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THE EFFECT OF PERIODICITY OF REINFORCEMENT ON FOOD ACCUMULATION[1]

EL EFECTO DE LA PERIODICIDAD DEL REFORZAMIENTO SOBRE LA ACUMULACIÓN DE COMIDA

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Abstract

Recent studies on food accumulation have shown that the rate of food-procuring responses increases by delaying the delivery of food (i.e., an increasing delay gradient). However, these studies have only delivered the food periodically, which could lead to the establishment of a behavior sequence between successive food deliveries. Therefore, the increasing delay gradient could be due to the establishment of different behavior sequences, composed of more food-procuring responses as the delay of reinforcement is lengthened. The present study investigated whether the increasing delay gradient occurs when the establishment of a behavior sequence is hindered by eliminating the periodicity of reinforcement from a situation of food accumulation. The periodicity of reinforcement was eliminated by using a variable delay in Experiment 1 and a variable inter-trial interval in Experiment 2. It was found that the increasing delay gradient occurred both with periodic and aperiodic reinforcement, which may imply that it does not depend on the establishment of a behavior sequence. In contrast, the increasing delay gradient was attributed to the temporal distribution of the food-procuring period within the inter-reinforcement time.

Keywords: food accumulation, delay gradient, periodicity of reinforcement, behavior sequences, rats

Resumen

Estudios recientes sobre acumulación de comida han mostrado que la frecuencia de las respuestas procuradoras de comida aumenta al demorar la entrega de la comida (i.e., un gradiente creciente de demora). Sin embargo, dichos estudios solo han entregado la comida periódicamente, lo que podría provocar el establecimiento de una secuencia de conducta entre las entregas de

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comida sucesivas. Por tanto, el gradiente creciente de demora podría deberse al establecimiento de distintas secuencias de conducta, compuestas por más respuestas procuradoras de comida conforme se alarga la demora de reforzamiento. El presente estudio investigó si el gradiente creciente de demora ocurre cuando se dificulta el establecimiento de una secuencia de conducta al eliminar la periodicidad del reforzamiento en una situación de acumulación de comida. La periodicidad del reforzamiento se eliminó usando una demora variable en el Experimento 1 y un intervalo entre ensayos variable en el Experimento 2. Se encontró que el gradiente creciente de demora ocurrió tanto con reforzamiento periódico como aperiódico, lo que podría implicar que no depende del establecimiento de una secuencia de conducta. En cambio, el gradiente creciente de demora se atribuyó a la distribución temporal del período de procuración de comida dentro del intervalo entre reforzadores.

Palabras clave: acumulación de comida, gradiente de demora, periodicidad del reforzamiento, secuencias de conducta, ratas

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By delivering a food pellet each time a rat presses a lever, many lever presses occasionally occur before food consumption, so that many pellets "accumulate" on the food cup (e.g., Cole, 1990; Killeen, 1974). Originally, food accumulation was attributed to the "effort" involved in obtaining the food, as it was shown that the amount of food accumulated increases by removing the lever from the food cup (e.g., Killeen & Riggsford, 1989; Reilly et al., 2012, Experiment 1) or by increasing the force and number of the presses on a second lever required to obtain the food (e.g., Killeen et al., 1981; see also Yankelevitz et al., 2008). However, it has been argued that all the manipulations of effort could be reduced to the delay of reinforcement (cf. Cruz & Bruner, 2014), since the delay between the procurement and the delivery of food varies concomitantly with such manipulations, and the amount of food accumulated increases by lengthening the delay of reinforcement, even without explicitly manipulating effort (e.g., French & Reilly, 2017; Killeen et al., 1981, Experiment 2).

Recent studies on food accumulation have shown that lengthening the delay of reinforcement not only increases the amount of food accumulated but also the rate of food-procuring responses. For example, Bruner et al. (2017, Experiment 1) exposed rats to a situation of food accumulation with three components. First, during a food-procuring component, a lever was extended for 20 s. Then, the lever was retracted and a delay component started, the duration of which varied between 30-session conditions by 0, 1, 4, 16, and 32 s. At the end of the delay, a food pellet was delivered for each lever press during the food-procuring component, and a 20-s inter-trial interval (ITI) started. They found that lengthening the delay component increased the number of pellets accumulated and, consequently, the rate of lever pressing (i.e., an increasing delay gradient). The latter finding is noteworthy, as the common effect of lengthening the delay between a response and a reinforcer is a decrease in the response rate (i.e., a decreasing delay gradient; cf. Lattal, 2010; Renner, 1964; Tarpy & Sawabini, 1974).

