaced to the right during Phases B and D,

exhibiting a scallop-like pattern of responding synchronized with water availability, particularly in the FT-35 group. Individual distributions showed some differences among subjects (see Figure A1), especially the pronounced licking scallop preceding water availability during B and D phases, which seemed to be maintained for some subjects during A phases, followed by an inverted-U shape licking distribution. These individual distributions also explain why sometimes the fitted curve in phases B and D may not correspond exactly to the mean group data.

Distributions for the FT35 group revealed almost no discernible temporal changes between phases. Distribution of responses, however, showed a sharp peak on phases B and D between seconds 5 and 7 (which does not always correspond to the curve for this group), right after water was made available. In phases A this peak happened during seconds 7 and 9, but it was part of the inverse-U shape. Distributions from group FT40 were displaced to the right in phases B and C, showing that SID occurred later in the interval than in phases A. The peak of drinking generally occurred between seconds 11 and 13 in phases B and D, and between 9 and 11 for phases A. This effect is even more pronounced for the FT50 group, that shows clearly differentiated distributions between phases A and phases B/D, as licking clearly occurred later in the interval when access to water was impeded in phases B and D. Maximum licking rate for FT occurred between seconds 22 and 25 in phases B and D, and seconds 6 and 9 in phases A. Interestingly, SID showed the same sharp peak during B and D phases (and sometimes during phases A, e.g., FT50-S8) for FT40 and FT50, as for FT35, although it was not as pronounced.

Figure 7

Distribution of licks and the fitted Gaussian curves throughout the inter-food intervals, for all phases of Experiment 2 and for each group independently



Note. Data from the three groups of Experiment 2 is shown. Top: FT35; middle: FT40; bottom: FT50. Blue symbols and lines regard the data from B and D phases; red is used for A phases. Colors are darker as phases advanced, using light for the first phases and dark for the last ones. Data are represented by squares and the fitted curve by a continuous line. Black vertical lines indicate standard error of the mean.

The results observed in phases B and D replicate previous studies (Ávila & Bruner, 1994; Daniel & King, 1975; Flory & O'Boyle, 1972; Gilbert, 1974; López-Crespo

et al., 2004). Rats developed SID despite water being inaccessible at the beginning of the inter-food intervals and continued to lick even if the moment of water availability changed, replicating the same distribution of licks in different parts of the interval. Additionally, its location within the interval changed, same as in López-Crespo et al. (2004), but the shape of the distribution varied during the sharp peak after water was made available in B and D phases.

Another relevant difference between this study and López-Crespo et al.'s (2004) is that in the current study licks before water availability were allowed and recorded (in López-Crespo et al. there was a door that closed the access to the waterspout when water was not available). One might expect rats to adequate their licking only to the moment of signaled water availability, in order to effectively obtain water. However, this is not what was observed here. Rats started licking from the beginning of the interval, increasing their response rate as water availability was approaching (in phases B and D), and concentrating its maximum drinking shortly after this moment had arrived, same as for López-Crespo et al., even though in their procedure rats could not lick until water was introduced. In this case, drinking resembled a goal-tracking behavior, as the first licks distributed similarly to an FI scallop (cf. Ferster & Skinner, 1957), particularly for the FT35 group. López-Crespo et al. (2004) conducted a final test with control rats that had previously experienced unrestricted water access. By restricting intake to the final 15 s and 30 s of FT 30-s and FT 90-s schedules, respectively, they obtained similar results: subjects drank only when water was available, with the peak of the distribution occurring just at the onset of water availability.

Figure 8 shows the mean quarter life, peak and width of the peak for all phases and groups. The quarter life shows clear differences among groups and phases, which were statistically significant (see Table A6). The best-fitting LMM for the quarter life includes delay, which was 0 s in phases A, and 5, 10, or 20 s, according to the group, as fixed factor and random intercepts for subjects (QL ~ Delay + (1 | Subject); $X^2_{(3)}$ =

196.280, p = 0.000). During phase A, all groups exhibited the same quarter life, occurring at 7.87 s. Introducing a 10-s delay (phases B and D in FT40) resulted in a significant shift of quarter life, which occurred 3.47 s later relative to phase A (t = 7.83, p = 0.001). A larger effect was observed with the 20-s delay (phases B and D in FT50), where quarter life occurred 12.20 s later than in phase A (t = 19.19, p = 0.001). In contrast, no significant changes in quarter life were observed for FT35 between phase A and phases B and D (estimate = 0.04 s, t = 0.07, p = 0.946), indicating comparable quarter life values under 0 s and 5 s delay conditions.

There were significant differences on the time of the peak among delays (for details, see Table A7). The LMM analysis for the peak suggested that it was a function of the delay, as the best-fitting model included delay (0, 5, 10 or 20 s) as fixed factor and random intercepts for subjects (Peak ~ Delay + (1 | Subject); $X^2_{(3)}$ = 206.190, p = 0.000). Under the no-delay condition (phase A), the peak of responding occurred at 11.61 s across all groups. Introducing a 10-s delay (phases B and D for FT40) resulted in a significant shift of the peak, which occurred 3.92 s later than the no-delay condition (t = 7.99, p = 0.001). A larger shift was observed with the 20-s delay (phases B and D for FT50), where the peak occurred 14.47 s later relative to no delay (t = 23.82, p < 0.001). In contrast, a 5-s delay (phases B and D for FT35) did not significantly alter peak time compared to no delay (estimate = −0.27 s, t = −0.44, p = 0.658). The inclusion of the delay variable allows a better understanding of the relationship between variables and the results obtained for the peak.

