



The role of schedules of reinforcement in the experimental analysis of social behavior

Marcelo Frota Benvenuti^{1,2}  · João Lucas Bernardy^{1,2}  · Thais Nogara de Toledo³  · Jéssica Santiago^{1,2}  · José de Oliveira Siqueira⁴  · Paulo Sergio Panse Silveira⁴ 

Accepted: 27 July 2024 / Published online: 19 September 2024
© Association for Behavior Analysis International 2024

Abstract

In this paper, we review some results produced by our research group regarding the role of schedules of reinforcement in social behavior. We discuss data from studies in which we attempted to create conditions in which interdependent gains overlapped with individual reinforcement schedules so that these situations were more or less competitive and conflicting. We argue that normative rules about reinforcement schedules and interdependent reinforcement are crucial for analyzing social behavior since these rules allow us to differentiate the effects of individual and social contingencies or an interaction of both. Our analysis demonstrates that temporal criteria in social episodes may be especially relevant in characterizing social behavior. In these episodes, responding to someone who initiates the social episode (the follower's response under the control of the leader's response) can be characterized as responding in a simple limited hold schedule, or in a variable DRL schedule. Leader and follower behaviors may be united by interdependent reinforcement, but their connection is itself a single schedule of reinforcement.

Keywords Social behavior · Reinforcement schedules · Temporal schedules · Pigeons · Humans · Simulation

The experimental analysis of social behavior poses a challenge for behavioral sciences, especially for those working within the tradition of learning theories initiated by authors such as E. C. Tolman (1922), C. Hull (1943), and B. F. Skinner (1938). Learning

✉ Marcelo Frota Benvenuti
mbenvenuti@usp.br

¹ Instituto de Psicologia, Universidade de São Paulo, Av. Prof. Mello Moraes, 1721, São Paulo 05508-030, SP, Brazil

² National Institute of Science and Technology About Behavior, Cognition and Teaching (INCT-ECCE), São Paulo, Brazil

³ Universidade Federal do Mato Grosso do Sul, Campo Grande, MS, Brazil

⁴ Departamento de Patologia, Universidade de São Paulo, São Paulo, SP, Brazil

theories are usually based on experiments rigorously controlled to avoid external influences from other organisms. For example, in the experimental analysis of behavior, notions of reinforcement and stimulus control are traditionally studied with human or non-human organisms, often in isolation from conspecifics.

However, this focus on individual behavior underscores the difficulty in extrapolating principles to the context of social behavior, a domain in which the aspiration to extend learning principles has persistently endured. One of the first attempts in this direction came from the classic “Principles of Psychology” (Keller & Shoenfeld, 1950). Their approach was to apply basic principles of learning to the field of social behavior, understood as changes in others’ behavior controlled by social discriminative stimuli and/or social reinforcement, as also later defined by Skinner (1953).

Skinner (1953) also argued that social behavior implies intermittent reinforcement, which is maintained by schedules of reinforcement (Ferster & Skinner, 1957). This feature results from the fact that social reinforcement depends on the behavior of the reinforcing agent. In Skinner’s words, “the reinforcing system is seldom independent to behavior reinforced” (Skinner 1953, p. 300), meaning that social reinforcement does not depend exclusively on features of behavior being reinforced; instead, it may drift due to conditions that affect only the reinforcing agent. Because the agent’s behavior can be variable, social reinforcement is typically intermittent.

Schmitt (1998) refined initial formulations of schedules involved in social behavior. Besides the criteria for the production of individual reinforcers, Schmidt emphasized the interdependency of reinforcement as a critical aspect of social behavior. Interdependent reinforcement implies that the consequences each individual receives depend, at least in part, on the behavior of others. This means that the social interaction situation itself constitutes a unique reinforcement schedule, as the performance of one individual adds criteria and restrictions in producing reinforcement for others and for themselves.

The sort of interdependent outcomes is a crucial aspect of strategic behavior and social dilemmas discussed in game theory (Camerer, 2003), in theoretical models of cultural evolution (McElreath & Boyd, 2013) and evolutionary theory about functional interdependency (Balliet, Tybur, & Van Lange, 2017). Despite their potential usefulness suggested by Skinner (1953), schedules of reinforcement are generally regarded as secondary in the economic discussion of social dilemmas and the evolutionary approach to social behavior. This may occur because in the traditions of economics and evolutionary biology, quantitative models of social behavior are widely used. In the experimental analysis of behavior, however, quantitative analysis has been proposed for individual performances, despite successful initial models that consider the behavior of individuals in groups (Baum, 1989).

In this paper, we review some results produced by our research group regarding the role of schedules of reinforcement in social behavior and interdependent reinforcement. Our goal is to show how embodying the knowledge about schedules may contribute to the study of social behavior in at least two ways: (1) it allows us to produce quantitative rules about schedules involved in social interactions that, in turn, (2) could aid researchers in planning experiments that clearly distinguish between social and non-social behavior. There are two central issues in the study of schedules of reinforcement that we have explored: the reinforcement feedback functions (RFF)

(Baum, 1973; Rachlin, 1978) and the discussion about inter-response time (IRT) as a unit of analysis in schedules of reinforcement (Zeiler, 1977). Both are related to constraints on the production of interdependent reinforcement, that is, they help identify the characteristic contingencies of social behavior.

In the classical studies by Ferster and Skinner (1957), behavior was the dependent variable, and reinforcement was the independent variable. Since the operant behavior is defined by the environmental changes it produces, the causality can be reversed: rate of reinforcement may be treated as the dependent variable, and rate of response as the independent variable. The RFF is a mathematical description of the latter relation, which provides normative rules about the relation between performance and a scheduled payoff. For this, RFF can be seen as economical constraints to the rate of reinforcement (Rachlin, 1989). Considering the problem posed by interdependent reinforcement, understanding these economic constraints to be individual and collective performance (maintained by interdependent reinforcement) may help understand when working alone or coordinating with the group is more worthwhile.

These rules are also related to the discussion about units of analysis brought forth by Zeiler (1977). In the context of individual behavior, a lever-press is part of a response class affected by a reinforcer, as suggested by Skinner (1935, 1953). However, in some cases, it may be more convenient to treat the IRT as a unit of analysis (Platt, Kuch, & Bitgood, 1973; Zeiler, 1977). Things become more challenging when this issue is applied to social behavior. Because interdependent reinforcement depends on the behavior of another person (Schmitt, 1998), social behavior demands that different individuals combine their response rates to produce interdependent reinforcement. In this sense, it would be possible to talk about a “social IRT” as the unit of analysis of social behavior, as recent experimental analysis of coordination seems to suggest (de Carvalho et al., 2018, 2020).

Next, we will briefly review the literature on the issue of interdependent reinforcement, demonstrating how considering social IRT as a viable unit of analysis can be useful. Then, we will further detail our studies on social behavior and the application of feedback functions and units of analysis for this topic.

A brief review of the role of interdependent reinforcement

Azrin and Lindsley (1956) ran an experiment where “cooperative responses” were recorded when two children placed sticks in holes across from one another within 400 ms. Similarly, Cohen and Lindsley (1964) recorded cooperative responses when two children responded within 500 ms of each other. Both experiments reported high rates of cooperative response. However, as Schmitt and Marwell (1968) pointed out, high response rates may also be expected due to individual contingencies. Based on this analysis, co-occurring responses in free operant procedures may simply be an artifact of spurious temporal relations between two individuals behaving independently from each other, following individual schedules despite the interdependent reinforcement programmed.

Schmitt and Marwell (1968) proposed adding a delay requirement between participants’ responses as a matter of experimental control. In Schmitt and Marwell’s

modified task, the first participant's response illuminated a light on the other participant's response panel for 3 s. Reinforcement occurred if the second participant pulled a plunger within 500 ms after the light went off. As a result, high cooperative response rates were obtained in the presence of the lights that signaled the responses from the other participants, demonstrating the cooperative responses from different participants under the discriminative control of a direct product of other's behavior.

The same issues of experimental control and data analysis can arise when working with non-human social behavior. Control strategies also evaluate how discriminative behavior adjustment occurs from one subject to another when interdependent reinforcement is in effect. Skinner (1962) worked with pairs of pigeons. They worked in adjacent compartments of the same experimental chamber separated by a transparent wall. Three response keys were arranged vertically on each side of the wall, such that each key on one side was horizontally aligned with a corresponding key at the same height on the other side. At each moment, only one pair of adjacent same-height keys was randomly designated as effective for food if both pigeons pecked the respective keys within a time interval. Skinner (1962) demonstrated that coordination was built in these situations. Besides that, a division of labor developed in the task: One pigeon (i.e., the leader) explored the keys, pecking each one randomly. The other pigeon (i.e., the follower) pecked the corresponding key and produced interdependent food.