Since behavior occurs continuously over time (cf. Schoenfeld & Farmer, 1970), varying the temporal relation between the food-procuring responses and food delivery has also involved the occurrence of other behaviors, such as grooming, walking, scratching, gnawing, or approaching the food cup (Anderson & Shettleworth, 1977; Shettleworth, 1975). When behaviors such as these occur in a consistent and regular order, without any change in exteroceptive stimulation, they have been considered to form a behavior sequence (cf. Catania, 2013; Kelleher, 1966). There is evidence that the establishment of a behavior sequence may enhance the temporal control over responding, by fulfilling a mediating function of the passage of time (cf. Richelle & Lejeune, 1980, pp. 188-192; Sidman, 1960, pp. 364-381). For instance, the inter-response time required by a differential reinforcement of low rates (DRL) schedule is established faster when a behavior sequence develops between successive responses (e.g., Glazer & Singh, 1971). Furthermore, the response rate does not decay by lengthening the delay of reinforcement when a behavior sequence is established between responding and reinforcement (e.g., Ferster, 1953).

The establishment of a behavior sequence has frequently been observed by delivering a reinforcer periodically with respect to another event, such as a stimulus (e.g., Ferster, 1953), a response (e.g., Azzi et al., 1964), or a previous reinforcer (e.g., Skinner, 1948). Similarly, a behavior sequence could have been established in recent studies on food accumulation, as the food has been delivered periodically with respect to the retraction of a lever (e.g., Bruner et al., 2017), the occurrence of a lever press (e.g., Flores & Bruner, 2018), or the previous delivery of food (e.g., Gaistardo & Bruner, 2021). Moreover, varying the delay of reinforcement could have modified the composition of such sequences, as it has been shown that changing the temporal distribution of reinforcement modifies the behaviors that compose a sequence or the order in which such behaviors occur (e.g., Lucas et al., 1988; Roper, 1978). Therefore, the increasing delay gradient could be due to the establishment of different behavior sequences, composed of more lever presses as the delay of reinforcement is lengthened.

To investigate whether the temporal control over a response depends on the establishment of a behavior sequence, responding has been compared by permitting or precluding the occurrence of such sequences. Thus, it has been observed that the temporal distribution of responding can be modified either by impeding the occurrence of a behavior in a sequence (e.g., Laties et al., 1969; Reid et al., 1993) or by eliminating the periodicity of reinforcement so that a behavior sequence cannot occur consistently before reinforcement (e.g., Davis & Hubbard, 1972; Staddon & Simmelhag, 1971). Consequently, some authors have explained the temporal control over responding based on the establishment of a behavior sequence (e.g., Ferster & Skinner, 1957; Schoenfeld & Farmer, 1970). However, there is evidence that the temporal control over responding sometimes persist by interrupting the occurrence of a behavior sequence (e.g., Dews, 1962; 1966), so other authors have considered the establishment of a behavior sequence unnecessary for the temporal control over responding (e.g., Dews, 1970; Staddon, 1977).

The purpose of this study was to investigate whether the increasing delay gradient depends on the establishment of a behavior sequence. First, as a baseline, Bruner et al.'s (2017) Experiment 1 was directly replicated, using a fixed delay and a fixed ITI to manipulate the temporal relation between lever pressing and food delivery. Then, to hinder the establishment of a behavior sequence, the periodicity of reinforcement was systematically eliminated. In Experiment 1, the periodicity of reinforcement was eliminated by using a variable delay in combination with a fixed ITI. In Experiment 2, the periodicity of reinforcement was eliminated by using a variable ITI in combination with a fixed delay.

Experiment 1

Studies on delay of reinforcement have frequently observed the establishment of a behavior sequence (e.g., Azzi et al., 1964; Ferster, 1953), from which diverse authors have explained the effect of the delay on responding (e.g., Keller & Schoenfeld, 1950; Schoenfeld & Farmer, 1970). To investigate whether a given effect of the delay of reinforcement depends on the establishment of a behavior sequence, responding with a fixed or a variable delay has been compared, as a variable delay would make the establishment of a behavior sequence less likely. For example, using a concurrent schedule, Cicerone (1976) observed that the response rate with a variable delay is higher than with a fixed delay, showing that "preference" between delayed reinforcers could depend on the establishment of a behavior sequence during the delay. In contrast, van Haaren (1992) found that response acquisition can occur both with a fixed and a variable delay, showing that the establishment of a behavior sequence is unnecessary for a response to be acquired under delayed reinforcement.

Since recent studies on food accumulation have only used fixed delays of reinforcement (e.g., Bruner et al., 2017), the establishment of a behavior sequence could have been involved in the occurrence of the increasing delay gradient. The purpose of this experiment was to investigate whether the increasing delay gradient occurs in a situation of food accumulation when the establishment of a behavior sequence during the delay of reinforcement is hindered by using a variable delay.

Method

Subjects

The subjects were six experimentally naive male Wistar rats, five months old at the beginning of the experiment. Each rat was housed in an individual Plexiglas box with free access to water. The daily access to food (Rodent Laboratory Chow, PMI Nutrition International) was restricted to maintain the subjects at 80% of their ad-lib weight. All subjects were cared following the Mexican Official Standard NOM-062-ZOO-1999 Technical Specifications for Production, Care, and Use of Laboratory Animals (Diario Oficial de la Federación, 2001).

