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EVALUATING THE SCALAR PROPERTY OF

SCHEDULE-INDUCED DRINKING

EVALUANDO LA PROPIEDAD ESCALAR DE
LA BEBIDA INDUCIDA POR PROGRAMA

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Index

Abstract

The role of schedule-induced behaviors (also known as adjunctive) in temporal estimation tasks is yet to be fully understood. Current theories suggest there may be two processes responsible for the development of behavioral patterns displayed by organisms and quantitative timing measures within an interreinforcement interval (IRI): induction and response-reinforcer proximity. Previous studies on the issue have failed to demonstrate the scalar property in schedule-induced behaviors, arguing that its absence was due to the lack of an explicit response-reinforcer contingency. To test this hypothesis, a conjunctive schedule of food reinforcement was arranged so that the development of schedule-induced drinking (SID) occurred under stricter control than mere contiguity. Rats were divided into three groups, depending on the value of the fixed-time (FT) schedule used; and all were exposed to a conjunctive FT (15-, 30- or 60-s) fixed-ratio 10 schedule. Preliminary results show that the scalar property is not properly manifested; however, a more comprehensive data analysis on timing measures such as time of transition and last lick do point to a certain scalarity of induced behaviors. Perhaps key to these results are the high variability encountered in FT-60 group, which allows for more proper inter-group comparisons that do show scalarity of SID in terms of duration but not rate. Theoretical implications of these results are discussed.

Keywords: schedule-induced behaviors, timing, scalar property, induction, reinforcement

Introduction

Schedule induction refers to the process of behavior being developed during inter-reinforcement intervals without an explicit arranged contingency between its occurrence and the delivery of reinforcement but only by the repeated occurrence of intermittent scheduled reinforcers (Pellón et al., 2020). Schedule-induced behaviors (SIBs) were formerly known as adjunctive behaviors, however, this term suggests that the behavior is dependent of the operant, so some authors (López-Tolsa, 2019; López-Tolsa & Pellón, 2021) advocate to use the term SIBs insomuch as it appeals to the intermittency of the reinforcement schedule as its cause. Some common characteristics (Álvarez et al., 2016; López-Tolsa, 2019; Pellón et al., 2020) present in SIBs are: (a) they appear to be strongly determined by the degree of deprivation of the reinforcer intermittently scheduled for delivery and its frequency; (b) they are dependent on the quality, magnitude, and delay of the reinforcer (c) they show a regular and excessive pattern compared to baseline levels; (d) they usually take place immediately after the delivery of the reinforcer; (e) they develop within intermittent schedules, with or without a response requirement of another behavior; (f) they develop and can be substituted by other schedule-induced behaviors depending on the conditions of the experiment; (g) there would be an optimal ratio between the length of the interval and the amount of reinforcement that would favor the development of each of them.

Following Falk's original discovery in 1961 of the phenomenon of induced polydipsia (Falk, 1961), he suggested, after further research, that schedule-induced behaviors occur when a consummatory activity is interrupted in a highly motivated animal, after which motivational explanatory theories emerged such as Staddon's (Staddon & Simmelhag, 1971; 1977), Falk and Kupfer's (1998) or Palya' (1993). Staddon suggested a three-fold division among adjunctive behaviors: *interim*, that would be schedule-induced and occur under an intermediate motivational state where the probability of reinforcement is low, *facultative*, which would not be schedule-induced because their expression is independent of the reinforcer schedule and would occur around the middle of the interval and *terminal*, that would occur towards the end of the interval when the reinforcer is closest and induces some sort of consummatory behavior (Staddon & Simmelhag, 1971; Staddon, 1977). Falk and Kupfer (1998) proposed a motivational conflict between opposite behavioral tendencies of an instrumental type, in which schedule-induced behaviors occur when the balance

between consummatory behavior (i.e., that which accesses the reinforcer) and escape behavior is in equilibrium. This model, while adequately explaining the bitonic relationship that shows the amount of schedule-induced behavior with the frequency of reinforcement, being high at intermediate values and lower when the frequency is small or very large, failed to solve some problems such as the temporal location of the schedule-induced behaviors, their occurrence in situations of high probability or constant reinforcement, nor does it explain the behavioral mechanisms responsible for their acquisition and maintenance (Pellón, 2004). Payla, for example, did explicitly defend the theory that adjunctive behaviors served as an effective means of escape from aversive periods inherent to intermittent reinforcement schedules, which explains why they normally occur at the beginning of the interval, farther away from the reinforcer, thus postulating a mechanism based on negative reinforcement, although this did not explain the absence of adjunctive behavior in low reinforcement frequency schedules. Lucas et al. (1988) considered schedule-induced behaviors as embedded in species-specific behavioral systems that are elicited by periodic delivery of the reinforcer; these organized adaptive behavioral sequences would also be related with the type of reinforcer.

There currently coexist two mainstream hypotheses on the origin and maintenance of schedule-induced behaviors. On the one hand, Killeen and Pellón (2013) conceptualize adjunctive behaviors as part of the operant class, strengthened and maintained by the delivery of the reinforcer. On the other hand, Baum (2012; 2018) proposes three laws of behavior: induction by *Phylogenetically-Important Events* (PIEs), allocation and covariance as the explanatory processes for all types of behaviors, including schedule-induced. Baum's conception of induction eliminates the concept of the reinforcer as a behavior strengthener, comparing induction to the presentation of a discriminative stimulus; that is, it is not a one-to-one relationship, but rather the presence of the inducing event that induces through its occurrence increments in some activities and decrements in others, as they are distributed over time. This conception thus assumes contingencies in terms of covariance: with repetition, PIEs induce related behaviors and decrease unrelated ones. Likewise, this model assumes that behaviors, both adjunctive and operant, compete hierarchically for distribution in the interval between reinforcers while the matching law comes to operation as the response rate and reinforcement rate tend to equal. It is thus a molar view of behavior where all situations involve choices between the performance of various behaviors –as opposed to one-to-

one relations and contiguity between discrete events– that end up determining their distribution in a particular situation, a view that opposes the molecular approach to behavior of discrete responses that are acquired by being strengthened by an immediate reinforcer (López-Tolsa, 2019).

The theoretical interpretation made by Killeen and Pellón (2013) on the reinforcement of schedule-induced behaviors is based on the model of competitive traces that they developed, which establishes that there are classes of behaviors, either adjunctive or operant, with different temporal windows in which they can be reinforced according to different exponential traces of proximity to the reinforcer. This gradient of delay of the differential reinforcer for each response will determine its order of distribution along the interval through competition (Pellón & Killeen, 2015), and several behaviors can consequently be maintained by the same reinforcer (López-Tolsa, 2019; López-Tolsa & Pellón, 2021; Ruiz et al., 2016). This conception would be similar in this sense to Baum's proposal on the hierarchization and competition of behaviors distributed in the interval and would come to articulate different molecular processes in a more complex interaction system than that of mere discrete behaviors maintained by a reinforcer. Killen and Pellón (2013) thus propose an analysis based on response-reinforcer proximity to explain the emergent behavioral patterns of animals, which include both operant and adjunctive responses, rather than an analysis based on contingency, thus extending the Skinnerian argument on contiguity to proximity (Skinner, 1948). At the same time, the division drawn by Staddon between adjunctive and operant responses would be without any basis in fact, arguing that there are many kinds of behavior but that they are all subject to the same set of principles, albeit with different parameters, which constitutes a more parsimonious argument (Killeen & Pellón, 2013)

López-Tolsa and Pellón (2019; López-Tolsa & Pellón, 2021) have recently posed a conciliatory hypothesis between these two theoretical models, arguing that the study of adjunctive behaviors presents an opportunity to determine the influence of induction and reinforcement to find out whether they constitute similar, different, contradictory, or complementary mechanisms. Thus, in such a proposal, behavior would be modulated by processes of induction and reinforcement: a reinforcer also may act as a discriminative stimulus of "future" presentation.

The scalar property

The scalar property assumes that behavior will express in a linear, proportionate manner across different interval lengths (Ferrara et al., 1997) . Different theories have been proposed to explain the temporal properties of behavior in this regard. For example, Gibbon's scalar expectancy theory (SET), that assumes an internal clock, proposes that the subjective time produced by the underlying timing mechanisms of organisms display two properties (Ferrara et al., 1997): *mean accuracy*, which is the requirement that average estimations of a real time "t" should equal "t" and the *scalar variance*, which sets the requirement for standard deviations of temporal estimations to increase as a constant fraction of the mean. In their behavioral theory of timing (BeT), Killeen and Fetterman (1988) observed the patterns of behaviors that are developed in interreinforcement intervals, interacting, and competing with one another, remaining semi-invariable once established (López-Tolsa & Pellón, 2021), suggesting that the ability of temporal estimation depends on a progression of SIBs that work as discriminative stimuli of the temporal moment in which they usually occur (behavioral clock). Machado et al. (2009) further deepened into BeT theory by proposing a mathematical model (Learning-to-time or LeT) that could explain and predict the learning process in an array of different timing procedures. This model assumes the activation of a series of behavioral states during conditioning trials, being each state paired with the operant response at different grades, depending on the temporal proximity to reinforcement. The overall rate of reinforcement would impact on the speed of activation across the states in such a way that their distribution along the interreinforcement intervals should show scalar property just as operants do.