Tan and Hackenberg (2016) employed a yoked strategy with rats to control the effect of interdependent reinforcement on cooperation mutual reinforcement. Rats in adjacent operant chambers received food if either rat pressed a lever within 500 ms of a lever press by the other rat. Coordinated response frequency was significantly higher than yoked-control conditions during mutual or interdependent reinforcement conditions. Relatedly, de Carvalho et al. (2018) and de Carvalho et al. (2020) showed that ratio-based mutual reinforcement also maintained coordinated responses in rats. These studies also show that, in addition to the high response rates, the coordinated pattern assumed a classic break-and-run pattern typically associated with the performance of a single organism. Manipulations on the VR requirement also systematically affected the post-reinforcement pause for synchronous behavior.

Notably, in interactions between two individuals, a social unit – coordination – is maintained by interdependent or mutual reinforcement. These interactions involve role specialization, even though these roles can be exchanged over multiple interactions: one of the individuals initiates the interaction (i.e., the leader), while the other follows the lead (i.e., the follower), meeting the criterion for reinforcement production. This role division suggests additional complexity in analyzing social behavior: the current leader is under more individual control conditions, while the follower is under control of conditions set by the experimenter, plus restrictions imposed by the leader's behavior. In Tan and Hackenberg (2016), for example, the schedule for the leader was generally the one imposed by the experimenter, a variable interval schedule. However, the follower worked on a variable interval schedule with a limited hold, characterized by the time criteria defining a coordinated response. The rats did not respond exclusively in those roles, occasionally swapping leader and follower. But as in Schmitt and Marwell (1968), the spacing requirement created a situation where the follower worked on a "social DRL" schedule, with the critical spacing interval initiated by the leader's behavior: if the follower responded within the interval, the

reinforcement was postponed; if responded with the correct interval, the reinforcement was delivered. Overall, the analysis of this “social DRL” shows that the social episode can be described as a “social IRT,” temporal spacing between responses of different individuals that became critical for meeting the contingencies for interdependent reinforcement.

Separating effects of individual and interdependent reinforcement

In Skinner’s (1962) experiments with pigeons, coordination did not conflict with any individual source of reinforcement provided by individual behavior. We replicated that experiment to create a situation where individual gains differed from gains obtained by engaging in the coordination episode (Velasco, Benvenuti, & Tomanari, 2012).

In Velasco, Benvenuti, Sampaio, and Tomanari (2017), three pairs of pigeons worked face-to-face in an operant chamber divided by a transparent wall. Each side of the chamber had two horizontally aligned response keys on the floor. Payoffs were illustrated in the left portion of Fig. 1: The pigeons could produce one of the following outcomes on each trial: (a) no reinforcement, (b) only the individual reinforcement (3 s access to food), (c) only the interdependent reinforcement (4 s access to food), or (d) both reinforcement (7 s access to food). Adding the interdependent contingency of reinforcement led to (a) a slight reduction of the production of individual and interdependent reinforcement without any coordinated response pattern, (b) the maintenance of high percentages of individual reinforcement with a concomitant increase in interdependent reinforcement, and (c) for only one subject, an increase in the production

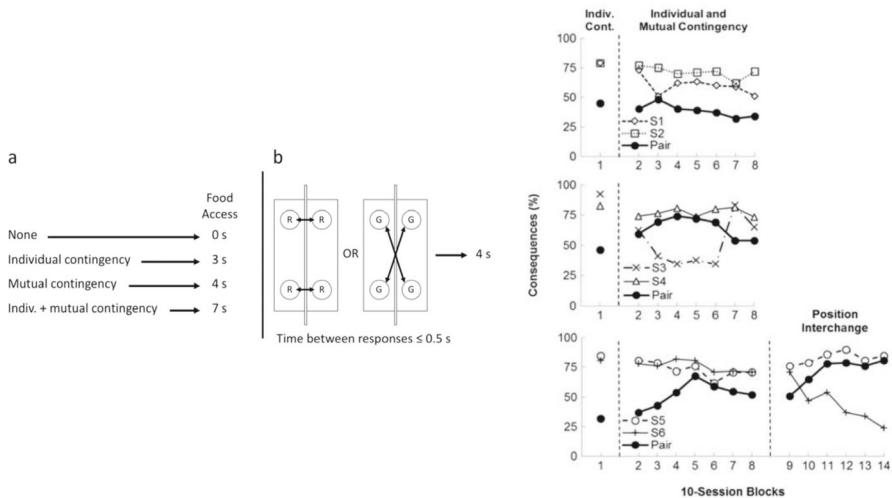


Fig. 1 Summary of experimental contingencies arranged in the individual and interdependent contingency phase: **a** Duration of food access produced by meeting the different contingency requirements and **b** the necessary coordination for the production of interdependent reinforcement (4-s food access for each pigeon). R = red; G = green. Data from Velasco et al., 2017

of interdependent reinforcement that was accompanied by a decrease in the rate of individual reinforcement.

Our experiment with pigeons was created to experimentally simulate a metacontingency (Glenn, 2004; Glenn et al., 2016). The central idea behind metacontingency is that when people work together, they may produce individual payoffs and aggregated products that result from coordinating several individuals' behaviors. Coordinated work and aggregated products may maintain a functional relationship with some external outcome. These payoffs for coordination do not preclude individual payoffs; individual behavior may be maintained by individual reinforcement, while coordination is maintained by collective outcome (Glenn et al., 2016). Our primary focus in the study with pigeons was to deal with the first part of the definition of a metacontingency: what occurs when an interdependent consequence is contingent upon coordination, superposed to a baseline of individual reinforcement? The answer is that a unit of analysis composed of the coordination of pigeon behavior can emerge due to interdependent reinforcement.

Schedule performance as a baseline for the experimental analysis of coordinated behavior

Another task we created to address the difference between the effects of individual and interdependent reinforcement was called free culturant (de Toledo et al., 2015), after free operant. The task is represented in Fig. 2. Up to four participants were allowed to simultaneously engage in the experimental task, resembling a virtual game. In the studies we report here, we always worked with groups of three people. The computer screen exhibits a quadrant for each participant. Each quadrant features a water tap (the manipulandum), which can be operated using the left mouse button or keyboard, and a water jug. Participants are instructed to use their respective water taps to produce water in their individual bottles. The experimenter may specify that pressing the water tap produces a portion of water in the jug, accompanied by a specific sound, based on a given schedule: continuous reinforcement (CRF), extinction (EXT), fixed ratio (FR), variable ratio (VR), fixed interval (FI), or variable interval (VI). When participants click on their water tap, their quadrant blinks for others to see.

Above the individual quadrants is a common area containing a public water tank. Participants were informed that, on certain occasions, it would be possible to produce a bonus that fills the town's water tank. Water in the public tank and bonuses depend on the coordinated behavior of the participants. For coordination, the experimenter may specify that water in the common tank occurs if all participants space their behavior in relation to other participants' behavior. In this case, the required spacing was defined as coordinated responding by participants where a time interval of x ms was required between the response of one first participant, a second participant, and a third (i.e., a minimum social IRT). The order of participants did not matter as long as each response was produced by a different participant. If the time requirement was not fulfilled, the production of collective water and the bonus were delayed. This condition is analogous to a differential reinforcement of low rates (DRL) schedule, except that it is social since responses meeting the criteria are produced by a group of three participants