Apparatus

Three experimental chambers (Med Associates Inc. ®, Model ENV-007) were used. A food cup (Med Associates Inc. ®, Model ENV-200 r1AM) was placed at the center of the front panel, 2 cm above the chamber floor, and was connected to a pellet dispenser (Med Associates Inc. ®, Model ENV-203-415R) by a plastic tube. Food pellets weighed 25 mg and were produced by remolding pulverized food (Rodent Laboratory Chow, PMI Nutrition International). A retractable lever (Med Associates Inc. ®, Model ENV-1128), sensitive to 0.15 N downward forces, was placed 6 cm to the left of the food cup and 8 cm above the chamber floor. At the center of the rear panel, 26 cm above the chamber floor, a 27-V houselight was placed. Each chamber was enclosed within a sound-attenuating box (Med Associates Inc. ®, Model ENV-018), equipped with a fan and a white-noise generator (Med Associates Inc. ®, Model ENV-225SM). Experimental events were controlled and recorded with the Med PC-IV software from a computer and an interface (Med Associates Inc. ®, Model SG-503) placed in an adjacent room.

Procedure

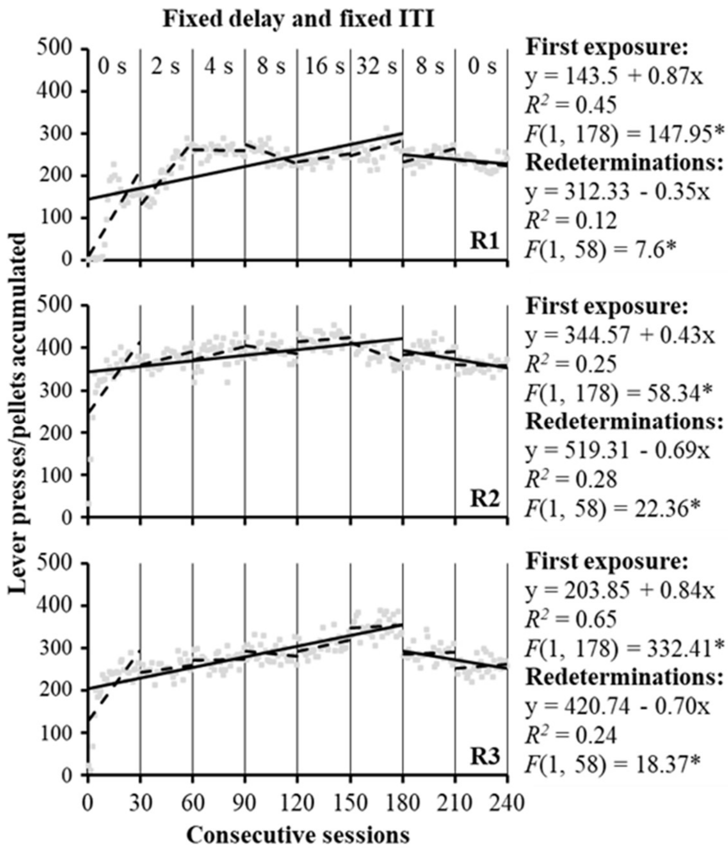
Subjects were directly exposed to the experimental situation, without previous training to press the lever or to approach the food cup. Trials started with a food-procuring component, during which the lever was extended for 20 s. Lever presses had no immediate consequences and were only recorded. At the end of the food-procuring component, the lever was retracted and a delay component started. For three subjects, the length of the delay component was determined by a fixed-time (FT) schedule, the value of which varied between 30-session conditions by 0 (t = 0 s, p = 1; cf. Schoenfeld & Cole, 1972), 2 (t = 2 s, p = 1), 4 (t = 4 s, p = 1), 8 (t = 8 s, p = 1), 16 (t = 16 s, p = 1), and 32 s (t = 32 s, p = 1), in ascending order. In the following two conditions, the 8- and 0-s FT values were redetermined in descending order. For the other three subjects, the length of the delay component was determined by a random-time (RT) schedule, the value of which also varied between 30-session conditions by 0 (t = 0 s, p = 1), 2 (t = 1 s, p = .5), 4 (t = 1 s, p = .25), 8 (t = 1 s, p = .125), 16 (t = 1 s, p = .062), and 32 s (t = 1 s, p = .031), in ascending order. The 8- and 0-s RT values were also redetermined in descending order during the following two conditions. At the end of the delay component, a food pellet was delivered for each lever press during the food-procuring component. The interval between successive pellets was 0.2 s. Trials ended after delivering all the programmed food and then a 20-s ITI started, during which the lever remained retracted until the next food-procuring component. All sessions concluded after 30 trials and were conducted daily at the same hour for each subject. The white-noise generator, the houselight, and the fan were on throughout the sessions.

Results

To describe the effect of varying the length of the fixed delay, Figure 1 shows the number of lever presses/pellets accumulated per session by the subjects exposed to the situation of food accumulation with a fixed delay (gray symbols). Each column corresponds to a delay length and each row corresponds to a subject. Regression analyses of the number of lever presses/pellets accumulated during the first exposure to all the delay intervals and during the redeterminations (solid lines) showed for the three subjects an increasing trend in responding as the delay was lengthened during the first exposure to the delays and a decreasing trend as the delay was shortened during the redeterminations. However, these changes in responding could be due to gradual changes within each delay condition which, together, gave rise to the general trend in responding, regardless of the delay length.