It has been hypothesized that the opportunity to engage in schedule-induced behaviors could serve as a temporal control of behavior (Ruiz et al., 2016). For example, Ruíz et al. (2016) evaluated whether the opportunity to engage in schedule-induced drinking improves behavioral adaptation to temporal regularities, thus optimizing temporal learning in fixed-interval programs. In this type of experiments, measures such as the post-reinforcement pause (PRP; time elapsed from the beginning of the interval after the delivery of the reinforcer until the first lever press or contingent response) or the quarter-life (time of the interval in which the animal emits a quarter of the total lever presses or contingent responses) are considered to signal a better temporal adjustment the longer they are, as they would indicate that they start emitting the behavior later in the interval. This was precisely what they obtained in a first

experiment with rats with access to water compared to another group without access to water, suggesting that engaging in schedule-induced drinking allows rats to perform temporal tasks more accurately such as the aforementioned fixed-interval task. That is, since drinking water begins as a post-pellet behavior that tends to occupy most of the interreinforcement interval, its development constitutes a competitive opportunity in which the rate of lever-press response decreases early in the interval, generating a more schedule-adjusted behavioral pattern. In parallel, there is evidence that rats that do not have access to water develop other exploratory-type behaviors without immediate consequence, which has an impact on a slower learning of some specific pattern and may also delay the subsequent development of induced drinking (Ruiz et al., 2016).

However, there is no lack of questions about the true nature of this temporal learning, with Ruiz et al. (2016) suggesting that the induced behaviors appear to serve as effective strategies for better performance in estimation or temporal discrimination tasks that may be misperceived by researchers as organisms' abilities to use one psychological process or another, but it is what the organism does and the specific reinforcement contingencies that shape a given behavioral pattern over temporal intervals what actually matters (López-Tolsa & Pellón, 2021; Ruiz et al., 2016). In this sense, the role of reinforcement can be seen as an organizer of existing behavioral sequences, with behavior being localized within environmental constraints including time (López-Tolsa & Pellón, 2021; Pellón & Killeen, 2015). One should thus expect that schedule-induced drinking is not actually time-dependent in the sense of showing scalar property, but dependent on the length of the interval between reinforcement, with a rather fixed temporal localization immediately after the occurrence of the reinforcer, thus explaining the functional characteristics of induced drinking related to parameters about food rather than water (Ruiz et al., 2016).

López-Tolsa and Pellón (2021), delving deeper into this issue about the possible temporal estimation function of schedule-induced behaviors, also did not find temporal scalarity in these behaviors (contrary to Machado's hypothesis about behavioral states) despite having similar distributions, attending to quantitative measures such as the time of the peak or the last lick and unlike lever presses, which immediately preceded the delivery of the reinforcer. In this experiment, three FI food reinforcement programs were used (15 s, 30 s and 60 s) in six groups of rats (three with access to water and three without it). The rats with access to water developed SID followed by an increase in lever pressing rate. The data they obtained in this experiment indicate that, while

schedule-induced drinking appears to influence behavioral patterns that organisms develop during temporal tasks, their impact on quantitative measures of temporal estimation is dependent on the interval length. In view of these results, since the data showed that some behaviors fit and others do not fit the scalar property, a second process involved in addition to the induction for drinking was suggested, which would be the strength of modulation by reinforcement dependent on the proximity response-reinforcer. The authors proposed for future research the use of an explicit contingency between schedule-induced drinking and reinforcer that would exert greater control over the behavior and thus try to obtain scalarity, since otherwise there would be no reason for it to emerge, since induced drinking is not forced to occur at a given time. The present experiment aimed to test this hypothesis.

Method

Subjects

Subjects were initially 30 male Wistar rats that were 36 weeks old at the beginning of the experiment and with previous experimental experience as control subjects in an activity-based anorexia model procedure (i.e., they had only been food-restricted, but had no experience with conditioning chambers). Their weights were progressively reduced for ten days before the beginning of the experiment and maintained at 85-87% of their *ad-libitum* weight, with an initial average of 523 g (range: 446 – 592 g). The rats were randomly paired and housed in transparent Plexiglas cages measuring 18 x 32.5 x 20.5 cm in an environmentally-controlled room (22ºC and 55% relative humidity) with a 12-hr light-dark cycle (lights on at 8:00 a.m.). Water was always available in the home cages. 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 bioethics committee of UNED.

Apparatus

Ten Letica LI-836 conditioning chambers (then customized by Cibertec, S.A., Madrid, Spain) measuring 29 x 24.5 x 35.5 cm were used. The front panel of each chamber was made of aluminum, the left wall of transparent Plexiglas, and the remaining walls of black Plexiglas. The floor consisted of a 16-bar metal grid. In the

center of the front wall at a height of 3.7 cm above the floor was located the food tray, in which 45-mg sweet food pellets (sucrose-based, unflavored) were dispensed (Bio-Serv F0021, Frenchtown, NJ) by a Letica Instruments dispenser. In the right wall, there was a 3.2 x 3.9 cm aperture, situated 20 cm from the front panel and 7 cm above the floor, through which subjects could reach the spout of a water bottle mounted on the exterior of the chamber. The water bottle could be removed if necessary. The spout was placed 2 cm towards the interior of the aperture to allow for licks rather than continuous drinking. Contact between the subject's tongue and the metal spout completed the electric circuit between the floor and the spout that allowed the recording of licks. Chambers were enclosed in a soundproofed box equipped with a ventilation system and a small observation window in the left panel. A fan located in the soundproofed housing produced an ambient noise of approximately 60 dB in each chamber to mask any exterior noise. The houselight consisted of an indirect 25-W light mounted in the soundproofed housing. Chambers were controlled using a MED-PC application under a Windows environment.

Procedure

Subjects were randomly divided into three groups (n = 10) considering the value of the fixed-time (FT) schedule: 15, 30 and 60 s used in training.

The experiment was conducted daily (Monday to Sunday), one session per day, and consisted of two phases: pretraining and training. During pretraining, rats were exposed to three conditions. The first condition, a shaping procedure to train rats to lick the spout in order to obtain pellets, was informally monitored and pellets were delivered manually with MED-PC at every instance the rats approached and faced the spout. When rats began to approach the spout directly after pellet consumption, the second condition, a FR2 schedule, was put in place. In this condition, rats were given a pellet contingent to two licks. Finally, a FR5 schedule followed, maintaining the FT schedule assigned to each group across all the sessions. Each pretraining session lasted 60 trials, or a maximum time assigned to each group (30 minutes for the FT15 group, 60 minutes for the FT30 group and 120 minutes for the FT60 group). Subjects stayed in each condition until they completed 60 trials before the end of the session, which most subjects did in less than 4 sessions for FR2 and 1 session for FR5. Based on this criterion, two subjects (one from the FT15 group and another from the FT30 group) did

not complete this initial phase in 5 sessions and so were removed from the training phase. Consequently, the final experiment had a total of 28 subjects.

During the training phase, rats were exposed to a conjunctive FT (15-, 30-, or 60- s) FR 10 schedule. In such a compound schedule, reinforcement is only delivered after subjects complete both schedules –i.e., they meet the response ratio and time requirements in each trial. Each session lasted 60 trials (food to food intervals): approximately 15 min for the FT15, 30 min for the FT30, and 60 min for the FT60. However, the sessions could extend for a few minutes if the subjects would emit the 10 required responses beyond the set fixed time(s). The same temporal constraints were used as in pretraining to end the sessions. The houselight was turned off at the end of the sessions and data automatically saved. A total number of 30 training sessions per subject were conducted.

Data Analysis

Initial treatment of the data was carried out using the MedPCPy package on PyCharm (Maldonado et al., 2023). Licks and magazine entries were recorded, and response rates per minute and distribution of responses in 1 s bins were calculated. Other timing measures were obtained such as post-reinforcement pause (PRP), breakpoint, time of the last lick and duration of schedule-induced drinking, all of them as averaged by the last three sessions.

The post-reinforcement pause (PRP) is the time from the beginning of the trial to the first response, and it was calculated using an Excel Macro, with the constraint that if the PRP < .5 s, the second response was used to calculate the PRP to avoid using a residual response from the previous trial. Longer PRPs would indicate a better adjustment to the FT schedule.