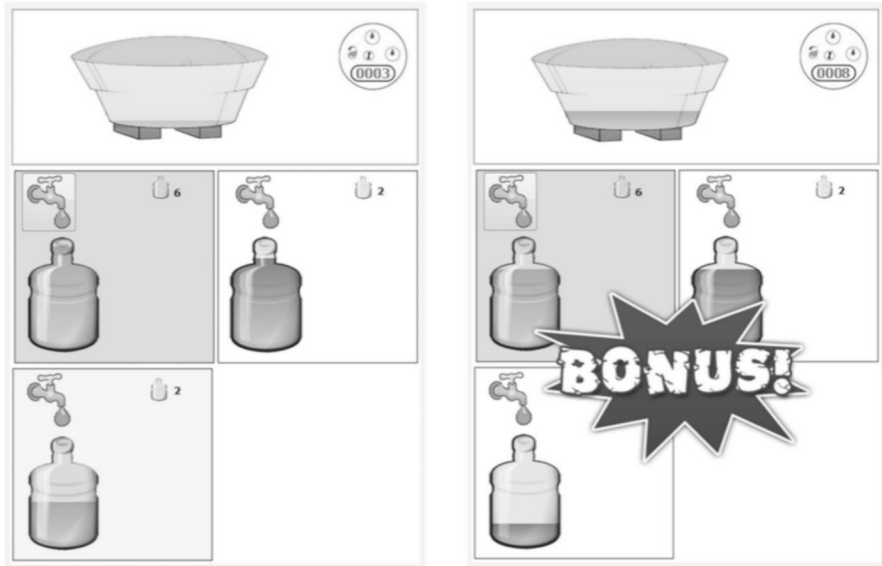


Fig. 2 A participant's computer screen at two different moments in a session with three simultaneous participants (three quadrants displayed). The active quadrant for the participant (*upper left quadrant*) has a green background on the original computer screen. The *left panel* depicts the moment another participant clicks on his or her water tap (highlighting its lower left quadrant with a different color background). The *right panel* depicts the moment when an interdependent consequence (bonus, collective water) is displayed. From: de Toledo and Benvenuti, 2015

instead of an individual. This spacing pattern was used to measure social behavior and serves as evidence of discriminative adjustment of a participant's behavior to that of another participant. So, the free culturant task allows a measure of individual behavior maintained by specific and individual schedules of reinforcement. Also, it allows an independent measure of coordinated behavior related to the same manipulandum, clicks on the water jug, with coordination-defined participants' spacing behavior.

In de Toledo and Benvenuti (2015), a VI 12 s was programmed for individual participants behavior: clicking on the water tap produced portions of water in each jug every 12 s on average. Condition A was utilized as a baseline: in this condition, only individual schedules of reinforcement were in effect. In Condition B, the demand for spacing for water production in the tank and bonuses were superimposed onto the requirements of the individual schedules.

Figure 3 presents data from this task with two triads of participants working simultaneously and side-by-side. Participants in the first triad (top graph) started the experiment with an average rate of 55 responses per minute (P1 and P2) and 150 responses per minute (P3) in Condition A. During the final portion of the Baseline, these rates decreased to about 14 responses per minute. However, even with similar response rates, participants rarely met the coordination criteria of the social DRL (which were not in effect, although the target spacing was being recorded). On the other hand, introducing the spacing requirement with different intervals (750, 1000, and 1250 ms) between the first, second, and third participant responses did not produce

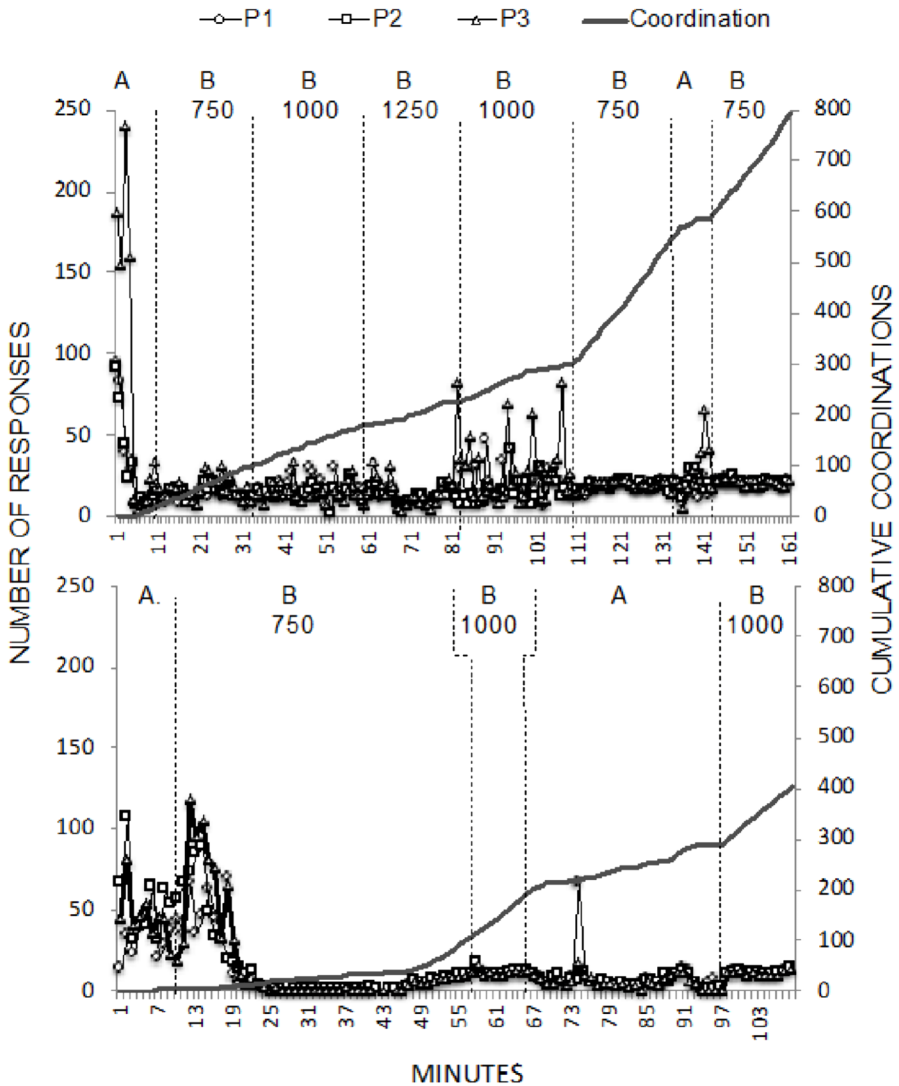


Fig. 3 Number of responses (main axis) and cumulative coordination (secondary axis), from two triads (top and bottom panels), in a VI 12 s as individual schedule. Dashed vertical lines signal the changing of conditions. The numbers below Condition B indicate the spacing criterion for coordination in milliseconds. From: de Toledo and Benvenuti, 2015

clear changes in individual response rates in Condition A. The spacing requirement was reduced from 1000 to 750 ms, and the three participants began to exhibit approximately 18 to 20 responses per minute. The stability criterion for the conclusion of Condition B, which was 10 to 14 occurrences of target spacing, achieved in the 25th minute of exposure to this condition (133th of the experiment). In the second exposure to Condition A, there was more variability in the three participants' response

and spacing rates. Starting from the third minute without the presentation of interdependent consequences, spacing began to occur at 4.5 per minute, eventually reaching 0.67 in the final three minutes of the second exposition to Condition A. Reintroducing the spacing criteria upon returning to Condition B resulted in reinstating the previous spacing pattern. Results were similar for the second triad (bottom chart), with the effects of interdependent reinforcement already being observed in the first exposure to Condition B.

In a subsequent study de Toledo, Benvenuti, Marques, and Glenn (2022), with the same task and similar procedure, we aimed to replicate these data with a greater focus on analyzing social IRTs. In this social IRT analysis, it did not matter which participant in the triad had emitted which response: the interval between all responses emitted was recorded independently of the participant who had emitted the response. This allowed us to count the intervals between all responses in the experiment and assess the density of these IRTs, from the shortest to the longest for each triad of participants. To facilitate data analysis and avoid the influence of very long IRTs, the logarithm (Log) of the IRTs was calculated. Figure 4 displays the distribution of IRTs for four selected triads in the experiment, two with the VI schedule in the Baseline and two with the VR schedule in the Baseline. All triads underwent an ABAB design, so the figure shows the data from the first AB exposure and the data from the second exposure on the left. IRT's density in the Baseline is represented by dashed lines, while IRT's density in experimental conditions is represented by continuous lines. The vertical dashed line represents the duration of the target spacing for the three participants in the triad. Comparison of IRT duration in Condition A with IRT duration in Condition B (where interdependent consequences required minimum spacing for three participants) show higher densities of shortest IRTs in A1 and A2 Conditions. In B Conditions, the density peaks appear around the IRT requirement for interdependent reinforcement. Additionally, in the A2 condition, all triads showed density peaks of IRT duration, which remained close to the B1 requirement.