Figure 1

Number of Lever Presses/Pellets Accumulated per Session by the Subjects Exposed to the Situation of Food Accumulation with a Fixed Delay and a Fixed ITI

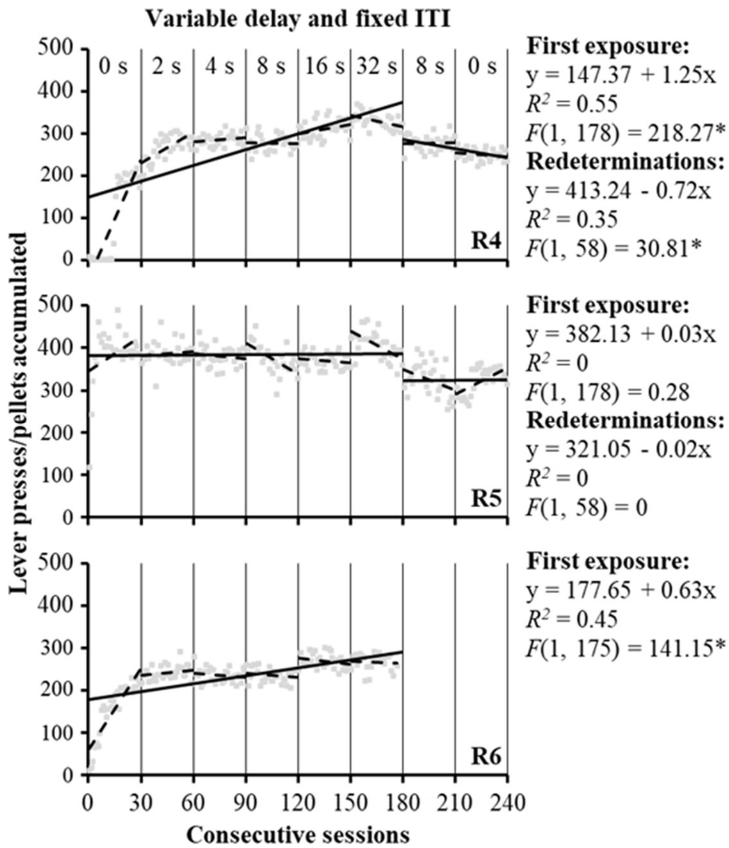


Note. Gray symbols correspond to the number of lever presses/pellets accumulated in each session. The dotted lines correspond to the linear regression of responding within each condition. The solid lines in the first six panels correspond to the overall linear regression of responding during the first exposure to the delays, while the solid lines in the last two panels correspond to the overall linear regression of responding during the redeterminations. Data on the right corresponds to the values of the overall regressions.

* $p < .01$

Figure 2

Number of Lever Presses/Pellets Accumulated per Session by the Subjects Exposed to the Situation of Food Accumulation with a Variable Delay and a Fixed ITI



Note. Gray symbols correspond to the number of lever presses/pellets accumulated in each session. The dotted lines correspond to the linear regression of responding within each condition. The solid lines in the first six panels correspond to the overall linear regression of responding during the first exposure to the delays, while the solid lines in the last two panels correspond to the overall linear regression of responding during the redeterminations. Data on the right corresponds to the values of the overall regressions.
* $p < .01$

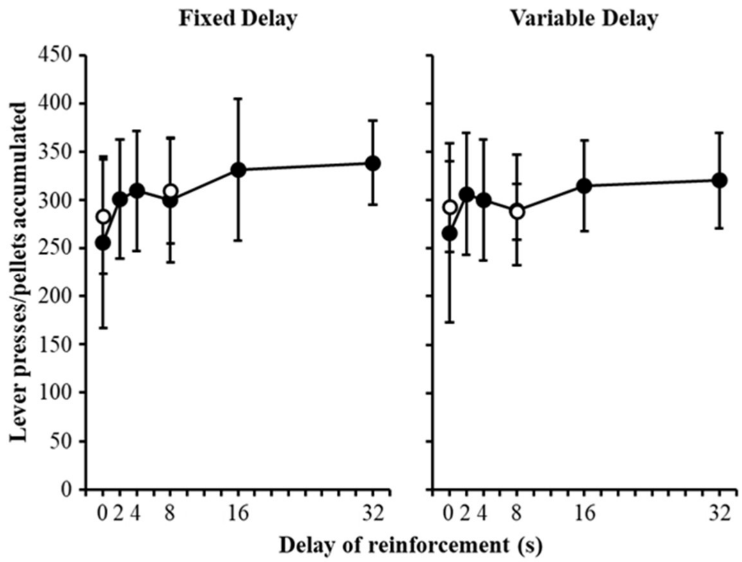
To explore this possibility, regression analyses of the number of lever presses/pellets accumulated per session within each condition were performed (dotted lines). For the three subjects, an increasing trend was obtained within most conditions, but not in all (e.g., for R1 with the 8-s delay or for R2 with the 32-s delay), which could imply that the general trend in responding was due to the changes in the delay length and not to the passage of the sessions.