The breakpoint (BP) is the time at which the response rate changes in an interval from a low response rate to a high response rate. It was calculated using an Excel Macro that ran the equation described by (Guilhardi & Church, 2004) in which the BP is the response time that maximizes the expression in the equation $BP = \max (d_1| r_1 - r | + d_2 |r_2 - r|)$, where d_1 is the duration before the breakpoint, d_2 is the duration after the breakpoint, r is the overall response rate of the trial, r_1 is the response rate during d_1, and r_2 is the response rate during d_2. To calculate the breakpoint, the trial had to have at least four responses (licks or magazine entries). The breakpoint of each session corresponds to the average values of d_1 (defined after the function was maximized)

across all intervals in that session. Breakpoints occurring later in the interval would indicate a better adjustment to the FT schedule.

Time of last lick was also calculated using Excel Macros. This measure refers to the average point in time within the interval where the rats emit their last lick before the reinforcer is delivered.

The duration of schedule-induced drinking was calculated by subtracting the time of the PRP to the time of the last lick by using the mean values obtained for each group.

The average peak time of licks and its width were obtained for each subject by fitting Gaussian distributions to individual data of the last 3 sessions to obtain more accurate quantitative estimations than using only visual inspection by using this equation:

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

where A operates parametrically by mapping Gaussian probabilities onto response rate, t measures time in seconds from the beginning of the interval, μ represents the peak time or mean of the distribution and σ is the standard deviation or width of the peak. The best fitting parameters were obtained by the least squares method using Microsoft Excel solver constrained to positive parameters only. For its part, the goodness of fitting was calculated using the coefficient of determination (R^2) (López-Tolsa, 2018).

Results

The aim of this study was to test for scalarity of SID by comparing the performance of rats on temporally proportionate FT schedules with an identical FR requirement (i.e., 10 licks) where an explicit response-reinforcer contingency was applied to SID. As Figure 1 shows, typical schedule-induced drinking patterns developed in each group (graphs show average data from the last three sessions), where a bitonic trend is observed approximately during the first half of the interreinforcement interval (IRI) – i.e., there is an immediate, sustained increase in licks following reinforcement delivery that reaches a peak after which a sustained decrease follows before next scheduled reinforcer. In parallel, magazine entries show an opposite trend where the highest rates coincide with the lowest rates of SID across the IRI – i.e., during

Figure 1

Mean distributions of licks and magazine entries by group
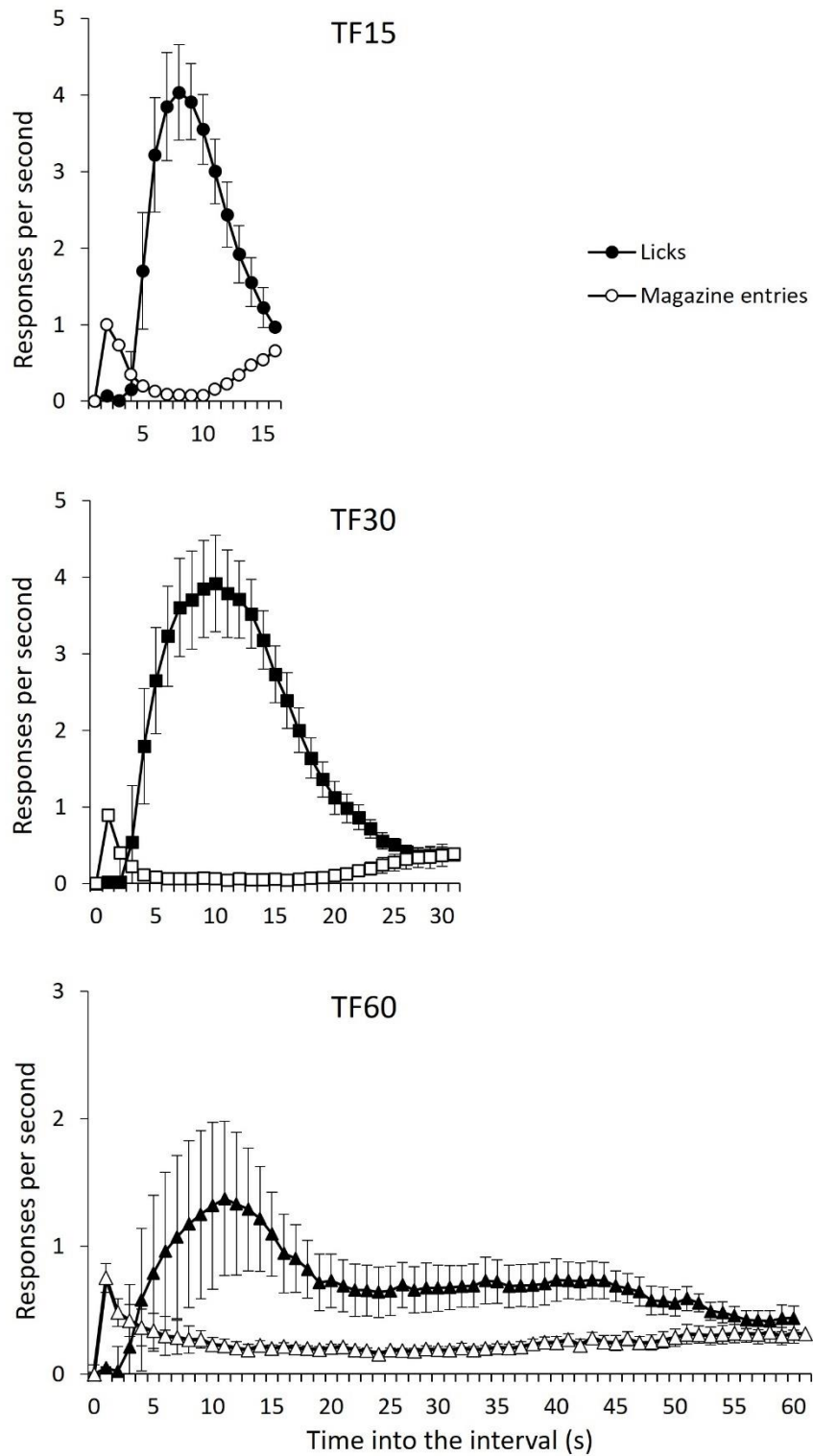
Note. Superposed distributions of spout-licking and mazagine entries mean rates in 1-s bins along interreinforcement intervals. Data are from the last three sessions of the experiment. Top panel: FT 15 s; middle panel: FT 30 s; lower panel: FT 60s. Vertical bars denote standard error of the mean. FT = fixed-time.

PRPs and immediately prior to reinforcement delivery. This typical pattern of SID is not however evident in the FT60 group, where SID does not show the expected decreasing trend following its peak nor does it reach zero level at any point across the interval, just as magazine entries.

In this regard, Figure 2 allows to observe a regrouping of the data from the FT60 subjects into three distinct subgroups according to the data displayed: post-pellet subgroup (subjects 3, 5 and 10), which does show the typical SID pattern just as the other FT groups; an intermediate drinking subgroup (subjects 1, 2 and 6), which does not show any clear pattern other than drinking distributed in the middle of the interval, and a post-pellet subgroup (subjects 4, 7, 8 and 9) which shows a typical operant trend of drinking preceding reinforcement with a parallel increase, albeit slighter, of magazine entries. A more thorough visual inspection of the data indicated that this parallel increase of magazine entries was only present for subjects 4 and 8. It is also worth noting the clear schedule-induced pattern of magazine entries in subjects 7 and 8 –and, to a lesser extent, subjects 4 and 9– (see Appendix I for individual graphs). Subjects in the intermediate drinking subgroup show both interesting and puzzling patterns: subject 1 shows a displaced peak of drinking but magazine entries do not follow, them appearing only at the beginning of the interval tracing a seemingly bitonic schedule-induced function, which would constitute two chained schedule-induced behaviors (see Lawler & Cohen, 1992) for previous findings); on its part, subject 2 spends most of the interval drinking, also showing a large bitonic curve. Lastly, subject 6 shows a seemingly weak, jagged schedule-induced drinking pattern while magazine entries slowly increase steadily all the way through (see Appendix I for individual graphs). Theoretical accounts of these differing results will be discussed later.

Figure 3 depicts the mean distribution of licks per group along with predicted Gaussian curves. Complementary data regarding mean peaks, standard deviations, or coefficients of determination for Gaussian estimations are included in Table 1. The mean peaks for all groups hover around the middle of each interval. Data conveys the inconsistency of the FT60 group as a whole showing substantially more width of the peak (14,69) than FT15 (3,18) and FT30 (5,72) groups and a lower R^2 value, in addition to an atypical maximum mean peak, close to the end if the interval, which is found in some subjects as it will be discussed later.