In Fig. 5, we compare a figure from our study with one of the first experimental analyses of cooperation as operant behavior. The first figure came from the study by

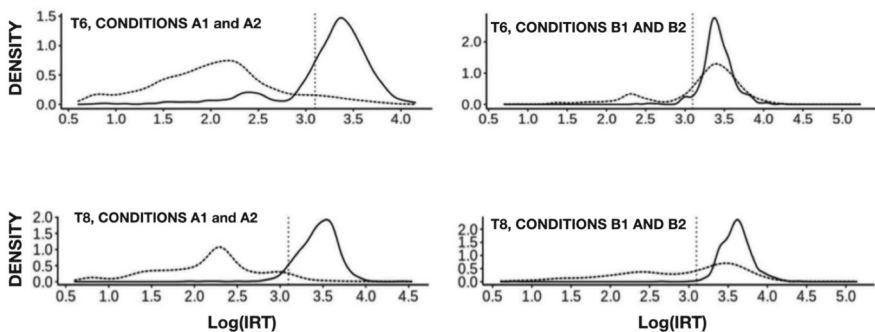


Fig. 4 Density of each IRT duration for two selected triads from de Toledo et al. (2022). The left panel presents IRTs densities during conditions A1 (dashed line) and B1 (solid line); the right panel during conditions A2 (dashed line) and B2 (solid line). The target IRT is indicated by a dashed vertical line

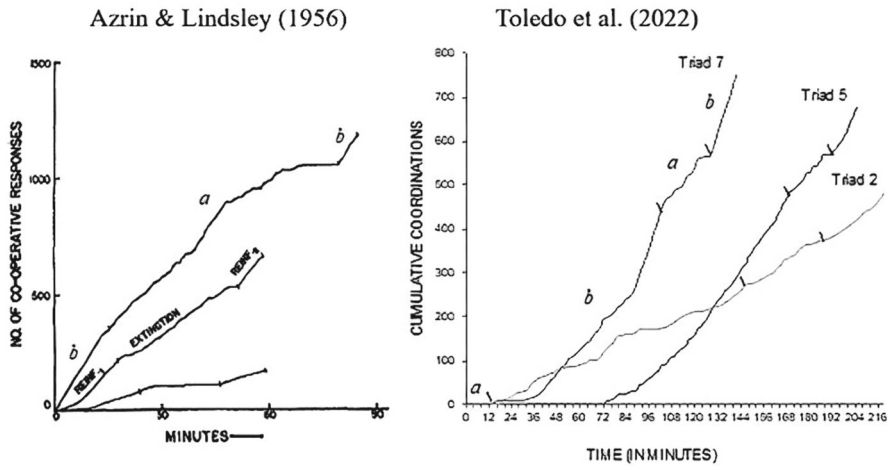


Fig. 5 Cumulative response records for three pairs and three triads in studies of Azrin and Lindsley (1956, left panel) and de Toledo et al. (2022, right panel). The slashes on cumulative records signal changes in conditions: without reinforcement (a); with reinforcement (b) for coordination [added information]

Azrin and Lindsley (1956) and showed cumulative records from three pairs of children under cooperative contingency. As shown in the figure, cooperative responses for each pair of kids increased in frequency when reinforced by a candy dispensed to participants contingent on pulling together. In the absence of this contingency, a clear pattern of extinction was observed for all three pairs of kids shown in the figure. We built the figure from our free culturant study inspired by Azrin and Lindsley's analysis. We chose three triads representing our observed general patterns and variability and plotted all registered times participants achieved the criteria for interdependent reinforcement. Results are astonishingly similar despite all the differences in cultural context and experimental task. There is a clear increase in the occurrence of spacing in experimental conditions (Condition B, with interdependent reinforcement superimposed on the reinforcement schedule) and a clear extinction pattern in baseline conditions (Condition A) with only the reinforcement schedules in place.

Results from the free culturant clearly show the establishment of discriminative control over behavior based on the behavior of another individual. The result is a coordination pattern that can be characterized as “social spacing,” that is, a behavior that occurs within a time span that depends on the previous response by another individual. This social spacing can be achieved by manipulating an interdependent consequence, meaning reinforcement does not depend solely on an individual's performance; it is contingent on coordination, the social IRT. In a free culturant, if individual and social contingencies are compatible, participants could “have their cake and eat it” since they could simultaneously optimize individual and social reinforcement. Conversely, if individual and social contingencies are in conflict, participants face a choice situation with mutually exclusive alternatives. We will analyze some quantitative aspects of the schedules involved in interdependent reinforcement conditions to discuss whether this conflict was established in our previous studies.

Free culturant and feedback functions

Schedules of reinforcement may be quantitatively described as feedback functions, in which the reinforcement rates are controlled by response rates (Rachlin, 1978; Baum, 1989). In ratio schedules, the reinforcement feedback function (RFF) is a straight line with an intercept equal to zero and a slope that is the reciprocal of the ratio size. In interval schedules, the reinforcement rate is further constrained by a temporal criterion, resulting in a monotonically increasing function that approaches a superior asymptote. In time schedules, reinforcement is independent of behavior; therefore, the RFF is a horizontal line with an intercept equal to the rate of reinforcement. For any reinforcement schedule, actual data should roughly fall within the constraints imposed by its feedback function.

We applied this feedback function analysis to the data obtained from de Toledo et al. (2022). For instance, these data from individual contingencies fit the VI feedback function, as shown in Fig. 6. Data in the left panel shows a difference between Condition A (Baseline) and Condition B1 (single schedule plus interdependent reinforcement). All participants presented higher response rates during Baseline than in Condition B1, suggesting that interdependent reinforcement contingencies maintained lower response rates, directly resulting from increased social IRT. Since the IRT is the reciprocal of the response rate, a larger IRT implies fewer responses per minute. It is also worth noting that the distance between response rates within the same triad decreased in Condition B1 compared to Condition A (Baseline). During the Baseline, the average differences in response rates were 12.92 responses per minute for the first triad (circles), 47.5 for the second triad (squares), and 18.38 for the third triad (triangles). During Condition B1, the average differences for the same triads were 1.54, 3.17, and 1.03, respectively. Data in the right panel shows that these differences did not return to the Baseline levels, even when the interdependent reinforcement contingency was suspended (Condition A2). Despite all changes in performance, there were

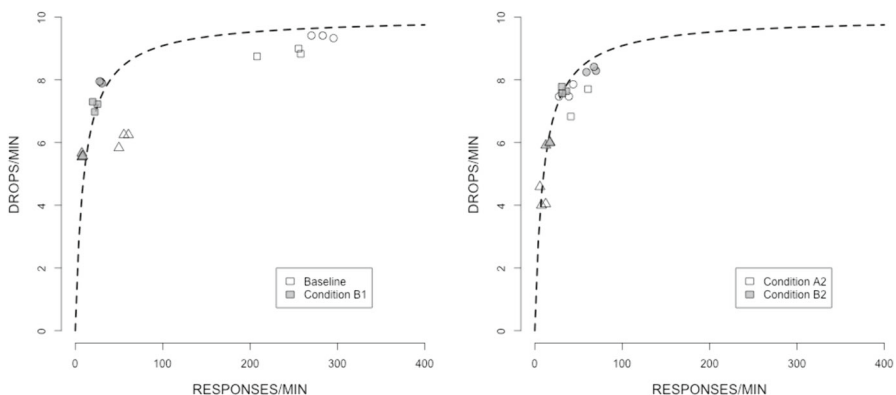


Fig. 6 Rate of drops as a function of response rate. The *left panel* shows data from the first pair of conditions, while the *second panel* shows data from replication. *Dashed curves* represent Baum's (1981) RFF for the VI 6s schedule. Each shape represents a triad of participants who worked side-by-side. Data from de Toledo et al. (2022)

no significant differences in reinforcement rates. In all cases, the individual losses resulting from spacing were always less than two drops per minute.

That result is partially due to the asymptotic nature of the VI RFF, but even during the Baseline condition, participants within each trial presented fairly close response rates. This apparent synchrony suggests that instructions or perhaps the fact that participants worked side-by-side could be sufficient to produce some coordination. This argument is supported by the sociological literature that reports the positive effects of communication on cooperation in a range of group tasks (e.g., Wichman 1970; Kolllock 1998). Furthermore, the frequency of each participant's behavior was also clearly signaled: with each response, the participant's quadrant on all monitors flashed. The flashing of other participants' quadrants could have also contributed to establishing a common pacing within each triad.