To describe the effect of varying the length of the variable delay, Figure 2 shows the number of lever presses/pellets accumulated per session by the subjects exposed to the situation of food accumulation with a variable delay (gray symbols). Redeterminations could not be conducted with R6 because this subject died during the last sessions with the 32-s delay. The overall regression analyses (solid lines) showed for R4 and R6 an increasing trend in responding as the delay was lengthened during the first exposure to all the delay intervals and a decreasing trend for R4 as the delay was shortened during the redeterminations. The trend in responding by R5 was flat both during the first exposure to the delays and during the redeterminations, but the absolute level of responding by R5 was lower during the redeterminations. Regression analyses of responding within each condition (dotted lines) did not have a systematic trend for any subject, so the overall trend in responding could be attributed to the changes in the delay length and not to the passage of sessions.

To facilitate the comparison between the effect of lengthening the fixed and the variable delays, Figure 3 shows the mean and standard deviation of lever presses/pellets accumulated per session by the three subjects exposed to the fixed delay (left panel) and by the three subjects exposed to the variable delay (right panel). Values were calculated from the last 10 sessions of each condition. Lever pressing slightly increased by lengthening both the fixed and the variable delay. Conversely, lever pressing decreased by shortening the fixed delay during the redeterminations. Also, lever pressing decreased by shortening the variable delay from 32 to 8 s during the redeterminations. However, lever pressing increased when the variable delay was shortened from 8 to 0 s, although its absolute level was still lower than with the 32-s delay. With both types of delay, the response rate was similar between the first exposure to the 8-s delay and its redetermination, but was slightly lower during the first exposure to the 0-s delay than during its redetermination. The response rate in all conditions was similar with both types of delay.

Figure 3

Mean and Standard Deviation of Lever Presses/Pellets Accumulated per Session by the Three Subjects Exposed to the Situation of Food Accumulation with a Fixed Delay and a Fixed ITI and by the Three Subjects Exposed to the Situation of Food Accumulation with a Variable Delay and a Fixed ITI



Note. Black symbols correspond to the values obtained during the first exposure to the delays, whereas white symbols correspond to the values obtained during the redeterminations. The values of the redeterminations with the variable delay were calculated with two subjects (R4 and R5).

Discussion

The purpose of this experiment was to investigate whether the increasing delay gradient occurs in a situation of food accumulation when the establishment of a behavior sequence during the delay of reinforcement is hindered by using a variable delay. The occurrence of a behavior sequence has frequently been observed in studies on delay of reinforcement (e.g., Azzi et al., 1964; Ferster, 1953), which has raised different explanations of the effect of the delay on responding (Keller & Schoenfeld, 1950; Schoenfeld & Farmer, 1970). However, by comparing responding with a fixed or a variable delay, it has been shown that the establishment of a behavior sequence during the delay of reinforcement may be involved in some circumstances (e.g., Cicerone, 1976), whereas it is unnecessary in others (e.g., van Haaren, 1992). Since the increasing delay gradient was similar by using a fixed or a variable delay in this experiment, it could also be argued that the establishment of a behavior sequence during the delay of reinforcement is unnecessary for the increasing delay gradient to occur.

Lengthening the fixed and the variable delays could have had a similar effect on lever pressing because the temporal distribution of the food-procuring component varied similarly with both types of delay. Across different situations it has been shown that spacing successive presentations of a discriminative stimulus (S^D) increases the response rate in the presence of that S^D (e.g., Taus & Hearst, 1970; Terrace, 1966). Similarly, successive food-procuring components were spaced by lengthening the delay of reinforcement in the present experiment. Since the extension of the lever during the food-procuring component acted as a S^D for lever pressing by setting the occasion in which it was reinforced (cf. Keller & Schoenfeld, 1950), lever pressing may have increased by lengthening the delay because successive lever extensions were spaced concomitantly (cf. Flores & Bruner, 2022). Therefore, as the mean interval between successive lever extensions increased similarly with the fixed and the variable delay, the increasing delay gradient obtained with both types of delay could be attributed to the temporal distribution of the food-procuring component.

Experiment 2

As in the case of delay of reinforcement, the establishment of a behavior sequence has frequently been observed between the delivery of a reinforcer and the next opportunity to procure it (e.g., Skinner, 1948). However, the establishment of such sequences can be hindered by eliminating the periodicity of reinforcement (e.g., Davis & Hubbard, 1972; Staddon & Simmelhag, 1971). Since it has been shown that eliminating the periodicity of reinforcement also changes the pattern (e.g., Zeiler, 1968) and rate of a response (e.g., Mandell, 1980; Tarpy et al., 1984), some authors have explained the effect of the time since the last reinforcement on responding based on the establishment of a behavior sequence (e.g., Ferster & Skinner, 1957; Schoenfeld & Farmer, 1970). In contrast, other authors have considered the establishment of a behavior sequence unnecessary for the time since the last reinforcement to control responding (e.g., Dews, 1970; Staddon, 1977), since interrupting an ongoing behavior sequence does not prevent responding from gradually increasing as the time since the last reinforcement elapses (e.g., Dews, 1962; 1966).