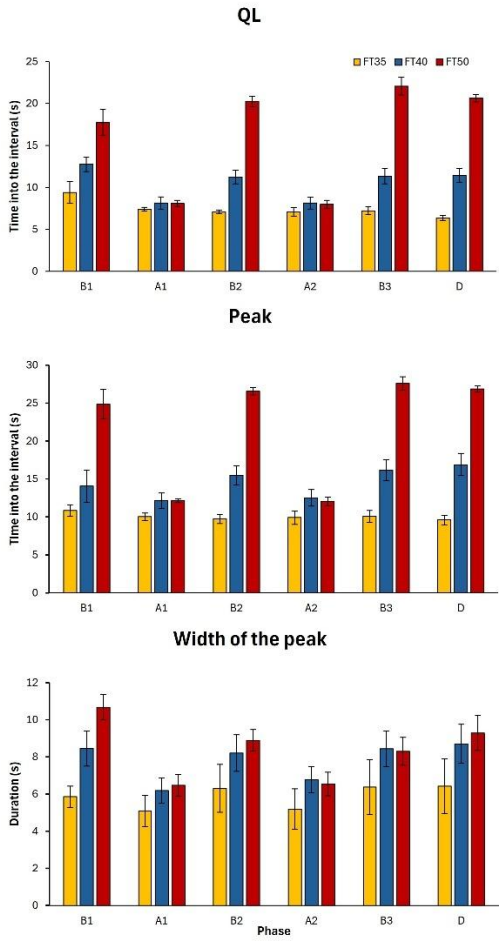
Lastly, the width of the peak changed significantly as well (see Table A8 for details). The LMM reveals that as for the other measures, the best-fitting model for the width of the peak included delay (0, 5, 10 or 20 s) as fixed factor and random intercept for subjects (Width ~ Delay + (1 | Subject); $X^2_{(3)}$ = 54.863, p = 0.000). Under the no-delay condition (phase A), peak width occurred at 6.12 s across all groups. Introducing a 5-s delay (phases B and D for FT35) resulted in a significant increase in peak width of 0.96 s relative to no delay (t = 2.22, p = 0.029). Larger increases were observed with

a 1- s delay (phases B and D for FT40), where peak width increased by 1.82 s ($t = 5.24$, $p = 0.001$), and with a 20 s delay (phases B and D for FT50), which produced the largest increase of 2.84 s compared to no delay ($t = 6.55$, $p = 0.001$). The clearest differences happen during B1, where FT35 had the least width (6 s), then FT40 (8 s), and FT50 had the most (11 s). The difference between FT40 and FT50 seems to dissipate in the rest of B and D phases. The significant increase in width for FT35 during B and D phases may be a result of the scallop of licking during these phases.

Data from the peak and width were derived from the fit of the Gaussian curves to ensure continuity with Experiment 1, however, they should be taken cautiously, as the distribution during phases B and D did not always follow an inverted-U shape. Moreover, the actual peak occurred earlier than the derived measure.

Figure 8

Mean QL (quarter life), time of the peak, and width of the peak, by group and phase of Experiment 2



Note. QL is represented in the upper row, the peak in the middle row, and width of the peak in the lower row. Groups are represented by different colors. Yellow corresponds to FT35, blue to FT40 and red to FT50. Results are shown by phase from left to right, from B1 (first phase) to D (last phase). Black vertical lines indicate standard error of the mean.

Overall, these results clearly show that SID was displaced to later parts of the inter-food intervals when access to water was impeded at their beginning during phases B and D for FT40 and FT50 groups. Furthermore, the displacement corresponded to the length of the impediment period, as FT50 showed a greater

displacement than FT40, and FT35 did not show a significant displacement of SID. This indicates that while some licks were recorded before water was made available, licking was mostly controlled by water availability (Ávila & Bruner, 1994; Daniel & King, 1975; Flory & O'Boyle, 1972; Gilbert, 1974; López-Crespo et al., 2004), rather than to the beginning of the inter-food interval or the delivery of the previous reinforcer.

Additionally, it is worth commenting that the light which signaled water availability might not have control over licking behavior, as distribution of licks was similar when the light was present (phases B) and when it was absent (phase D). Licking rates seemed to increase slightly when the signal was removed, but the distribution was similar to phases B in which it was present. A plausible explanation is that the feedback produced by licking the valve (i.e., the presence or absence of water) overshadowed the signal light (cf. Pavlov, 1927). In this case, the more salient sensory feedback from the licking response may have prevented the light from acquiring effective stimulus control. In other words, the feedback given by the valve when water was available and rats licked may have shown a greater contingency with water delivery, eliminating any possible control of the light over the licking response. The increase in licking may simply reflect a variation in the response rate due to extended exposure to experimental conditions similar to those in B3; alternatively, it could be the result of anticipatory licking occurring prior to water availability.

General Discussion

The main goal of this study was to displace to latter parts the normal moment of occurrence of SID at the beginning of inter-reinforcement intervals, and to test whether the resisting evidence of the temporal location of licking proportional to inter-food interval length can be disproved. In the first experiment, this was done by introducing during the initial seconds of the inter-food intervals lick-contingent delays once SID had been established, using both unsignaled and signaled delays to facilitate the discrimination of these delays, although distributions remained the same. In the second

experiment, a procedure of water restriction in the first seconds of inter-food intervals was effectively used to displace the moment of occurrence of SID, proving that SID occurred when water was available, despite it being distant from the previous reinforcer.