Figure 7 shows results from the same procedure with different triads of participants, but for these participants the individual schedules superimposed on interdependent reinforcement was a VR 2 instead of a VI 6 s. These data reveal a similar effect regarding response rates. However, in VR schedules, reinforcement depends solely on the response rate. Therefore, the social IRT resulting from interdependent reinforcement contingencies led to significantly lower rates of individual drops per minute for most triads. Contrary to the VI conditions previously analyzed, the individual lost drops per minute, even when the mutual reinforcement contingency was no longer in place (Condition A2).

At first, it might seem that de Toledo et al. (2022) successfully established a conflict between individual and social payoffs. Nevertheless, these differences may be an artifact produced by differences between individual and interdependent reinforcers. At the experiment's outset, participants were informed that every ten drops delivered to an individual bottle would be worth R\$ 0.01 (Brazilian money). In contrast, bonuses (i.e., interdependent reinforcement) delivered to the common water tank would be worth R\$ 0.03 for each participant. In other words, a single unit of an interdependent

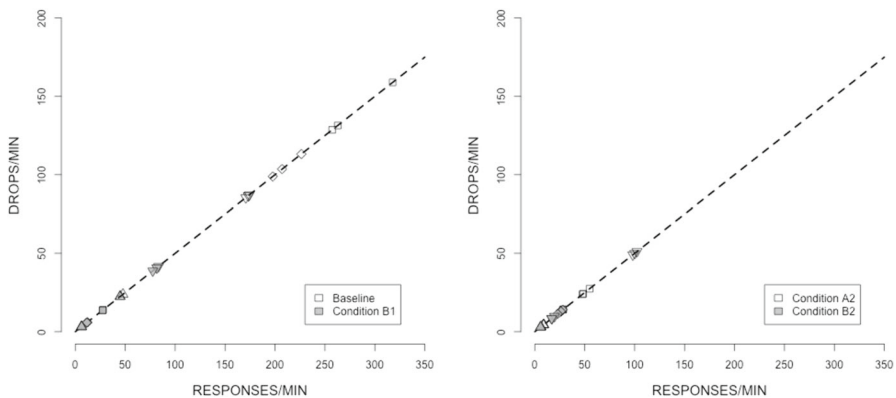


Fig. 7 Rate of drops as a function of response rate. The *left panel* shows data from the first pair of conditions, while the *second panel* shows data from replication. *Gray dashed curves* represent RFF for the VR 2 schedule. Each shape represents a triad of participants who worked side-by-side. Data from de Toledo et al. (2022)

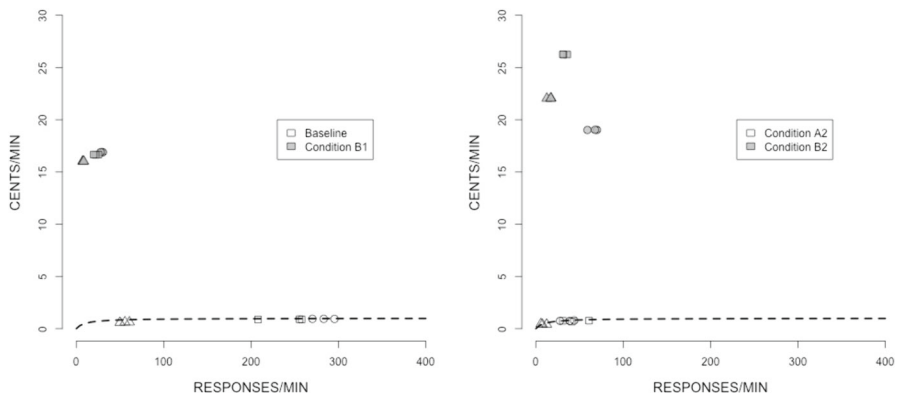


Fig. 8 Rate of Brazilian cents (R\$) per minute as a function of response rate. The *left panel* shows data from the first pair of conditions, and the *second panel* shows data from replication. *Gray dashed curves* represent RFF for the VI 6 s schedule for individual gains. Each shape represents a triad of participants who worked side-by-side. Data from de Toledo et al. (2022)

reinforcer was worth three times a unit of an individual reinforcer. A consequence of this difference is that a strong bias toward coordination would maximize monetary gain. This relation can be observed in Figs. 8 and 9.

Filled shapes in Fig. 8 do not fit the predicted RFF for individual gains because they represent monetary gains from conditions when interdependent reinforcement was available. In these conditions, it is clear that participants could increase gain with relatively small response rates. The same might be said about participants in triads who worked in an individual VR schedule, as shown in Fig. 9.

If we accept the argument that the relevant reinforcer was money in de Toledo et al.'s (2022) experiment, then Figs. 8 and 9 show that there was no actual conflict

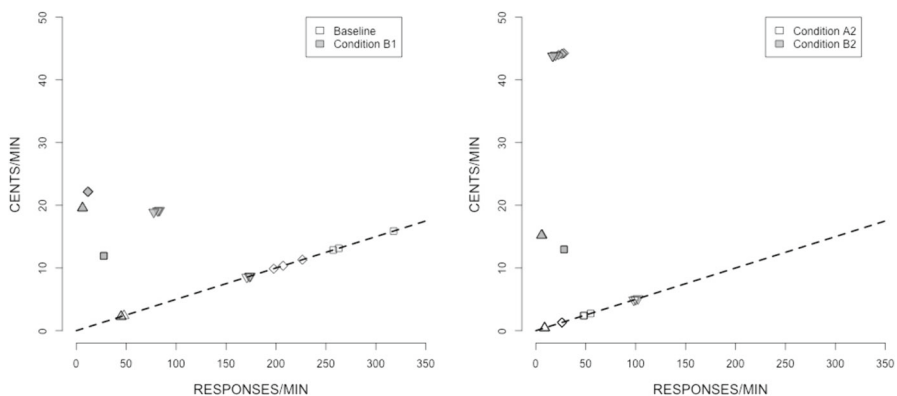


Fig. 9 Rate of cents (R\$) per minute as a function of response rate. The *left panel* shows data from the first pair of conditions, and the *second panel* shows data from replication. *Gray dashed curves* represent RFF for the VR 2 schedule for individual gains. Each shape represents a triad of participants who worked side-by-side. Data from de Toledo et al. (2022)

between social and individual contingencies because schedules requirements could accommodate both interdependent and individual reinforcement. The losses in terms of drops per minute were compensated for by the differences in monetary amounts attributed to interdependent and individual reinforcers.

Therefore, the experimental literature on social behavior has posed relevant questions and answered them partially.

One of the concerns we addressed in our introduction is the notion of interdependent reinforcement and the units of analysis that are constructed based on its effects (Schmitt, 1998). Our experiments aimed to clarify this issue, but as we have shown, the experimental arrangements still fail to clearly distinguish between contingencies for individual behavior and for social behavior. This is so because participants can meet the requirements of social contingencies and maximize individual reinforcement at the same time. The present analysis, based on feedback functions, can help to evaluate whether there was a conflict between social and individual contingencies. It is in this sense that a quantitative analysis of social behavior can be decisive.

Following, we will propose a normative model for a more straightforward hypothetical situation that could be experimentally tested. Our model can be seen as a feedback function of social behavior. It could inspire further formulations of situations closer to the typical experiments with social behavior. Implicitly, the model also recognizes the issue of social the IRT as a unit of analysis of social behavior by emphasizing the role of the response rates of two or more individuals behaving in a coordinated manner for the production of interdependent reinforcement.

Modeling interdependent reinforcement

So far, the experimental literature has typically approached social behavior by designing situations in which two or more organisms have to interact to produce reinforcement. This situation was defined by Schmitt (1998) as interdependent reinforcement. Skinner (1953) went so far as to point out that social interactions result in intermittency. However, the modern literature on schedules of reinforcement allows us to go further. Feedback functions can provide some insights about social reinforcement and its particulars.

In experiments with a single participant, feedback functions depended solely on the algorithm set by the experimenter. In interdependent reinforcement situations, one degree of freedom lies with the participant who responds first (i.e., the leader), whose behavior sets the time constraints for another participant's (i.e., the follower) reinforcement. The specifics of this situation vary greatly among experiments. In Tan and Hackenberg (2016), there was no individual reinforcement schedule for the leader, while in de Toledo et al. (2022), a simple schedule was in force (i.e., VI 6 s or VR 2) for all participants. In Tan and Hackenberg, the follower had to respond immediately after the leader up to a limited hold of 500 ms, while in de Toledo et al., the follower could respond after a minimum time had elapsed (e.g., 750 ms). Furthermore, most experiments do not dictate which participant is the leader or the follower, and these roles are allowed to vary throughout the experiment.