Recent studies on food accumulation have used an ITI to manipulate the time between the delivery of food and the next opportunity to procure it (e.g., Bruner et al., 2017). However, Gaistardo and Bruner (2021) showed that the effect of the delay of reinforcement on food accumulation also depends on the length of the ITI. They exposed rats to a situation of food accumulation similar to that used by Bruner et al. The delay of reinforcement also varied between 30-session conditions by 0, 1, 4, 8, 16, and 32 s. However, the ITI length varied between 5, 10, 20, 40, and 80 s, assigning three subjects to each length. Although they replicated the increasing delay gradient with all the ITI lengths, the increasing delay gradient became gradually higher as the ITI was longer, showing that the ITI is also a parameter of the effect of the delay of reinforcement on food accumulation.

Since recent studies on food accumulation have only used fixed ITIs (e.g., Gaistardo & Bruner, 2021), the occurrence of the increasing delay gradient could also have involved the establishment of a behavior sequence during the ITI. The purpose of this experiment was to investigate whether the increasing delay gradient occurs in a situation of food accumulation when the establishment of a behavior sequence during the ITI is hindered by using a variable ITI.

Method

Subjects

The subjects were three experimentally naive Wistar rats, five months old at the beginning of the experiment, under conditions similar to those of the subjects of Experiment 1.

Apparatus

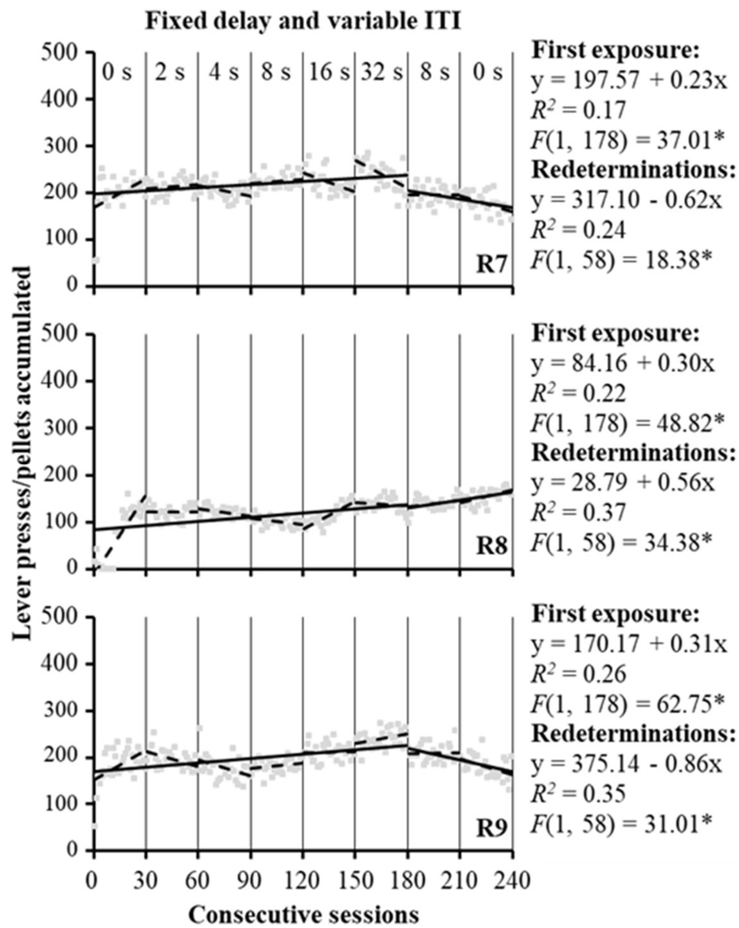
The apparatus was as described in Experiment 1.

Procedure

Subjects were directly exposed to the experimental situation, without prior training to press the lever or to approach the food cup. Trials started with a food-procuring component, during which the lever was extended for 20 s. Lever presses had no immediate consequences and were only recorded. The lever was retracted at the end of the food-procuring component and then a fixed delay component started, the duration of which varied between 30-session conditions by 0, 2, 4, 8, 16, and 32 s, in ascending order. In the following two conditions, the 8- and 0-s delays were redetermined in descending order. At the end of the delay component, a food pellet was delivered for each lever press during

Figure 4

Number of Lever Presses/Pellets Accumulated per Session by the Subjects Exposed to the Situation of Food Accumulation with a Fixed Delay and a Variable ITI



Note. Gray symbols correspond to the number of lever presses/pellets accumulated in each session. The dotted lines correspond to the linear regression of responding within each condition. The solid lines in the first six panels correspond to the overall linear regression of responding during the first exposure to the delays, while the solid lines in the last two panels correspond to the overall linear regression of responding during the redeterminations. Data on the right corresponds to the values of the overall regressions.

the food-procuring component. The interval between successive food pellets was 0.2 s. Trials ended after delivering all the programmed food and then an ITI started, during which the lever remained retracted until the next food-procuring component. The duration of the ITI was determined by a 20-s RT schedule (t = 2 s, p = .1). All sessions concluded after 30 trials and were conducted daily, at the same hour for each subject. The white-noise generator, the houselight, and the fan were on throughout the sessions.