Together, the results from these studies show that displacement of SID can be achieved under certain conditions but is highly dependent on whether water is available or not (licking hardly occurred when it did not resulted in water delivery, except for its anticipation – see below). The procedure employed in Experiment 1 resulted in a failure to displace SID, most likely due to subjects not being sensitive to the contingency between the licks and food delays, similarly to what Moran and Rudolph (1980) suggested. In contrast, the procedure employed in Experiment 2 accomplished the objective, showing that SID was displaced, but dependent on water availability (López-Crespo et al., 2004), as the displacement was not maintained when water impediment was removed.

Both experiments account for subjects drinking at the beginning of the water-availability time. In Experiment 1, subjects started licking at the beginning of the interval, even despite the contingent delays (likely because they did not discriminate them as associated with the food delays, even when they were signaled). In Experiment 2, they responded the most once water was available, but subjects from all groups started to lick before this period (as can be observed in the individual graphs of the Appendix). This could reflect an anticipation of water arrival, as well as operant responding anticipates the reinforcer's arrival. In this case, the value of water as a reinforcer could be more as a conditioned reinforcer than a primary one (López & Bruner, 2011; Ruiz et al., 2016, 2017), as rats were not deprived of it.

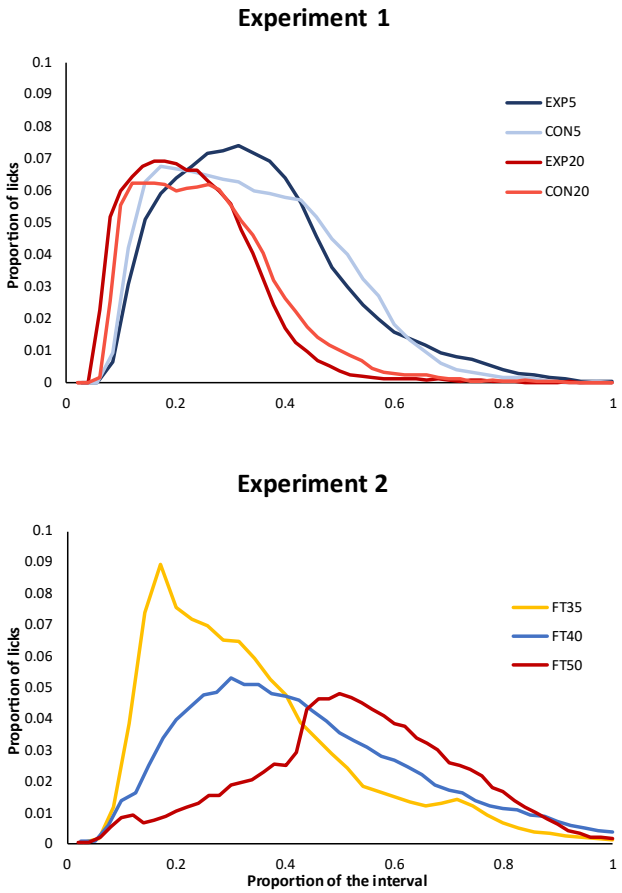
Results from this study expand previous findings about SID displacement (see Table A5) which did not report response distributions during inter-reinforcement intervals, permitting to observe how licking was organized. Nevertheless, the presence of SID in different moments than the first seconds of the inter-food intervals (due to its

impediment) is a common point between all of them and the present second experiment. Additionally, Flory and O'Boyle (1972) found that impeding drinking during the first quarter of a 1 min interval attenuated drinking the most, but in our Experiment 2, the group with the sorter delay (5 s, FT35) showed the least licking, even compared to FT50, which could not drink for the first 20 s.

The main reason to displace SID was to test the timing scalar property (Gibbon, 1977; Matell & Portugal, 2007), which has not apparently been observed on SID in the past (López-Tolsa & Pellón, 2021). In both experiments of the present study, distributions are clearly not overlaid (see Figure 9), which indicates the lack of scalarity in relation to the moment of food occurrence. In Experiment 1, displacement was not achieved, and as observed in previous studies with different inter-reinforcement interval lengths (López-Tolsa & Pellón, 2021), drinking seems to proportionally occupy more of the interval during the 5-s delay than during the 20-s delay (Figure 9, top graph, blue vs red lines; data taken from the phase with signaled delays). In Experiment 2, a non-typical post-reinforcement location proportional to the time added without the possibility of drinking was observed, suggesting sensitiveness to the contingencies, but scalarity was not in evidence (Figure 9, bottom graph; data taken from phase B2, as to compare with the results from Experiment 1 in the sense of being a second experience with delays and having an immediate previous phase without delays).

Figure 9

Proportion of the distribution of total licks as a function of the proportion of different inter-food interval lengths for data of all groups from Experiments 1 and 2



Note. Top panel: results from Experiment 1, SD phase. Dark blue and light blue lines represent Groups EXP5 and CON5, respectively; dark red and light red lines represent Groups EXP20 and CON20, respectively. Bottom panel: results from Experiment 2, Phase B2. Yellow, blue, and red lines indicate the 5-s, 10-s, and 20-s restriction conditions, respectively.