Figure 2

Mean distributions of licks and magazine entries by FT60-subgroups
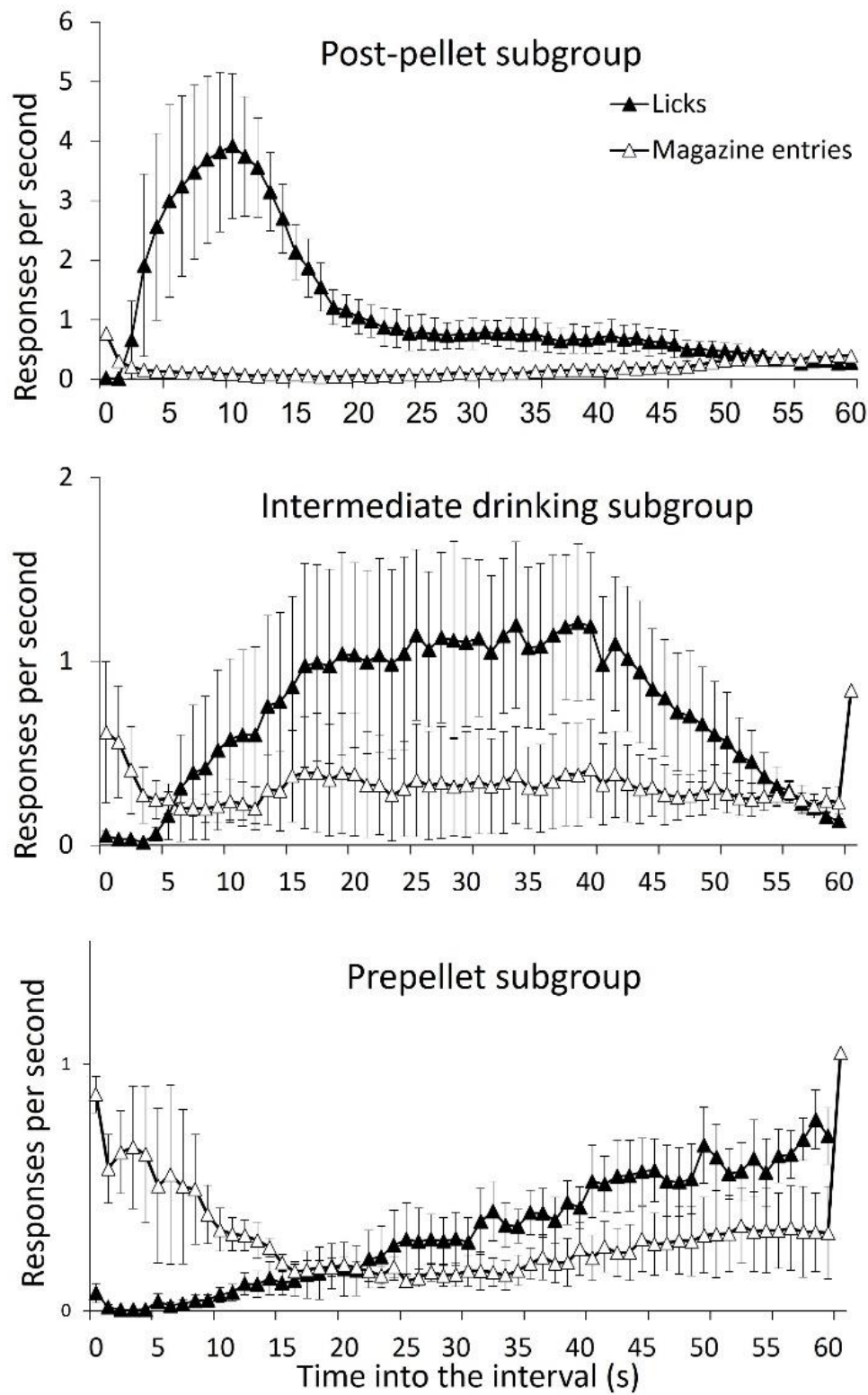
Note. Top panel: FT 60 s post-pellet subgroup; middle panel: FT 60 s intermediate drinking subgroup; lower panel: FT 60 s prepellet subgroup. See Figure 1 for complete notation.

Figure 3

Mean distributions of licks and Gaussian curves
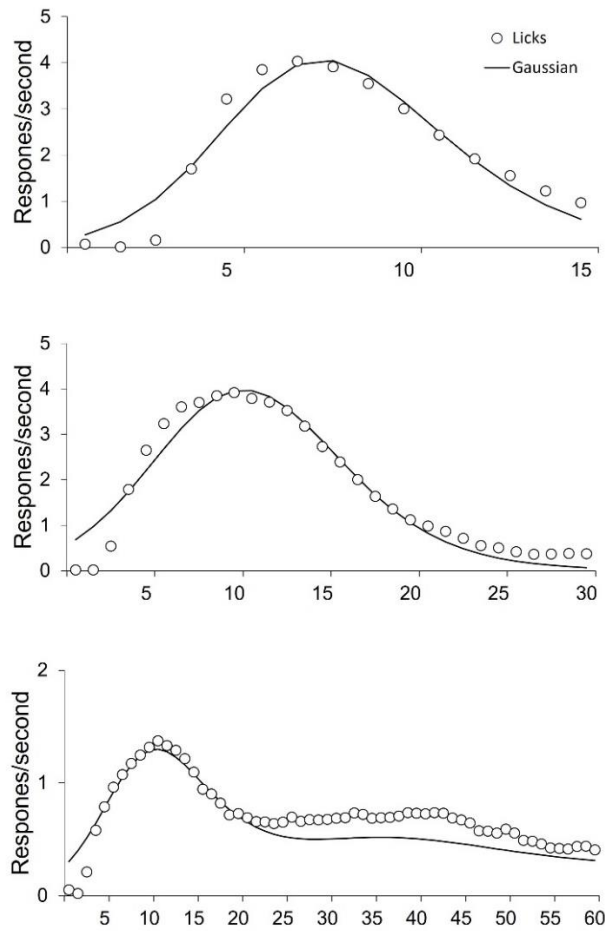
Note. Normalized distributions of spout-licking mean rates (white dots) in 1-s bins along interreinforcement intervals for FT 15 s (upper panel), FT 30 s (middle panel) and FT 60 s (lower panel) groups compared to the fitted curve. Data are from the last three sessions of the experiment. FT = fixed-time.

Table 1

*Mean peaks and widths per group based on Gaussian probability distributions for the last three sessions,*

Group	Minimum	Mean Peak	Maximum	Mean Width	R^2
FT15	6,65	8,57	10,25	3,18	0,90
FT30	8,55	12,04	17,65	5,72	0,88
FT60	9,20	32,72	56,82	13,37	0,86

Note. The FT60 group data for mean peak, mean width and R^2 does not include outlier subject (see Appendix II).

Scalarity of SID is not evident by looking at Figure 4 normalized distributions of the three groups, whose curves would overlap otherwise (see Machado et al., 2009). Magazine entries on the contrary display some scalarity at certain points (e.g., see FT15 and FT30 distributions from the middle to the end of the interval).

Figure 4

*Normalized distributions of licks (upper panel) and magazine entries (lower panel) by group*
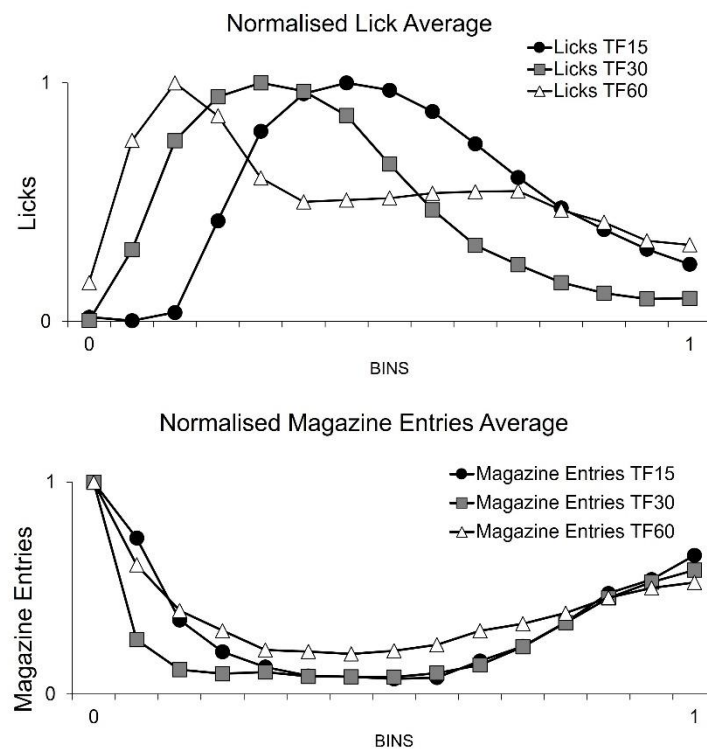
Note. Normalized distributions of spout-licking (upper panel) and mazagine entries (lower panel) mean rates in 1-s bins (FT15), 2-s bins (FT30) and 3-s bins (FT60) along interreinforcement intervals for each FT group. Data are from the last three sessions of the experiment. FT = fixed-time.