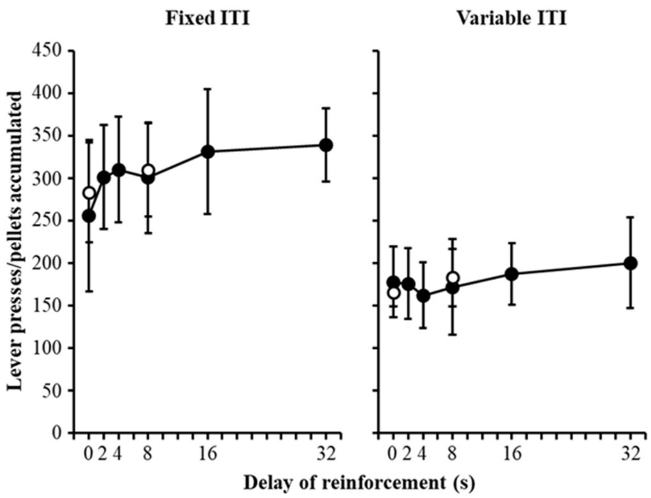
Results

To describe the effect of varying the length of the delay of reinforcement in a situation of food accumulation with a variable ITI, Figure 4 shows the number of lever presses/pellets accumulated per session by the three subjects of this experiment (gray symbols). Overall regression analyses (solid lines) showed for the three subjects an increasing trend in responding as the delay of reinforcement was lengthened during the first exposure to the delays. Conversely, the trend of lever pressing when the delay was shortened during the redeterminations was decreasing for R7 and R9, although it was increasing for R8. Regression analyses of responding within each condition (dotted lines) did not have a systematic trend for any subject, so the overall trend in responding could be attributed to the changes in the delay length and not to the passage of sessions.

To compare the effect of lengthening the delay of reinforcement in a situation of food accumulation with a fixed or variable ITI, Figure 5 shows the mean and standard deviation of the number of lever presses/pellets accumulated per session by the subjects of this experiment (right panel), exposed to a fixed delay and a variable ITI, and by the three subjects of Experiment 1 exposed to a fixed delay and a fixed ITI (left panel). Values were calculated from the last 10 sessions of each condition. Whereas lever pressing by the subjects exposed to the fixed ITI consistently increased by lengthening the delay, the response rate by the subjects exposed to the variable ITI remained constant between the 0- and 4-s delays, and only increased when the delay was lengthened from 8 to 32 s. Both with the fixed and the variable ITI, lever pressing gradually decreased by shortening the delay during the redeterminations. Furthermore, with both types of ITI, the lever-pressing rate was similar between the redeterminations and the first exposure to the 8- and 0-s delays. In all conditions, the lever-pressing rate with the variable ITI was substantially lower than with the fixed ITI.

Figure 5

Mean and standard deviation of lever presses/pellets accumulated per session by the three subjects exposed to the situation of food accumulation with a fixed delay and a fixed ITI during Experiment 1 and by the three subjects exposed to the situation of food accumulation with a fixed delay and a variable ITI during Experiment 2



Note. Black symbols correspond to the values obtained during the first exposure to the delays, whereas white symbols correspond to the values obtained during the redeterminations.

Discussion

The purpose of this experiment was to investigate whether the increasing delay gradient occurs in a situation of food accumulation when the establishment of a behavior sequence during the ITI is hindered by using a variable ITI. Although recent studies on food accumulation have used an ITI to control the time between the delivery of the food and the next opportunity to procure it (e.g., Bruner et al., 2017), it has been shown that the length of the ITI is also a parameter of the effect of the delay of reinforcement on food accumulation (Gaistardo & Bruner, 2021). However, this effect of the ITI could have involved the establishment of a behavior sequence, as only fixed ITIs had been used in previous studies. Some authors have explained the effect of the time since the last reinforcement from the establishment of a behavior sequence (e.g., Ferster & Skinner, 1957; Schoenfeld &

Farmer, 1970) since precluding the occurrence of such sequences modifies the pattern and rate of responding (e.g., Mandell, 1980; Tarpy et al., 1984; Zeiler, 1968). However, other authors have considered the establishment of a behavior sequence unnecessary for the time since the last reinforcement to control responding (e.g., Dews, 1970; Staddon, 1977), as it has been shown that disrupting an ongoing behavior sequence does not prevent responding from gradually increasing as the time since the last reinforcement elapses (e.g., Dews, 1962; 1966). As in the latter case, it could be argued that the increasing delay gradient does not depend on the establishment of a behavior sequence during the ITI, since the increasing delay gradient also occurred by using a variable ITI in this experiment.