Regarding the notion of scalarity, the observation that licking was organized around water availability suggests that water may have functioned as a conditioned reinforcer. This finding indicates that responding tends to concentrate at a maximum near water occurrence, consistent with the scalar property of timing where the peak and spread of the distribution scale proportionally with its time location. In most operant

responding experiments, the reinforcer ceases the target operant behavior that is being measured (e.g. lever pressing stops when the food pellet is delivered; see López-Tolsa & Pellón, 2025). It could then be discussed whether scalarity responds to a tendency of occurrence of a behavior within the interval at the time of reinforcement, or rather to responding being reinforced in a specific moment. One possible approach to test this would be to evaluate if a learned operant response in an intermittent schedule maintains scalarity if a delay is added between its occurrence and reinforcer delivery, similar to what it is supposed to be occurring with SID (cf. Killeen & Pellón, 2013).

Despite not observing the timing scalar property (but see above), these findings can be gathered as evidence of SID as an operant response (Clark, 1962; Killeen & Pellón, 2013; Pellón & Killeen, 2015). One of the main arguments against considering schedule-induced behaviors as operants is that they usually occur during the first part of the inter-reinforcement interval (Falk, 1966b, 1971; Staddon, 1977; Staddon & Simmelhag, 1971). However, data from this study highlights that, although SID normally occurs at the beginning of the interval, its occurrence and distribution depend on when water is available and on the delivery of the reinforcer at the end of the interval (Killeen & Pellón, 2013), as it occurred even when there was a delay between the delivery of the previous reinforcer and the availability of water.

The marking effect, observed as an increase in responding when a neutral stimulus (a tone here) was made contingent upon licking, is a feature which has been demonstrated both in operant (Azzi et al., 1964; D'Amato et al., 1968; Lieberman et al., 1979; Williams et al., 1990) and induced behaviors (Killeen & Pellón, 2013; Moran & Rudolph, 1980; Patterson & Boakes, 2012). Also, subjects from group EXP20 (Experiment 1), which experienced longer lick-food intervals, had a lower licking rate than subjects in EXP5 group (Experiment 1), revealing a suppression of SID due to the longer delay between licking and reinforcer delivery, indicating again that SID is sensitive to its consequences in terms of food delivery (e.g., Álvarez et al., 2016; Pellón & Castilla, 2000). Therefore, the marking effect observed here could be evidence of

operant conditioning through the neutral stimulus signaling responding occurrence that would support delayed reinforcement (Killeen & Pellón, 2013), or alternatively acting as a conditioned reinforcer (Molines, 2025).

The similar (albeit displaced) type of distributions observed among groups and phases in Experiment 2, despite the duration of the initial water restriction, could reflect the action of delayed reinforcement (Killeen & Pellón, 2013). Since the period of water availability was always 30 seconds, the reinforcer (food) would have the same retrospective effect over drinking in all groups (especially when comparing FT40 and FT50 groups). Also, SID displacement may reflect a reinforcing effect of water availability on licking, which is subsequently reinforced by food delivery. This pattern, evident in the distributions showing a peak in licking shortly after water became available, parallels operant findings: for example, Farmer and Schoenfeld (1966a, 1966b) demonstrated that introducing a neutral stimulus altered the distribution of pigeons' key pecking. A similar mechanism could underlie the displacement of SID, since both operant and induced responses appear sensitive to environmental manipulations. Replicating such effects with a neutral stimulus might offer a more symmetrical comparison, and the absence of scalarity in relation to reinforcer occurrence in these results does not preclude considering SID as an operant behavior.

The fact that rats licked before water was available may support SID being part of a behavioral pattern (Killeen, 2023; Molines, 2025; Ruiz et al., 2016), suggesting some form of learning not only tied to the primary reinforcer (food) but also to the conditioned value of water. The sharp peak during B and D phases for FT35 and some FT40 and FT50 subjects could reflect this, and perhaps the most pronounced effect on FT35 rats is due to their closer proximity to previous food delivery that facilitated its induction. It could be argued that pellet consumption reinforces magazine visits, magazine visits reinforce licking when water is available, and licking when water is available reinforces licking when water is not available. The key then would not be

contingency, but proximity between behavior and reinforcers (Killeen, 2023; Killeen & Pellón, 2013; López-Tolsa & Pellón, 2025; Molines, 2025; Skinner, 1948).

What can be called a “molecular induction explanation” (Cowie et al., 2011, 2017; López-Tolsa, 2019; López-Tolsa & Pellón, 2021, 2025) can also be valid for the results of the experiments here. In Experiment 1, the pellet consumption would be inducing SID, explaining its occurrence at the beginning of the inter-food interval, as seen for the QL and peak measures. The tone in SD could be acting as a discriminative stimulus for licking, further enhancing its occurrence due to the pairing with the inducer stimulus (the pellet consumption). This would explain the increase in the experimental subjects’ licking rate during this phase, compared to UD or BL2. In Experiment 2, pellet consumption would also induce licking, as subjects started licking even before water was available in B and D phases. Finally, the light added when water was available, as seen, did not have any effect, probably due to an overshadowing effect.

A “molar view of induction” (Baum, 2012, 2018) seems less consistent with the present findings, since behaviors are learned through the covariation between phylogenetically important events and those behaviors, a process described by the matching law. A reduction in the covariation between food delivery and licking, therefore, should also reduce licking, which was not the case in either of the present experiments. In fact, Experiment 1 showed increased response rates despite longer lick-food delays, directly contradicting the theory. Similarly, in Experiment 2, FT40 and FT50 produced higher response rates than FT35, with rates increasing as inter-food intervals lengthened. In general, this molar account of induction is focused at describing steady-state behavior but is silent on local data as the ones reported here, because it does not account for the temporal location of behavior and how it can be altered or shifted by environmental contingencies.