Other timing measures, nevertheless, do point to certain scalarity as shown by the trendlines (see Figure 5), such as breakpoints (bottom panel; FT15 = 9,52; FT30 = 19,35; FT60 = 41,55), and times of last lick (middle panel; FT15 = 13,56; FT30 = 24,77; FT60 = 59,19). Both data and visual inspection of the graphs indicate how these values for FT60 are approximately double of FT30 values, which in turn are close to double the values for FT15. This is not the case, however, for PRPs (top panel; FT15 =

Figure 5

Post-reinforcement Pauses (PRPs), Times of Last Lick and Breakpoints
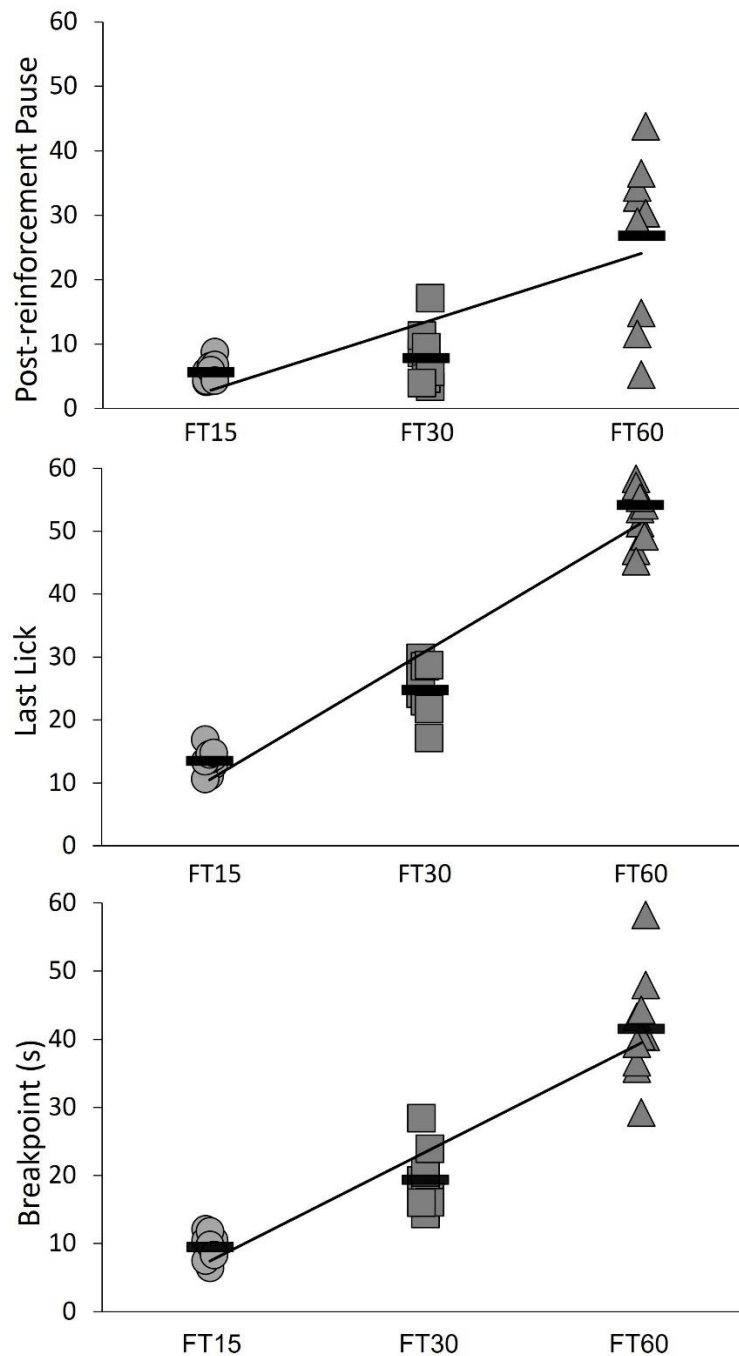
Note. Each symbol shows the mean value of each measure of the last three sessions of the experiment for each subject. The black horizontal line represents the mean of the group. The trendline is based on each group mean.

5,65; FT30 = 7,85; FT60 = 26,87). The inter-subject variability found within the FT60 group may nonetheless be a confounding source which impedes a better estimation of

these timing measures – i.e., considering TF60 post-pellet subgroup alone, which shows a typical SID temporal pattern, the mean of PRPs is 15,73, which is virtually double the mean of TF30 group (7,85). Similarly, the mean of last lick times for the post-pellet subgroup is 49,32, being almost exactly double the mean of TF30 group (24,77). Lastly, breakpoint is 40,04 in the post-pellet subgroup, which runs closer to double the mean of TF30 breakpoints (19,35). But perhaps more interestingly, when the mean duration of schedule-induced drinking is measured in seconds passed between PRPs and the last lick, the results obtained are virtually scalar (see Figure 6). The factors that may account for these differences within the TF60 subjects will be also discussed along with its theoretical implications.

Interestingly, Figure 7 shows no evident scalarity for means of magazine entries breakpoints (FT15 = 12,56; FT30 = 19,92; FT60 = 42,65). Furthermore, the breakpoint mean of magazine entries in the FT60 would be higher if considered post-pellet subgroup only (44,56), as highest rates of magazine entries in the other subgroups

Figure 6

Scalarity of SID duration, PRP, BP of licks and last lick across FT15, FT30 and FT60 as averaged by the last three sessions
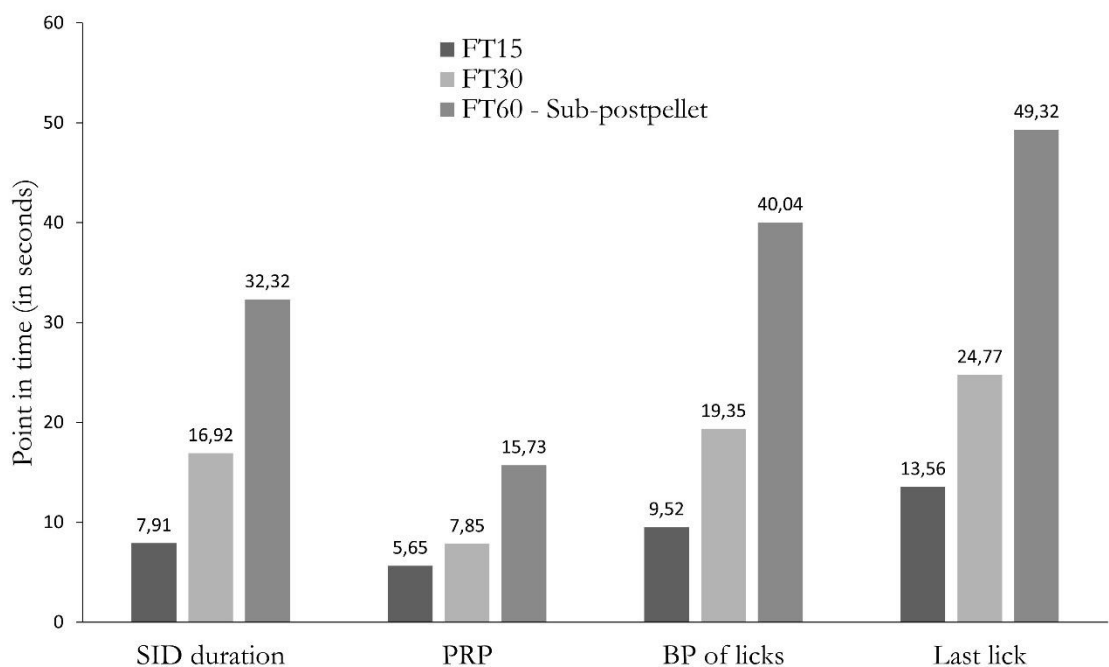
Note. The values above each bar denote seconds either in duration (for SID) or temporal point in the interval for PRP, BP of licks and Last lick.

appear mostly throughout the first part of the interval, except for subject 4 and 8 that show an increasing trend of magazine entries parallel to licks within the second part of the IRI (see Appendix I for individual graphs). Possible factors that may account for these differences will be discussed below.

Figure 7

Breakpoints of Magazine Entries
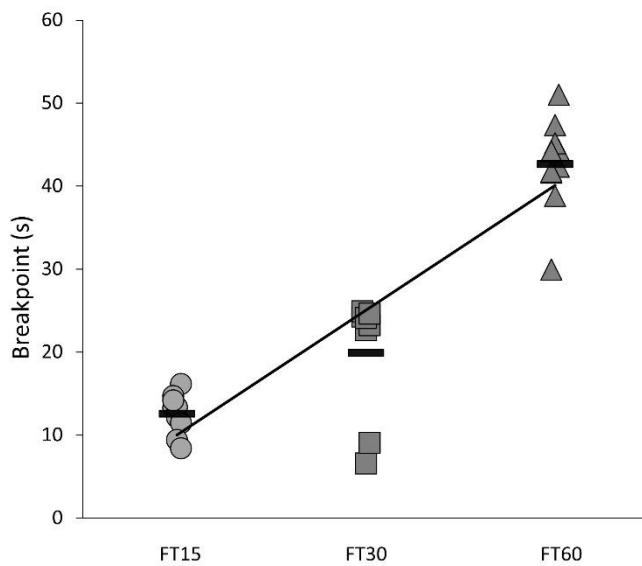
Note. Each symbol shows the mean time of transition of the last three sessions of the experiment for each subject. The black horizontal line represents the mean of the group.