For clarity, herein, we will work with two assumptions. First, we assume fixed roles: one participant is always the leader, and the other is always the follower. Second, we disregard the effects of communication or other sources of stimulus control over the follower's behavior. Our situation is analogous to the organisms working in separate rooms, but it is still social in that participants make contact through interdependent reinforcement, much as people cooperating remotely. However, it follows our assumptions that the leader works almost individually, while the follower's behavior should track the leader's behavior to produce reinforcement. In this case, while the RFF for the leader resembles an individual reinforcement situation, the RFF for the follower is the joint product of the experimental task and the leader's behavior.

For instance, de Toledo et al. (2022) established that followers should respond after a minimum interval since the leaders' last response. If the follower responded too soon (e.g., ≤ 500 ms after the leader's response), reinforcement was postponed, and a new alternation would begin. Therefore, the follower participant is exposed to a schedule similar to differential reinforcement of low rates (DRL). However, it is not a fixed 500 ms DRL because the leader controls when the fixed inter-assignment interval starts to count.

To model this situation, we must consider the leader's behavior. If there is an individual schedule in order, like in de Toledo et al. (2022), it is reasonable to assume that the leader's response rate depends on the rate of reinforcement contingent on the task and alternative sources of reinforcement (Herrnstein, 1970). If no individual schedule is superposed, the leader will receive indirect feedback depending on the follower's performance. More specifically, the leader would produce delayed reinforcement, and the delay would be the sum of the fixed portion of the DRL (e.g., 500 ms) and a variable portion depending on the follower's average IRT. Whatever the case, if the leader's behavior reaches a stable state, it becomes possible to analyze the schedule for the follower.

Here, we assume the leader's behavior follows a Poisson distribution. This assumption is important but not fundamental to our analysis. One could assume any other distribution of responses (e.g., Nevin & Baum 1980). The necessary component here is a known distribution that describes the structure of the leader's behavior. We can estimate the probability of responses within an interval from such a distribution. For instance, if the leader's behavior follows a Poisson distribution, at every instant in time, there is a probability of occurrence of a response. Therefore, within a period T , k responses can occur with a certain probability, that is, $P(B = k)$, where B stands for responses.

$$P(B = k) = \frac{e^{-\lambda T} (\lambda T)^k}{k!}, \quad k = 0, 1, 2, \dots, \infty \quad (1)$$

In Eq. 1, the critical parameter is λ , which represents the average response rate after stability. This formulation concerns the follower participant because it can be used to calculate the probability that the leader has produced at least one response within an interval equals T . It follows from Eq. 1 that the probability of at least one response within T time units is given by:

$$P(B \neq 0) = 1 - e^{-\lambda T} \quad (2)$$

For instance, if the shortest IRT for a follower participant equals 0.3 s, at the end of every $T = 0.3$, there is a probability that the leader initiated an interaction. Such probability depends on λ (i.e., average response rate of the leader) and can be estimated by Eq. 2. Assuming $\lambda = 100$ responses minute, there is a probability of 0.39353 that the follower will respond at least once until 0.3 s. Here, 0.3 s is arbitrary. A more concrete estimate of T could consider the distribution of inter-response times produced by the participant (Millenson, 1963). In that case, Eq. 2 would model the ongoing probability that the leader has produced at least one response, offering the follower the opportunity to produce mutual reinforcement.

Interestingly, in such conditions, the follower participant faces a dilemma: responding slowly maximizes efficiency (since the cumulative probability of a single response by the leader approaches unity) but falls short of the maximum reinforcement rate. On the other hand, responding faster increases the reinforcement rate, but responding too fast may postpone reinforcement to infinity.

This situation resembles a VDRL schedule; responses during the inter-assignment interval postpone reinforcement for an average period equal to the schedule size. The quantitative properties of this schedule were proposed by Silveira et al. (2023). Through computational simulations, they were able to propose an RFF for the VDRL and explore some of its quantitative properties.

For the social situation to be the strict VDRL proposed by Silveira et al. (2023), some additional procedural details should be observed. For instance, further responses by the leader should reset the timer. If that is true, the reinforcement schedule for the follower shares this property with a VDRL, its size in seconds would be given by:

$$\mu_{VDRL} = \frac{T'}{P(\bar{B})} \quad (3)$$

In Eq. 3, μ_{VDRL} is the average size of the VDRL, where T' is the minimum inter-assignment time for reinforcement, while p is the probability that a reinforcer will be assigned after each T' interval. In the case of social reinforcement, T' could be, for instance, the smallest IRT produced by the leader, while p is the probability of at least one response by the leader within T as calculated by Eq. 2. However, in most social cases, the VDRL is not exactly as initially proposed by Silveira et al. (2023). For instance, in the task used by de Toledo et al. (2022), the follower should wait a fixed time (e.g., .5 s) before responding to produce a reinforcer. Therefore, the size of the VDRL for the follower participant is:

$$\mu_{VDRL} = \mu_{DRL} + \frac{T'}{1 - e^{-\lambda T}} \quad (4)$$

Silveira et al. (2023) produced a series of normative rules regarding the VDRL. How well these rules apply to the interdependent reinforcement situation depends on a series of additional details, including stimuli associated with responding by the other participant, stability of the leader's behavior, and contingencies for the individual behavior of the follower. Therefore, values obtained in an actual experiment could deviate significantly from Silveira et al.'s predictions. Still, we predict that the function

should maintain its general form since the social situation resembles the feedback system for the VDRL because both can be described by two competing processes (Killeen, 1975; Silveira et al., 2023). If response rates are low, reinforcement falls short due to contingency; conversely, high response rates are punished since reinforcement is frequently postponed.

Because of that similarity, we argue that this exercise could provide insights into further improving the model and programming social experiments. With this caveat in mind, we expect the feedback function for the follower's behavior to approach the VDRL RFF described by Silveira et al. (2023). According to Silveira et al., this feedback function is given by:

$$R = \frac{60}{V} \left(\exp \left(-\frac{V}{e^6} B \right) - \exp \left(-\frac{V}{e^5} \right) \right) \quad (5)$$

In Eq. 5, the only parameter is V , the VDRL size. In our example, V may be calculated through Eq. 4. Since the RFF is a constraint for the reinforcement rate, the outcomes for followers should roughly fit the RFF. Furthermore, given the form of the function, there is a specific response rate that maximizes payoff. According to Silveira et al. (2023), the response rate that maximizes reinforcement for the follower participant is given by:

$$B_{Max} = \frac{e^6}{(e - 1)V} \quad (6)$$

Again, V represents the VDRL size, in our previous example, 1.26 s. Therefore, the response rate that maximizes reinforcement is approximately 186.3 responses per minute. Figure 10 shows the feedback function and optimal response rate for the hypothetical follower participant.

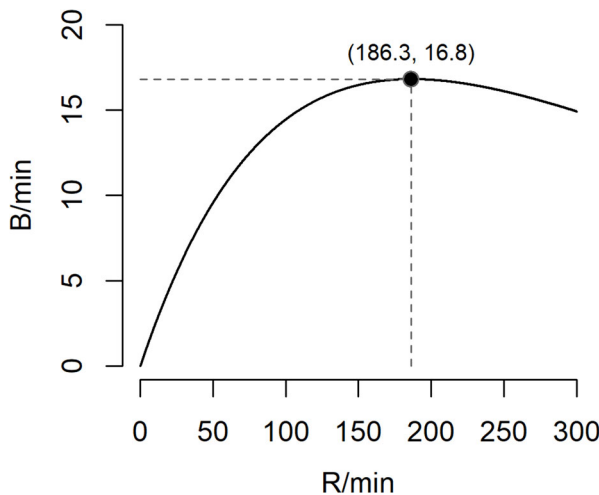


Fig. 10 RDRL 1.26s feedback function. Dashed gray lines represent optimal response and reinforcement rates from coordinates above the point of maximal payoff

Since the response rate of the leader controls the size of the VDRL, we can use Eq. 4 to extrapolate the example in Fig. 10 and build a generalized relation between the leader's response rate and the resulting VDRL size for the follower. Figure 11 represents such a relation for six different values of μDRL (see Eq. 4).