To conclude, both experiments accounted for similarities between induced and operant behavior. The increase of a response due to its marking with a neutral stimulus

and the displacement of a learned response due to experimental conditions are clearly shared effects between SID and typical operant responses. A delayed reinforcement mechanism seems the most parsimonious account for the present results, as well as a chained account of behavior (Killeen & Pellón, 2013; Molines, 2025). Molecular induction may be a valid complementary mechanism, since it may give account of the persistent location of SID at the beginning of inter-reinforcement intervals (López-Tolsa & Pellón, 2025). Further studies of induced behaviors with delayed reinforcement are needed to complement the present findings in evaluating how the timing of responses and reinforcers interact.

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CRediT authorship contribution statement

ÁM: Data curation, formal analysis, investigation, software, visualization, writing – original draft. **GELT:** methodology, project administration, supervision, writing – review and editing. **SR:** supervision, writing – review and editing. **MP:** investigation, writing –

review and editing. **RP:** conceptualization, methodology, project administration, supervision, writing – review and editing.

Declaration of competing interests

None to declare.

Appendix

Table A1

Lick-contingent food delay procedures used in the literature to study their effects on schedule-induced drinking (SID)

Authors	FT	Delay duration	Signal	Results
Falk (1964, cited in Segal and Oden, 1969)	VI 1-min bar-press	15 s	No	No reduction/suppression of SID.
Segal and Oden (1969)	1-min	30/60 s	No	Lower acquisition of SID if delays were contingent upon licking. Lower SID with larger delays.
Hawkins et al. (1972)	1-min	4 min	No	No reduction of well-established SID. Long delays could prevent the development of SID.
Flory and Lickfett (1974)	1-min	No / 10-80 s	Lever retraction	Resistance to punishment once SID was established.
Moran and Rudolph (1980)	1-min	Up to 4 min	No / light / tone	Longer delays negatively affected SID development. Tone and light enhanced SID.
Pellón and Blackman (1987)	1-min	10 s	No / blackout	Larger reductions of established SID when delay were signaled than unsignaled.
Pellón and Blackman (1991)	1-min	10 s	No / blackout	Signaled delays increased drinking at first, then ended up reducing the final development of SID the same as unsignaled delays.

Authors	FT	Delay duration	Signal	Results
Lamas and Pellón (1995a)	1-min	2/50 s	No	Larger reduction of the development of SID with 50-s than 2-s delays.
Lamas and Pellón (1997)	1-min	10 s	No	Bodyweight affects SID, whose development was negatively affected by delays
Pellón and Castilla (2000)	18/60-s	3-18 s	Blackout	Punishment effect on established SID dependent on delay length.

Note. This table provides a summary of investigations to date using signaled or unsignaled lick-contingent food delay procedures. Studies are organized chronologically from top (oldest) to bottom (recent). The following characteristics are presented from left to right: author, fixed-time (FT) schedule, delay duration, presence and/or type of signal, and main results.

Table A2

Data of the estimated model fitted to the data of the QL

	Estimate	Std. Error	df	t value	Pr(> |t|)
(Intercept)	8.99	0.43	48.83	20.76	< .001***
Phase2	-1.26	0.38	78.00	-3.31	.001 **
Phase3	-0.35	0.38	78.00	-0.93	.355
Phase4	-1.14	0.38	78.00	-2.99	.004 **

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

***p< .005. ***p* < .001.

Table A3

Data of the estimated model fitted to the data of the moment of the peak

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	10.23	0.48	43.11	21.46	< .001***
Phase2	0.49	0.38	78.00	1.31	.194
Phase3	-0.14	0.38	78.00	-0.38	.707
Phase4	0.99	0.38	78.00	2.64	.010 *

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

**p< .05. ***p* < .001.

Table A4

Data of the estimated model fitted to the data of the width of the peak

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	4.05	0.28	48.79	14.39	< .001***
Phase2	0.24	0.25	78.00	0.96	.341
Phase3	-0.05	0.25	78.00	-0.20	.845
Phase4	1.19	0.25	78.00	4.79	< .001***

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

****p* < .001.

Table A5

Schedule-induced drinking (SID) displacement studies

Authors	N	Method	Results
Ávila and Bruner (1994)	3	FI 128 s; 16 s placement of water probe.	Drink increased when water probe moved forward
Daniel and King (1975)	12	FT 65 s. Water available only 20 s in one segment per group (3 groups).	SID developed equally in all segments
Flory and O'Boyle (1972)	3	FI 1 min. Water unavailable during ¼ periods of the interval.	Rats drank during all periods. Unavailability during first quarter attenuated drinking the most.
Gilbert (1974)	2	Water available last 30, then 10, s of a FI 1min in first procedure. Different periods (10-35) in second procedure. FI 60s and FI 210 s.	Ubiquity of SID in first and second procedures was found, except for one rat which stopped drinking under FI 210 s (first procedure).
López-Crespo et al. (2004)	38/ 31	First procedure: FT 30 with access to water in half of the interval, control with free water access. Second procedure: FT 90 s, experimental groups with water access during 1/3 of the interval, control with free access.	SID developed in different parts of the interval, both in FT 30 s and FT 90 s. Excessiveness, U-shaped distributions and persistence were found. Displacement of the peak when temporal distance from previous pellet increases.