Discussion

The data obtained in our study allows us to support a few assertions. The most paramount is the observation that the scalar property is manifested in terms of duration, but not rate across those groups that developed the typical pattern of SID, i.e.: FT15, FT30 and FT60 post-pellet subgroup (see Figure 1, 2 and 6). To support this statement, we found additional evidence of scalarity through other timing measures such as breakpoint of licks and time of the last lick, contrary to post-reinforcement pauses (Figure 5). These results lead us to take a deep analysis to the different FT60 subgroups and their individual distributions (Figure 3). As it may be observed in Figure 2, we may

contemplate in a single shot the differential effects of induction, reinforcement or both processes on schedule-induced drinking distributions (López-Tolsa, 2019; López-Tolsa & Pellón, 2021). It is not clear why this variability occurs and what is causing it in the FT60 group subjects –as opposed to the subjects in the other groups with shorter intervals– and whether this is mainly an effect of the IRI length (Roper, 1978).

When looking at Figure 4, scalarity does not reveal itself evident for SID across the three groups. But why is there no scalarity yet after applying an explicit response-reinforcer contingency? Perhaps *induction* has no reason to show scalarity because it solely depends on the beginning of the interval, contrary to *reinforcement*, which does depend on the moment that the response is emitted to effectively contact the reinforcer. This statement is furthermore supported by the scalarity manifested by other timing measures such as the time of the last lick and breakpoint of licks (Figure 5), which depend on the length of the interval and are therefore related to the end of the IRI, while PRPs, which depend on the beginning of the interval, do not show such scalarity inasmuch as it would rely more on induction. Machado's LeT model's predictions on the scalarity of schedule-induced behaviors in terms of rate would go against our present results.

Nevertheless, as mentioned above, the inter-subject variability found within the FT60 might be misleading and it would seem only fair to consider separately the FT60 post-pellet subgroup in order to make appropriate comparisons across the different groups, which adds extra layers of interpretation, that in turn sheds further light on our primal quest and may make for new paths for investigation. It is again worth noting how every timing measure but PRPs calculated in this investigation tend to approach scalarity in a more or less tightly manner (see Figure 6). However, although the duration of SID appears to depend on the duration of the IRI and roughly meets temporal scalarity, this relationship appears to be asymptotic (i.e., as the IRI increases, the relationship with SID tends to zero as its rate can only diminish).

We should further consider in this regard the effects on SID when applying an explicit contingency to it, in the sense that both processes, although operating simultaneously at shorter intervals (López-Tolsa, 2019), become more distinguishable in their effects at longer intervals where the sparse reinforcer can only strengthen more proximate behaviors (Killeen & Pellón, 2013), while induction alone deems insufficient to sustain SID, especially for subjects with initial low rates of behavior, as it seems to be the case for the FT60 pre-pellet subgroup subjects. A possible explanation for the

patterns developed by these subjects is that, given the low rates of drinking displayed, those less "aroused" (Killeen et al., 1978; Killeen & Fetterman, 1988) from the get-go would only meet the ratio requirement closer to the end of the interval or even after the set interval time (60 s) elapsed, therefore developing and operant pattern for drinking. This baseline rate could be key to explaining the individual differences that led to differential outcomes. Thus, those subjects with a higher initial overall rate of behavior would be more prone to develop SID (post-pellet subgroup) since by the first half of the interval they likely had already met the ratio requirement of the conjunctive schedule, optimizing this way the reinforcement rate (Falk, 1971). Nonetheless, the paradoxical fact that subject 7 within this group developed schedule-induced magazine entries leads us to further investigate the role of the food reinforcer and its interactions with behavior in longer intervals. This possibly indicates that food reinforcers are inducing both drinking and magazine entries in a sequence that falls out of total experimental control, even with the established contingency. An alternative explanation is that water may have acquired reinforcing properties by virtue of its continuous association with food delivery and becoming itself a conditioned reinforcer (Ruiz et al., 2016).

Subjects in the intermediate drinking subgroup deserve separate consideration. As discussed in the results section, the pattern of subject 1, consisting of SID and magazine entries is puzzling in what it seems to constitute two induced behaviors and a displaced drinking. The finding would not be that rare (Lawler & Cohen, 1992) unless magazine entries are considered as a form of foraging behavior (Lucas et al., 1988). The large bitonic curve displayed by subject 2 while drinking is also puzzling in that it takes the entire interval and there seems not to be any possible competitor behavior. Possibly, the effect of the contingency in terms of ratio requirement coupled with moderate initial baseline rates produced this singular pattern. Subject 6 pattern may suggest unresolved continuous competition among different behaviors due to very low overall rates of behavior, which may have led the rat to learn sustained drinking across the interval while increasing approach to the magazine as the interval elapses and reinforcement delivery is imminent.

A tentative explanation for the non-scalarity of magazine entries breakpoints shown in Figure 7 is that as the IRI length increases, the organisms are left with more time after SID fades away [FT15 = 1,44 s (9,6% of the total time until the end of the interval); FT30 = 5,23 s (17,43%); FT60 *post-pellet* 10,68 s (17,8%)] even if SID itself occupies approximately more than half of the interval relative to its total length in a

proportionate fashion, which may lead the organism to rush to the magazine for food, at least in the FT15 and FT30 group. Notwithstanding this, the actual breakpoint mean of magazine entries in the FT60 would be higher if considered post-pellet subgroup only (44,56), as highest rates of magazine entries in the other subgroups appear throughout the first part of the interval, except for subject 4 and 8 as previously mentioned, that show an increasing trend of magazine entries parallel to licks within the second part of the IRI). This may suggest that other so-called interim behaviors (Staddon, 1977) may be at play within the post-pellet subgroup, that unfortunately were not recorded nor systematically observed.

It may also very well be that displaying three curves with different intervals and rates into a normalized graph (Figure 4) is not the best strategy to test for scalarity inasmuch as the longer the IRI, the more available the time for other behaviors to express. It may not be by chance that in both López-Tolsa and Pellón (2021) and our study the normalized curves appear staggered from greater interval to smaller, since the purpose is to condense units of behavior in a space two or three times shorter, which doubles or triples the value of the same unit of behavior (licks), resulting in artificial curves. Thus, for a perfect scalarity to be in a normalized graph, the rate of behavior would have to vary constantly at a double and triple rate in each bin according to the IRI, but this may never occur because, as the IRI increases, not only is the licking rate lower, but there is more time space for other behaviors, leaving less margin for competition among them and configuring more disparate distributions (Roper, 1978). Hence the high variability in the FT60 and the non-scalarity of the magazine entries breakpoints –in the normalized graph, it would be no coincidence either that it is only between the FT15 and FT30 groups that there is scalarity of magazine entries in the middle part of the interval (i.e., when SID is occurring)–. Furthermore, the end of the drinking curves may somewhat be artificial (as aggregated curves usually are, see Baron & Leinenweber, 1994) because it is not that the rats are progressively decreasing their drinking rate; rather, these curves show the different averaged points in time where they stopped drinking. The use of the last licks as a measure remedies this issue.

In summary, the contingency applied to SID in this experiment and its effects on differential distributions of behaviors may have only been apparent in the FT60 subjects, especially in those with initial low rates of behavior. It could be argued then that it is not the effect of the contingency itself applied to SID that has contributed to manifest any scalarity; rather, it seems that the interaction among initial rates of

behavior (individual differences), the IRI lengths and the established response-reinforcer contingency are responsible for the differential distributions obtained in the FT60. Furthermore, it seems only attainable to look for scalarity in terms of duration but not rate of schedule-induced behaviors. This assertion may add extra support to the theory that schedule-induced behaviors could enhance adjustment of organisms to temporal regularities (López-Tolsa & Pellón, 2021; Ruiz et al., 2016). However, this scalarity is highly dependent on the initial rates of behavior and the rate of reinforcement (interval length), so it is expected only to dissolve as the rate of reinforcement decreases (the increasingly delays of the intervals) or extinction comes at play. Perhaps future research could further determine the extent to which the scalar property of SID is apparent in terms of duration by increasing interval lengths across different groups, which would in turn add evidence that the rates of induced behaviors cannot possibly be scalar. A possible alternative to deepen our knowledge on the scalar property of SID could entail increasing the magnitude of reinforcement proportionally to the intervals. Although some studies have shown that the magnitude of the reinforcer is positively correlated with the rate of SID (Couch, 1974; Flory, 1971; Jacquet, 1972; Osborne, 1978; Roca & Bruner, 2011), to our knowledge, there have not been any studies that had tried to systematically assess these effects in terms of the scalar property of SID, either establishing a contingency to it or not.