Figure 11 shows that as the leader response rates increase to infinity, the VDRL size approaches an asymptote that is equal to the sum of the μDRL (the fixed portion) and T' from Eq. 3, meaning that the follower participant's rate of reinforcement is only constrained by the fixed portion of the schedule and by the leader's performance, as demonstrated by

$$\lim_{\lambda \rightarrow \infty} \left(\mu DRL + \frac{T'}{1 - e^{-\lambda T}} \right) = \mu DRL + T' \quad (7)$$

The T' in Eq. 7 stands for the smallest IRT observed by the leader. In our previous example, we assumed a minimum IRT of 0.3 s, roughly matching actual response rates for mouse clicking. However, other response topographies (e.g., pulling a lever or spinning a revolving crank) would result in different constraints. It is also worth noting that extremely low response rates by the leader would produce ever-increasing VDRL sizes for the follower.

Even though our predictions can be tested, they are also limited compared to the typical social experiment. For instance, in de Toledo et al. (2022), a new response by the leader would also postpone reinforcement, restarting the social DRL for the follower. Therefore, from the follower's perspective, the situation resembles a VDRL with a limited hold, where the sizes of the VDRL and the limited hold depend on the leader's behavior. In this situation, if the leader's average IRT is less than the fixed portion of DRL, the reinforcement rate would decrease dramatically. Also, de Toledo

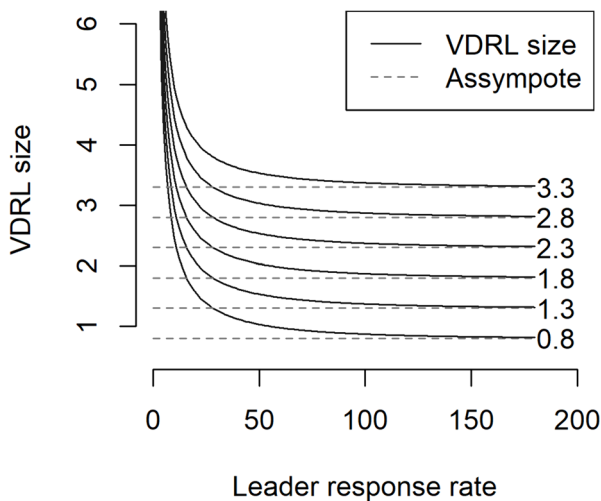


Fig. 11 The solid curves represent VDRL size functions for six different values of μDRL (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 ms). Dashed gray lines represent asymptotes for increasing leaders' response rates. The respective asymptotic values are represented by the numbers at the end of each curve

et al.'s participants could alternate between leading or following, meaning there was no punishment if the follower started an interaction. Therefore, the decreasing portion of the RFF (punishment for high response rates) could be less steep. Moreover, de Toledo et al. worked with triads of participants, another source of complexity to the model, considering that actual response distributions vary within and between participants.

There are still other factors that should be considered for future investigation similar to de Toledo et al. (2022), which superimposed interdependent reinforcement with individual schedules (i.e., VI 6s or a VR 2). It is plausible to assume that, despite the differences in amount, collective and individual reinforcers cannot be summed since some degree of interaction is expected. These reinforcers may be qualitatively different and, therefore, not be perfectly substitutable (Rachlin, Kagel, & Battalio, 1980). Beyond that, participants worked side-by-side, so communication and social distance could play a role in how participants value one another's gains (Rachlin & Jones, 2008). Another limitation is that our model considers responses as discrete events, which could be an issue in experimental tasks involving response topographies with longer durations. Our model assumes an unwavering leader-follower relationship. This clearly does not happen in most behavioral experiments, where there is a constant alternation of these roles. In this sense, our assumption can be seen as a limitation of the model. However, the model as a whole can stimulate experiments and analytical solutions to account for more complex social interactions.

The simplicity of our model compared to actual experiments shows how far behind we are regarding normative rules for experiments involving social interactions. Still, we should not abandon them altogether since they are crucial in planning experiments. These rules can guide researchers toward creating tasks that pose an actual conflict between individual and social gains. Consequently, the experimental study of social behavior would greatly benefit from studies addressing the quantitative properties of such schedules of reinforcement.

On the other hand, the lack of normative rules can also invite researchers to review their procedures. Research designs for the study of social behavior are often complex enough to hinder modeling. It may be worth stepping back and departing from simpler preparations that allow for a clear distinction between social and individual outcomes and their interactions.

Conclusion

We have argued that normative rules about reinforcement schedules are crucial in describing social behavior and planning experiments that create a conflict between individual and social contingencies. Dynamics present in individual reinforcement schedules can explain much of what is considered "social" behavior. At the same time, schedules dynamics may be especially relevant in characterizing social behavior. As an example, we analyzed situations in which the participant responds to someone who initiates the social episode (i.e., the follower's response under the control of the leader's response, in Skinner's 1962, terms).

From the follower's perspective, this situation can be characterized as responding in a simple limited hold schedule or a variable DRL schedule. Leader and follower

behaviors may be united by interdependent reinforcement, but their connection results in a single reinforcement schedule.

The data we have reviewed here clearly demonstrate the importance of addressing reinforcement schedules in investigating social behavior. Such a consideration may have significant repercussions on the definition of social behavior, including how it is measured and how it differs from individual behavior (Zeiler, 1977). In adequate conditions, the results of experiments on social behavior like those described here can be seen as a choice between individual or collective work. Choices, in turn, are controlled by reinforcement rates related to each of these alternatives (Herrnstein, 1970).

This view approaches the analysis of social behavior and the correlational-based law of effect proposed by Baum (1973, 2018). This is not entirely new. There is some evidence that the generalized matching law might accurately describe collective behavior of groups of individuals, both human (Kraft & Baum, 2001a; Reed, Critchfield, & Martens, 2006) and nonhuman (Bell & Baum, 2002; Kraft & Baum, 2001b; Tan & Hackenberg, 2012; Tan et al., 2014). However, to our knowledge, no study is dedicated explicitly to conflict between individuals and interdependent outcomes in social behavior. This choice-based view emphasizes the correlation between rates of behavior and reinforcement and how feedback functions constrain reinforcement. Reinforcement interdependency, as suggested by Schmitt (1998), introduces a new dimension to be considered in a social episode: the leader's behavior as a schedule parameter to the follower. Our main contribution is to advance the analysis of the role of feedback functions and the social IRTs to understand social interactions in terms of reinforcement schedules.

Funding Marcelo Benvenuti is member of the National Institute of Science and Technology on Behavior, Cognition, and Teaching (INCT - ECCE), supported by São Paulo Research Foundation (FAPESP, grant No. 2014/50909-8), the Brazilian Council for Scientific and Technological Development (CNPq; grant #465686/2014-1), and the Coordination for the Improvement of Higher Education Personnel (CAPES; grant #88887.136407/2017-00).

João Lucas Bernardy is supported by a Post-doctoral fellowship granted by The São Paulo Research Foundation (FAPESP, grant #2023/07516-4).

The first version of this work was presented at the 45th Annual Conference of the Society for the Quantitative Analyses of Behavior (SQAB) in Denver, CO in May 2023. The presentation was supported by São Paulo Research Foundation (FAPESP; grant #2023/02669-7).

Declarations

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript. All previously published figures were reproduced with authorization.

Conflict of interest The authors declare no any other Conflict of interest concerning the submission of this manuscript.