Note. This table summarizes experiments that restricted or prevented water access during specific periods of the inter-reinforcement interval. Studies are organized chronologically from top (oldest) to bottom (recent). The following characteristics are presented from left to right: author, number of subjects (N), method, and main results.

Table A6

Data of the estimated model fitted to the data of the QL

	Estimate	Std. Error	df	t value	Pr(> |t|)
(Intercept)	7.87	0.41	29.87	19.19	< .001***
10 s delay	3.47	0.44	102.16	7.83	< .001***
20 s delay	12.20	0.54	102.81	22.51	< .001***
5 s delay	0.04	0.54	102.81	0.07	.946

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

****p* < .001.

Table A7

Data of the estimated model fitted to the data of the moment of the peak

	Estimate	Std. Error	df	t value	Pr(> |t|)
(Intercept)	11.61	0.59	22.16	19.73	< .001***
10 s delay	3.92	0.49	97.38	7.99	< .001***
20 s delay	14.47	0.61	100.19	23.82	< .001***
5 s delay	-0.27	0.61	100.19	-0.44	.658

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

****p* < .001.

Table A8

Data of the estimated model fitted to the data of the width of the peak

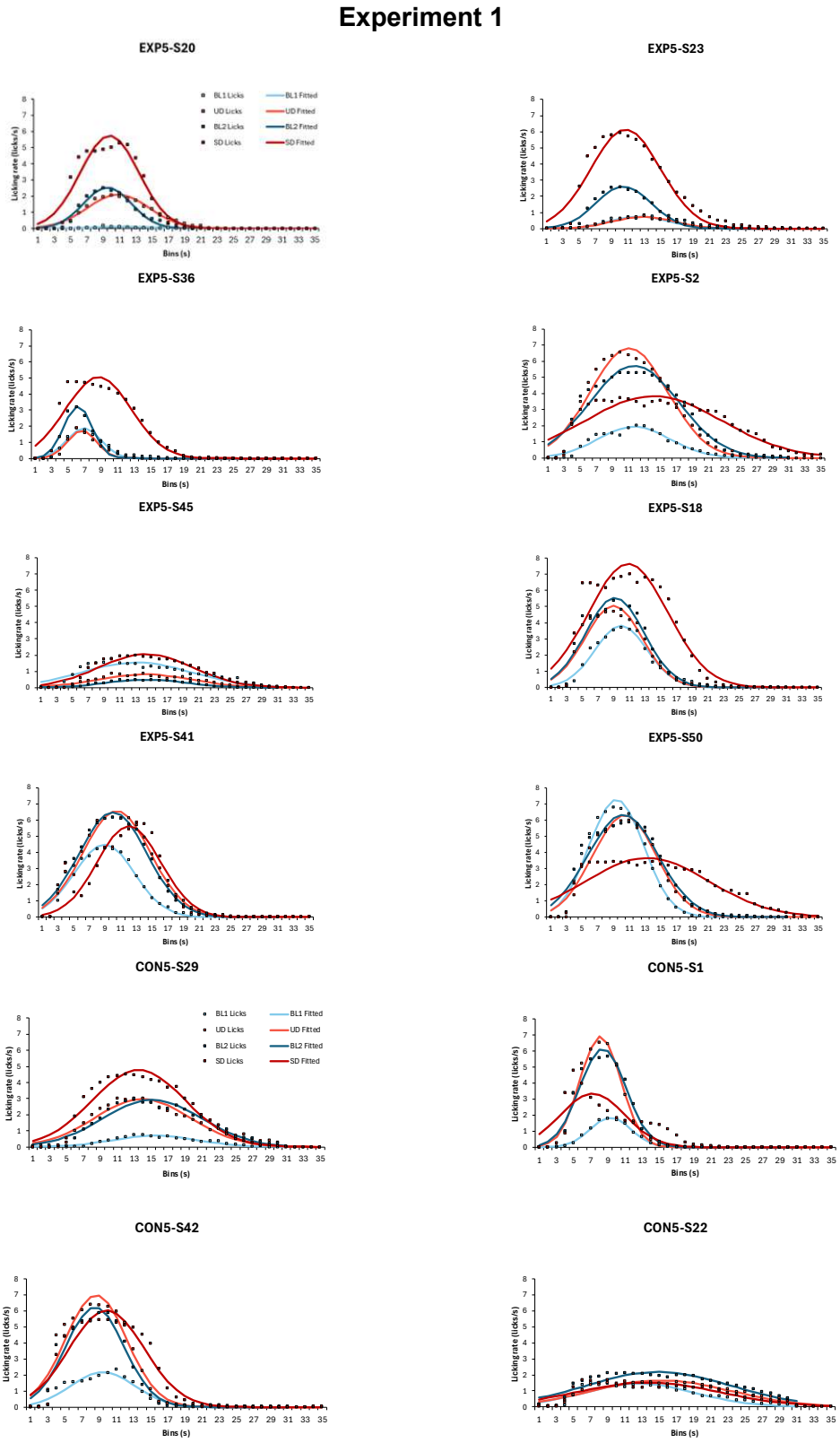
	Estimate	Std. Error	df	t value	Pr(> |t|)
(Intercept)	6.12	0.50	20.52	12.16	< .001***
10 s delay	1.82	0.35	94.38	5.24	< .001***
20 s delay	2.84	0.43	96.72	6.55	< .001***
5 s delay	0.96	0.43	96.72	2.22	.029*

Note. Columns from left to right indicate the estimate, standard error, degrees of freedom, t-value, and significance level. All data are presented in seconds.