Appealing to Killeen and Pellón's model of competitive traces (2013) and concepts such as differential associability of responses to the reinforcer, differential decay of the potential of association over time and the different delay-of-reinforcement gradients associated, our results fit into this model insofar as the long-course, shallower associative potential that SID has as an interim behavior and that manifests itself in scalar duration at different intervals is considered. Moreover, the decreasing rate of SID as a function of interval length would constitute further evidence of such a decay of association potential. Viewed in this way, we cannot expect to find scalarity in the rate of drinking as an interim behavior –as opposed to more terminal behaviors with steeper gradients such as magazine entries–, since it is associated with the same reinforcer. Similarly, if the impact of the magnitude of the reinforcer on the scalarity of the SID rate were to be determined in subsequent studies, these results could only strengthen this model that supports the notion that schedule-induced behaviors are operants.

References

Álvarez, B., Íbias, J., & Pellón, R. (2016). Reinforcement of schedule-induced drinking
in rats by lick-contingent shortening of food delivery. *Learning & Behavior, 44*(4),
329-339. 10.3758/s13420-016-0221-6

Baron, A., & Leinenweber, A. (1994). MOLECULAR AND MOLAR ANALYSES OF
FIXED-INTERVAL PERFORMANCE. *Journal of the Experimental Analysis of
Behavior, 61*(1), 11-18. 10.1901/jeab.1994.61-11

Baum, W. M. (2012). Rethinking Reinforcement: Allocation, Induction, and
Contingency. *Journal of the Experimental Analysis of Behavior, 97*(1), 101.
10.1901/JEAB.2012.97-101

Baum, W. M. (2018). Three laws of behavior: Allocation, induction, and covariance.
Behavior Analysis: Research and Practice, 18(3), 239-251. 10.1037/BAR0000104

Couch, J. V. (1974). Reinforcement Magnitude and Schedule-Induced Polydispsia: A
Reexamination. *The Psychological Record, 24*(4), 559.
https://www.proquest.com/scholarly-journals/reinforcement-magnitude-schedule-
induced/docview/1301209848/se-2?accountid=14609

Falk, J. L. (1961). Production of polydipsia in normal rats by an intermittent food
schedule. *Science (New York, N.Y.), 133*(3447), 195-196.
10.1126/SCIENCE.133.3447.195

Falk, J. L. (1971). The nature and determinants of adjunctive behavior. *Physiology &
Behavior, 6*(5), 577-588. 10.1016/0031-9384(71)90209-5

Falk, J. L., & Kupfer, A. S. (1998). Adjunctive behavior: Application to the analysis and treatment of behavior problems.

Ferrara, A., Lejeune, H., & Wearden, J. H. (1997). Changing sensitivity to duration in human scalar timing: An experiment, a review, and some possible explanations. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 50B*, 217-237.

Flory, R. K. (1971). The control of schedule-induced polydipsia: Frequency and magnitude of reinforcement. *Learning and Motivation, 2*(3), 215-227. 10.1016/0023-9690(71)90022-1

Guilhardi, P., & Church, R. M. (2004). Measures of temporal discrimination in fixed-interval performance: A case study in archiving data. *Behavior Research Methods, Instruments, and Computers, 36*(4), 661-669. 10.3758/BF03206548

Jacquet, Y. F. (1972). SCHEDULE-INDUCED LICKING DURING MULTIPLE SCHEDULES1. *Journal of the Experimental Analysis of Behavior, 17*(3), 413-423. 10.1901/jeab.1972.17-413

Killeen, P. R., & Fetterman, J. G. (1988). A behavioral theory of timing. *Psychological Review, 95*(2), 274-295. 10.1037/0033-295X.95.2.274

Killeen, P. R., Hanson, S. J., & Osborne, S. R. (1978). Arousal: Its genesis and manifestation as response rate. *Psychological Review, 85*, 571-581. 10.1037/0033-295X.85.6.571

Killeen, P. R., & Pellón, R. (2013). Adjunctive behaviors are operants. *Learning & Behavior, 41*(1), 1-24. 10.3758/s13420-012-0095-1

Lawler, C. P., & Cohen, P. S. (1992). Temporal patterns of schedule-induced drinking and pawgrooming in rats exposed to periodic food. *Animal Learning & Behavior, 20*(3), 266-280.

López-Tolsa, G. E. (2018). *Development of schedule-induced behaviour in temporal tasks and its impact on timing.*Available from http://e-spacio.uned.es/fez/view/tesisuned:ED-Pg-PsiSal-Gelopez

López-Tolsa, G. E. (2019). Conductas adjuntivas: entre la inducción y el reforzamiento. In I. Zepeda Riveros, F. Cabrera González, J. A. Camacho Candia & E. Camacho Gutiérrez (Eds.), *Aproximaciones al Estudio del Comportamiento y sus Aplicaciones* (pp. 109-124). Universidad de Guadalajara.

López-Tolsa, G. E., & Pellón, R. (2021). Assessment of the 'Timing' Function of Schedule-Induced Behavior on Fixed-Interval Performance. *Journal of Experimental Psychology: Animal Learning and Cognition, 47*(3), 326-336. 10.1037/XAN0000308

Lucas, G. A., Timberlake, W., & Gawley, D. J. (1988). Adjunctive behavior of the rat under periodic food delivery in a 24-hour environment. *Animal Learning & Behavior, 16*(1), 19-30. 10.3758/BF03209039/METRICS

Machado, A., Malheiro, M. T., & Erlhagen, W. (2009). Learning to time: A perspective. *Journal of the Experimental Analysis of Behavior, 92*(3), 423-458. 10.1901/JEAB.2009.92-423

Maldonado, D. E., López-Tolsa, G. E., & González-Torres, R. U. (2023). *Introducing the MedPCPy library for behavioral data analysis.* Unpublished manuscript. https://doi.org/10.31234/osf.io/87u4k

Osborne, S. R. (1978). A quantitative analysis of the effects of amount of reinforcement on two response classes. *Journal of Experimental Psychology: Animal Behavior Processes, 4*, 297-317. 10.1037/0097-7403.4.4.297

Palya, W. L. (1993). BIPOLAR CONTROL IN FIXED INTERFOOD INTERVALS. *Journal of the Experimental Analysis of Behavior, 60*(2), 345-359. 10.1901/jeab.1993.60-345

Pellón, R. (2004). La ley del efecto y la conducta innata. *Inteligencia y aprendizaje, 2004, ISBN 84-344-0914-3, págs. 89-114* (pp. 89-114). Ariel España.

Pellón, R., & Killeen, P. R. (2015). Responses compete and collaborate, shaping each others' distributions: Commentary on Boakes, Patterson, Kendig, and Harris (2015). *Journal of Experimental Psychology: Animal Learning and Cognition, 41*(4), 444-451. https://www.academia.edu/21780859/Responses_compete_and_collaborate_shaping_each_others_distributions_Commentary_on_Boakes_Patterson_Kendig_and_Harris_2015_

Pellón, R., López-Tolsa, G. E., Gutiérrez-Ferre, V. E., & Fuentes-Verdugo, E. (2020). Schedule-Induced Behavior. *Encyclopedia of Animal Cognition and Behavior,* , 1-5. 10.1007/978-3-319-47829-6_2089-1

Roca, A., & Bruner, C. A. (2011). Un análisis del origen del consumo excesivo de agua del beber inducido por el programa. *Revista mexicana de análisis de la conducta, 37*(2), 177-204. doi:10.5514/rmac.v37.i2.26146 Retrieved from http://www.redalyc.org/articulo.oa?id=59319255011

Roper, T. J. (1978). Diversity and substitutability of adjunctive activities under fixed-interval schedules of food reinforcement. *Journal of the Experimental Analysis of Behavior, 30*(1), 83-96. 10.1901/JEAB.1978.30-83

Ruiz, J. A., López-Tolsa, G. E., & Pellón, R. (2016). Reinforcing and timing properties of water in the schedule-induced drinking situation. *Behavioural Processes, 127*, 86-96. 10.1016/J.BEPROC.2016.03.018

Skinner, B. F. (1948). Superstition in the pigeon. *Journal of Experimental Psychology, 38*(2), 168-172. 10.1037/H0055873

Staddon, J. E. R., & Simmelhag, V. L. (1971). The "superstition" experiment: A reexamination of its implications for the principles of adaptive behavior. *Psychological Review, 78*(1), 3-43.