References

- Azrin, N. H., & Lindsley, O. R. (1956). The reinforcement of cooperation between children. *Journal of Abnormal and Social Psychology*, 52(1), 100–102. <https://doi.org/10.1037/h0042490>
- Balliet, D., Tybur, J. M., & Van Lange, P. A. M. (2017). Functional interdependence theory: An evolutionary account of social situations. *Personality and Social Psychology Review*, 21(4), 361–388. <https://doi.org/10.1177/1088868316657965>
- Baum, W. M. (1973). The correlation-based law of effect. *Journal of the Experimental Analysis of Behavior*, 20(1), 137–153. <https://doi.org/10.1901/jeab.1973.20-137>
- Baum, W. M. (1989). Quantitative prediction and molar description of the environment. *The Behavior Analyst*, 12(2), 167–176. <https://doi.org/10.1007/bf03392493>
- Baum, W. M. (2018). Three laws of behavior: Allocation, induction, and covariance. *Behavior Analysis: Research and Practice*, 18(3), 239–251. <https://doi.org/10.1037/bar0000104>
- Bell, K. E., & Baum, W. M. (2002). Group foraging sensitivity to predictable and unpredictable changes in food distribution: Past experience or present circumstances? *Journal of the Experimental Analysis of Behavior*, 78(2). <https://doi.org/10.1901/jeab.2002.78-179>
- Camerer, C. F. (2003). *Behavioral game theory: Experiments in strategic interaction*. Russell Sage Foundation.
- Cohen, D. J., & Lindsley, O. R. (1964). Catalysis of controlled leadership in cooperation by human stimulation. *Journal of Child Psychology and Psychiatry*, 5(2), 119–137. <https://doi.org/10.1111/j.1469-7610.1964.tb02134.x>
- de Carvalho, L. C., dos Santos, L., Regaço, A., Barbosa, T. B., da Silva, R. F., de Souza, D. d. G., & Sandaker, I. (2018). Cooperative responding in rats maintained by fixed- and variable-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 110(1), 105–126. <https://doi.org/10.1002/jeab.457>
- de Carvalho, L. C., dos Santos, L., Regaço, A., Couto, K. C., de Souza, D. d. G., & Todorov, J. C. (2020). Cooperative responding in rats: II. Performance on fixed-ratio schedules of mutual reinforcement. *Journal of the Experimental Analysis of Behavior*, 114(3), 291–307. <https://doi.org/10.1002/jeab.628>
- de Toledo, T., & Benvenuti, M. (2015). Efeitos da exigência de desempenhos entrelaçados sobre linha de base em esquemas simples de reforço [Effects of a demand for interlocking performances superimposed on baseline in simple schedules of reinforcement]. *Revista Brasileira de Análise do Comportamento*, 11(2), 184–194. <https://doi.org/10.18542/rebac.v11i2.1971>
- de Toledo, T., Benvenuti, M., Sampaio, A., Marques, N., Cabral, P., & Araújo, L. (2015). Free culturant: A software for the experimental study of behavioral and cultural selection. *Psychology and Neuroscience*, 8(3). <https://doi.org/10.1037/pne0000016>
- de Toledo, T.F.N., Benvenuti, M.F.L., Marques, N.S., & Glenn, S. S. (2022). Schedule Performance as a Baseline for the Experimental Analysis of Coordinated Behavior: Same or Different Units of Analysis?. *Psychological Record*, 72, 185–195. <https://doi.org/10.1007/s40732-022-00510-4>
- Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*.
- Glenn, S. S., Malott, M. E., Andery, M. A. P. A., Benvenuti, M., Houmanfar, R. A., Sandaker, I., ... Vasconcelos, L. A. (2016). Toward consistent terminology in a behaviorist approach to cultural analysis. *Behavior and Social Issues*, 25(1), 11–27. <https://doi.org/10.5210/bsi.v25i0.6634>
- Glenn, S. S. (2004). Individual behavior, culture, and social change. *The Behavior Analyst*, 27(2), 133–151. <https://doi.org/10.1007/BF03393175>
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, 13(2), 243–266. <https://doi.org/10.1901/jeab.1970.13-243>
- Hull, C. (1943). *Principles of behavior: An introduction to behavior theory*. New York: Appleton-Century-Crofts.
- Keller, F. S., & Shoenfeld, W. N. (1950). *Principles of Psychology*. New York: Appleton-Century-Crofts.
- Killeen, P. (1975). On the temporal control of behavior. *Psychological Review*, 82(2), 89–115. <https://doi.org/10.1037/h0076820>
- Kollock, P. (1998). Social dilemmas: The anatomy of cooperation. *Annual Review of Sociology*, 24, 183–214. <https://doi.org/10.1146/annurev.soc.24.1.183>
- Kraft, J. R., & Baum, W. M. (2001a). Group choice: The ideal free distribution of human social behavior. *Journal of the Experimental Analysis of Behavior*, 76(1). <https://doi.org/10.1901/jeab.2001.76-21>
- Kraft, J. R., & Baum, W. M. (2001b). Group choice: The ideal free distribution of human social behavior. *Journal of the Experimental Analysis of Behavior*, 76(1), 21–42. <https://doi.org/10.1901/jeab.2001.76-21>

- McElreath, R. (2013). *Mathematical models of social Evolution*.
- Millenson, J. R. (1963). Random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 6(3), 437–443. <https://doi.org/10.1901/jeab.1963.6-437>
- Nevin, J. A., & Baum, W. M. (1980). Feedback functions for variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 34(2), 207–217. <https://doi.org/10.1901/jeab.1980.34-207>
- Platt, J. R., Kuch, D. O., & Bitgood, S. C. (1973). Rats' lever-press durations as psychophysical judgments of time 1. *Journal of the Experimental Analysis of Behavior*, 19(2). <https://doi.org/10.1901/jeab.1973.19-239>
- Rachlin, H. (1978). A molar theory of reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, 30(3), 345–360. <https://doi.org/10.1901/jeab.1978.30-345>
- Rachlin, H. (1989). *Judgment, decision, and choice: A cognitive/behavioral synthesis*. W.H: Freeman.
- Rachlin, H., & Jones, B. A. (2008). Altruism among relatives and non-relatives. *Behavioural Processes*, 79(2), 120–123. <https://doi.org/10.1016/j.beproc.2008.06.002>
- Rachlin, H., Kagel, J. H., & Battalio, R. C. (1980). Substitutability in time allocation. *Psychological Review*, 87(4), 355–374. <https://doi.org/10.1037//0033-295x.87.4.355>
- Reed, D. D., Critchfield, T. S., & Martens, B. K. (2006). The generalized matching law in elite sport competition: Football play calling as operant choice. *Journal of Applied Behavior Analysis*, 39(3), 281–297. <https://doi.org/10.1901/jaba.2006.146-05>
- Schmitt, D. R. (1998). Social Behavior. *Handbook of research methods in human operant behavior* (pp. 471–505). Boston, MA: Springer US.
- Schmitt, D. R., & Marwell, G. (1968). Stimulus control in the experimental study of cooperation. *Journal of the Experimental Analysis of Behavior*, 11(5), 571–574. <https://doi.org/10.1901/jeab.1968.11-571>
- Silveira, P. S. P., de Oliveira Siqueira, J., Bernardy, J. L., Santiago, J., Meneses, T. C., Portela, B. S., & Benvenuti, M. F. (2023). Modeling VI and VDRL feedback functions: Searching normative rules through computational simulation. *Journal of the Experimental Analysis of Behavior*, 119(2), 324–336. <https://doi.org/10.1002/jeab.826>
- Skinner, B. F. (1935). The generic nature of the concepts of stimulus and response. *The Journal of General Psychology*, 12(1). <https://doi.org/10.1080/00221309.1935.9920087>
- Skinner, B. F. (1938). *The Behavior of Organisms*. New York: Appleton-Century-Crofts.
- Skinner, B. F. (1953). *Science and Human Behavior*. New York: Macmillan.
- Skinner, B. F. (1962). Two “Synthetic Social Relations”. *Journal of the Experimental Analysis of Behavior*, 5(4), 531–533. <https://doi.org/10.1901/jeab.1962.5-531>
- Tan, L., & Hackenberg, T. (2012). Social foraging in rats: Group and individual choice in dynamic environments. *Revista mexicana de análisis de la conducta*, 38(2).
- Tan, L., Sosa, F., Talbot, E., Berg, D., Eversz, D., & Hackenberg, T. D. (2014). Effects of predictability and competition on group and individual choice in a free-ranging foraging environment. *Journal of the Experimental Analysis of Behavior*, 101(2). <https://doi.org/10.1002/jeab.76>
- Tan, L., & Hackenberg, T. D. (2016). Functional analysis of mutual behavior in laboratory rats (*Rattus norvegicus*). *Journal of Comparative Psychology*, 130(1), 13–23. <https://doi.org/10.1037/com0000015>
- Tolman, E. C. (1922). A new formula for behaviorism. *Psychological Review*, 29(1), 44–53. <https://doi.org/10.1037/h0070289>
- Velasco, S., Benvenuti, M., & Tomanari, G. (2012). Metacontingencies, experimentation and nonhumans: Searching for conceptual and methodological advances. *Revista Latinoamericana de Psicología*, 44(1).
- Velasco, S., Benvenuti, M., Sampaio, A., & Tomanari, G. (2017). Cooperation and metacontingency in pigeons. *Psychological Record*, 67(4). <https://doi.org/10.1007/s40732-017-0256-x>
- Wichman, H. (1970). Effects of isolation and communication on cooperation in a two-person game. *Journal of Personality and Social Psychology*, 16(1), 114–120. <https://doi.org/10.1037/h0029845>
- Zeiler, M. (1977). Schedules of reinforcement: The controlling variables. *Handbook of operant behavior*.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.