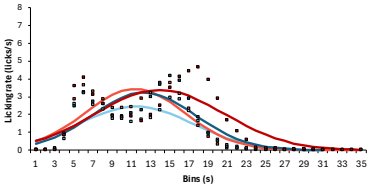
**p<.05; ***p* < .001.

Figure A1

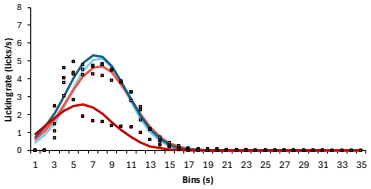
Temporal distributions of licking for each individual rat of Experiments 1 and 2



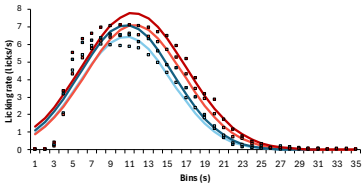
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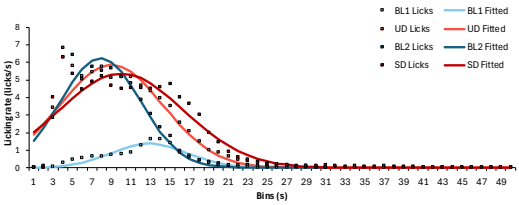
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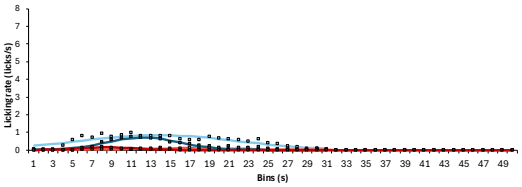
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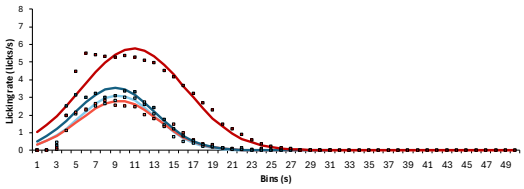
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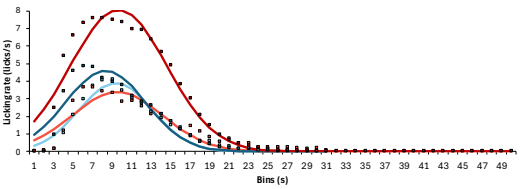
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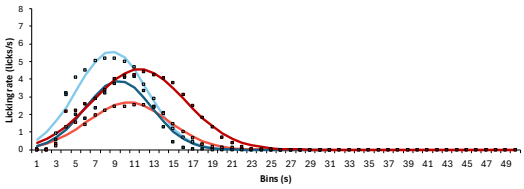
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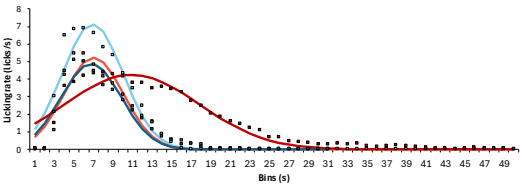
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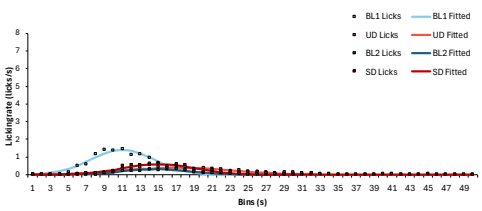
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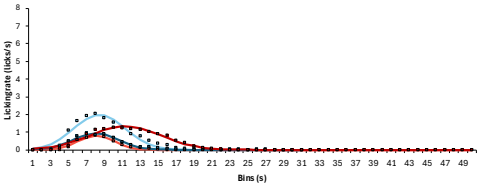
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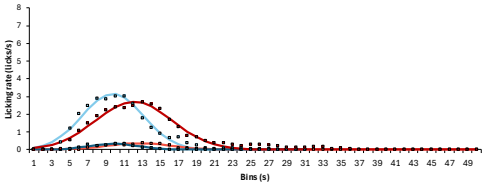
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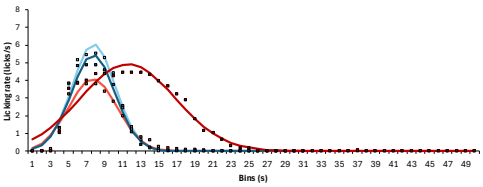
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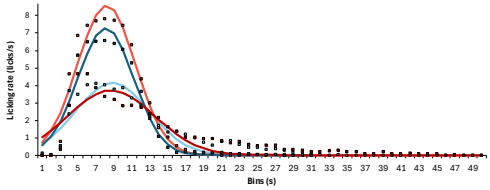
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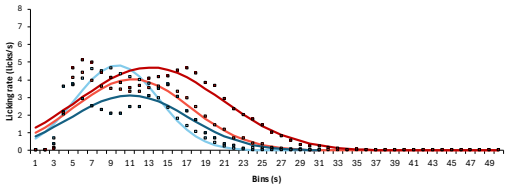
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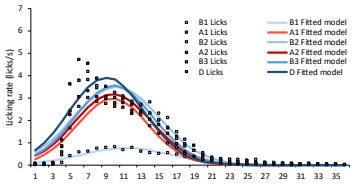