Staddon, J. E. R. (1977). Schedule-induced behavior. In W.K. Honig, & J.E.R. Staddon (Eds.), *Handbook of Operant Behavior* (pp. 125-152). NJ: Prentice-Hall.
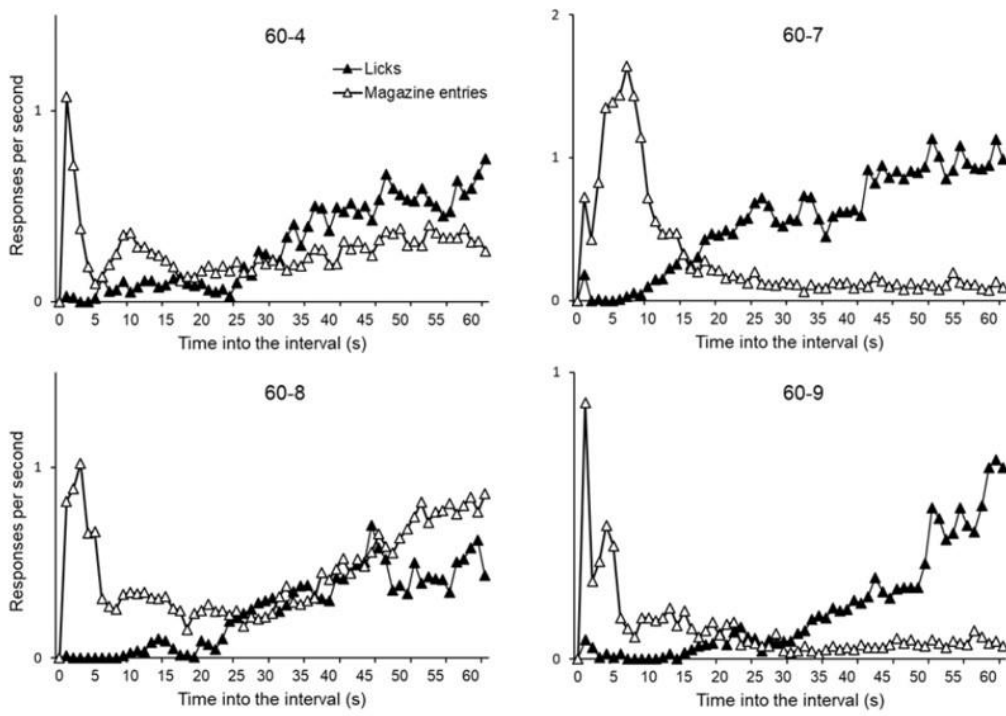
Appendix I

Individual graphs of FT60 post-pellet subgroup subjects
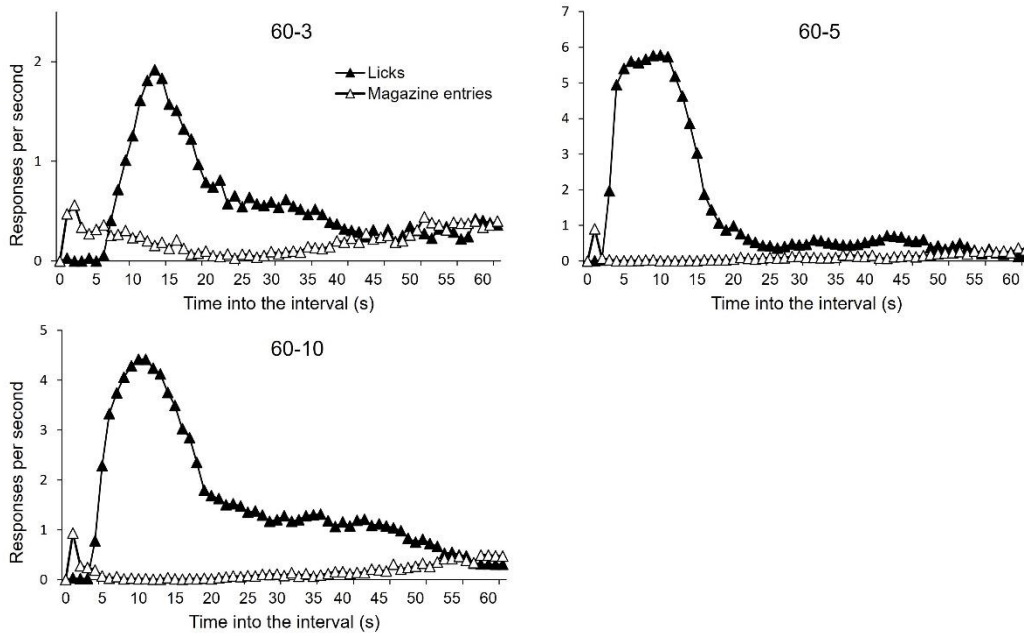
Individual graphs of FT60 intermediate drinking subgroup subjects
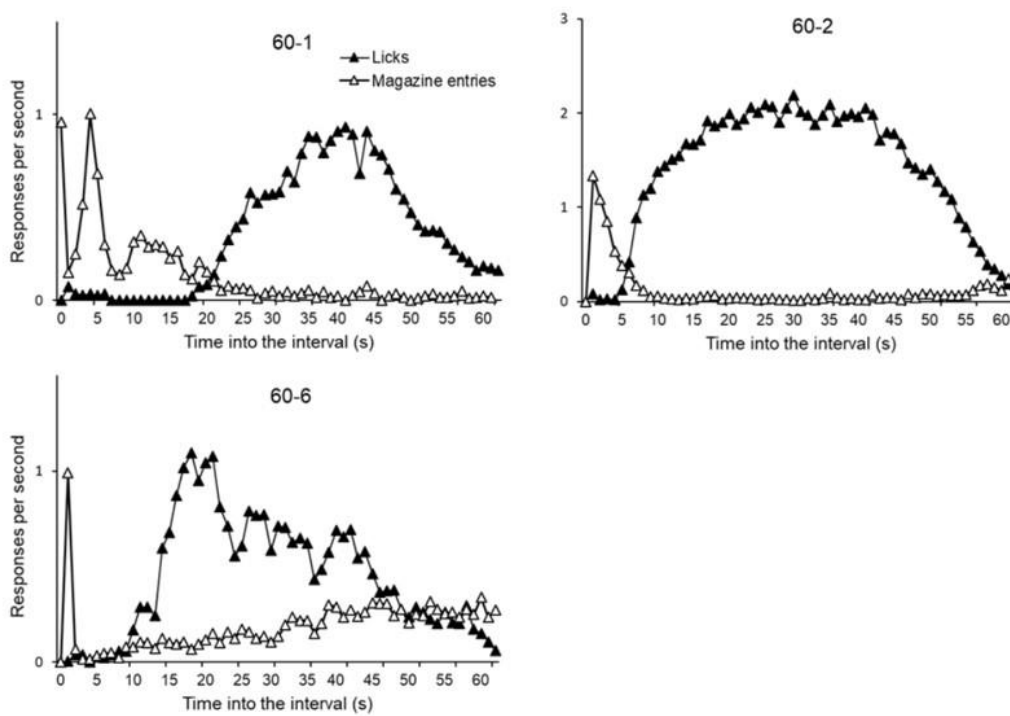
Individual graphs of FT60 pre-pellet subgroup subjects

Appendix II

TF15 Gaussian adjustments

Subject	Mean	Standard Deviation	R^2
21	8,63931511	3,3071979	0,89298261
23	7,10700814	2,64627441	0,90602087
24	9,66068446	2,33726413	0,96824873
25	6,65795485	2,11221866	0,96023169
26	7,30415476	2,51697671	0,93750916
27	10,0187159	3,86856384	0,89151653
28	7,96847848	3,16979067	0,87422026
29	10,257699	4,92195183	0,81222763
30	9,55579825	3,75503942	0,91071902
Group	8,57	3,18	0,90

TF30 Gaussian adjustments

Subject	Mean	Standard Deviation	R²
11	12,5840604	5,20159161	0,93023718
12	14,0132548	6,11776524	0,90641768
13	8,55919834	4,22820028	0,93450088
15	11,4410179	5,69802718	0,82092939
16	11,0761923	4,88827587	0,94681888
17	10,0460261	4,58350645	0,92811997
18	11,973691	6,67044208	0,88236614
19	11,0642143	4,68854114	0,89266655
20	17,652763	9,41312928	0,69882151
Group	12,04	5,72	0,88

TF60 Gaussian adjustments

Subject	Mean	Standard Deviation	R^2
1	38,0114071	9,92700357	0,96694891
2	29,7157612	16,1191807	0,8910894
3	15,0526475	5,94928193	0,76199925
4	55,2588394	19,6593998	0,91401037
5	9,20056643	4,63338949	0,9377709
6	27,567808	13,533886	0,69111243
7	56,8237548	26,0853561	0,90015196
8	50,4877806	17,8469792	0,87667237
9	~~*92,3792063~~	~~26,6296275~~	~~0,95515395~~
10	12,4269598	6,58554795	0,78369512
Group	32,72	13,37	0,86

Note. The outlier value obtained for subject 9 was removed.