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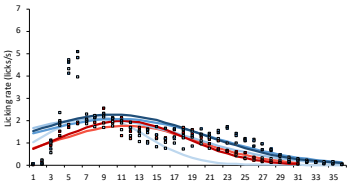


Experiment 2

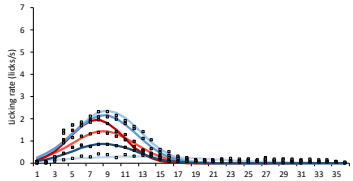
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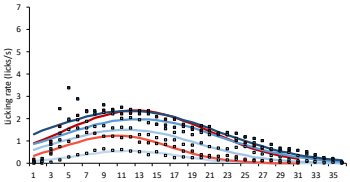
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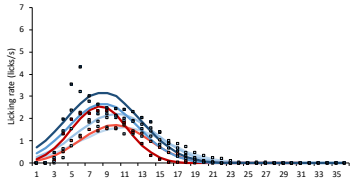
FT35-S4



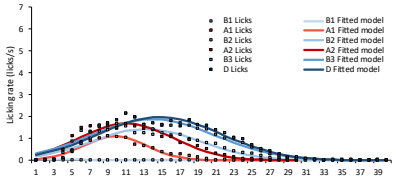
FT35-S6



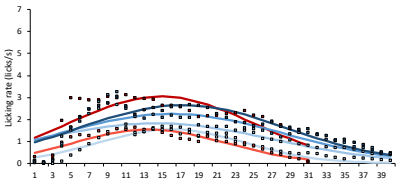
FT35-S7



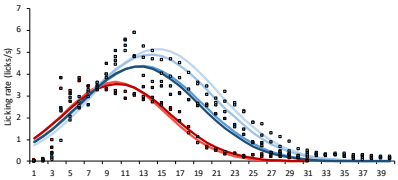
FT40-S1



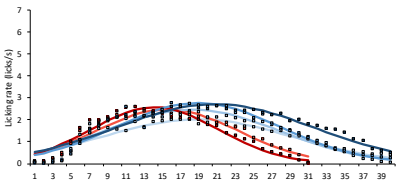
FT40-S2



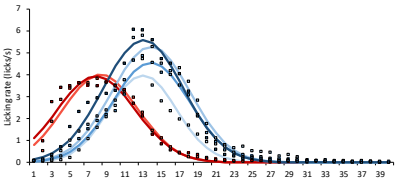
FT40-S3



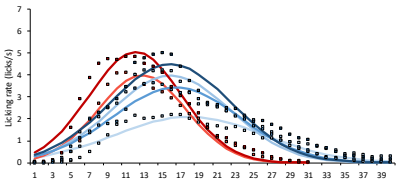
FT40-S4



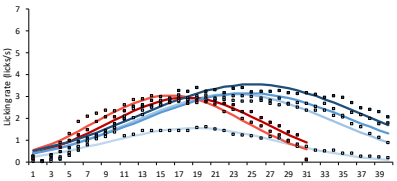
FT40-S5



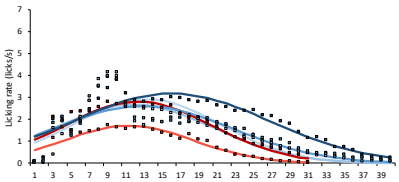
FT40-S6



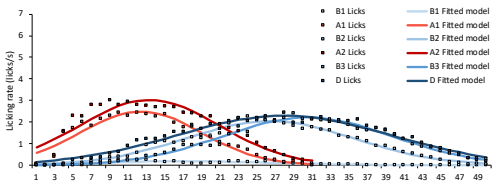
FT40-S7



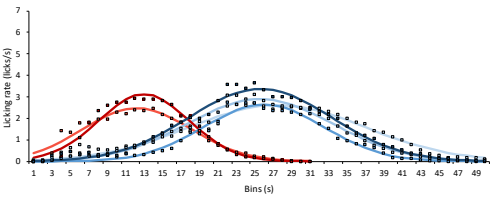
FT40-S8



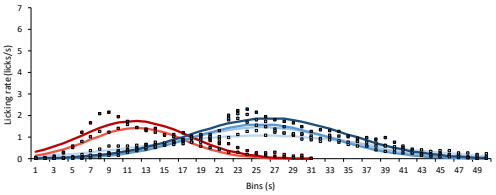
FT50-S2



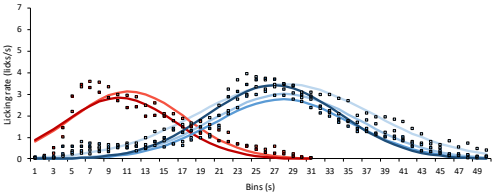
FT50-S4

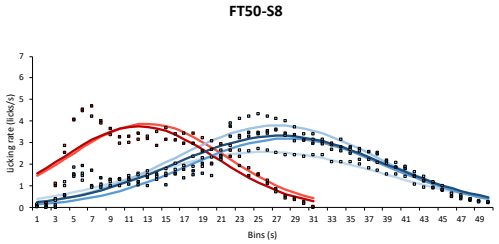


FT50-S6



FT50-S7





Note. Individual licking distributions are shown in the following order; Experiment 1: EXP5, CON5, EXP20, CON20; Experiment 2: FT35, FT40, FT50.

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