As in Experiment 1 of this study, the increasing delay gradient obtained by using a variable ITI in this experiment could be explained by the temporal distribution of the food-procuring component (cf. Flores & Bruner, 2022), since successive food-procuring components were also spaced by lengthening the delay of reinforcement. However, the increasing delay gradient obtained with a variable ITI was lower than that obtained with a fixed ITI, which could suggest that the absolute level of responding in the situation of food accumulation indeed depends on the establishment of a behavior sequence between the delivery of the food and the next opportunity to procure it. Previous studies where rodents' lever pressing was positively reinforced had reported the occurrence of behavior sequences composed of behaviors such as walking around the chamber, grooming, approaching the food cup, or eating (e.g., Anderson & Shettleworth, 1977; Azzi et al., 1964; Shettleworth, 1975). From the causal observation of the subjects of this study, such behaviors were also found to occur, as well as other behaviors such as approaching the lever slot or pressing the lever. Whereas a fixed ITI could have let these behaviors to occur in such an order that they did not interfere with lever pressing, a variable ITI could have prevented the occurrence of such an order, delaying or precluding lever pressing in some trials (cf. Davis & Hubbard, 1972; Staddon & Simmelhag, 1971). This interference on lever pressing could have been due to a disruption in the discriminative control of food delivery (cf. Reid, 1958) or the conditioned reinforcing function of lever extensions (cf. Keller & Schoenfeld, 1950) on the behaviors that occurred during the ITI.

General Discussion

The purpose of this study was to investigate whether the increasing delay gradient depends on the establishment of a behavior sequence. The establishment of a behavior sequence has frequently been observed by delivering a reinforcer periodically with respect to another event (e.g., Skinner, 1948; Ferster, 1953). Thus, the increasing delay gradient found in recent studies on food accumulation could also have involved the establishment of a behavior sequence, since the food has been delivered periodically with respect to the retraction of a lever (e.g., Bruner et al., 2017), the occurrence of a lever press (Flores & Bruner, 2018), or the previous delivery of food (e.g., Gaistardo & Bruner, 2021). Some authors have explained the temporal control over responding from the establishment of a behavior sequence (e.g., Ferster & Skinner, 1957; Schoenfeld & Farmer, 1970), as it has been shown that precluding the occurrence of such sequences can disrupt the temporal control over responding (e.g., Laties et al., 1969; Staddon & Simmelhag, 1971). However, other authors have considered the establishment of a behavior sequence unnecessary for the temporal control over responding (e.g., Dews, 1970; Staddon, 1977), as it has been shown that such control may persist when the occurrence of a behavior sequence is disrupted (e.g., Dews, 1962; 1966). As in the latter case, the findings of this study could imply that the occurrence of the increasing delay gradient does not depend on the establishment of a behavior sequence, since the increasing delay gradient also occurred when the establishment of a behavior sequence was hindered by using a variable delay (Experiment 1) or a variable ITI (Experiment 2).

The increasing delay gradients obtained in this study were flatter than those obtained by Bruner et al. (2017, Experiment 1), but were similar to those obtained in more recent studies in our laboratory (e.g., Flores & Bruner, 2022). Flores and Bruner attributed this flattening in the increasing delay gradient to a recent change in the strain of the rats provided by the biotherium of the School of Psychology of UNAM, which could also apply to the present study. However, although the delay gradients obtained in this study were flatter than those obtained in previous studies, none of the delay gradients of this study were decreasing, in contrast to most of the studies on delay of reinforcement (cf. Lattal, 2010; Renner, 1964; Tarpy & Sawabini, 1974).

It has frequently been shown that the establishment of a behavior sequence may enhance the temporal control over responding by fulfilling a mediating function of the passage of time (cf. Richelle & Lejeune, 1980; Sidman, 1970). For example, when a behavior sequence is established by gradually lengthening the delay of reinforcement, the response rate can be sustained with delays as long as 120 s (e.g., Azzi et al., 1963; Ferster, 1953). The establishment of a behavior sequence could also have been facilitated in recent studies on food accumulation, as they had only gradually lengthened the delay of reinforcement (e.g., Bruner et al., 2017). However, since this study showed that the establishment of a behavior sequence is unnecessary for the increasing delay gradient to occur, the present study poses the possibility of replicating the increasing delay gradient without gradually lengthening the delay of reinforcement.

In both experiments of this study, only the delay of reinforcement was lengthened, while the duration of the other components was kept constant. Therefore, lengthening the delay of reinforcement extended the temporal context of the food-procuring component, so that the food-procuring component was shorter compared to the inter-reinforcement time (IS^RT). Across different situations it has been shown that the response rate during a segment of the IS^RT increases by lengthening the IS^RT (e.g., Taus & Hearst, 1970; Terrace, 1966). Thus, some authors have argued that the response rate during a given segment of the IS^RT does not only depend on the delay between such segment and reinforcement, but on the whole temporal context in which such segment occurs (cf. Dews, 1970; Jenkins, 1970; Fantino, 1981). Similarly, the increasing delay gradient found in studies on food accumulation has been attributed to an extension in the temporal context of the food-procuring component produced by lengthening the delay (cf. Flores & Bruner, 2022), as it has been shown that the food-procuring response rate also increases by extending its temporal context, either by shortening the food-procuring component (Flores et al., 2015) or by lengthening the ITI (Gaistardo & Bruner, 2021). This study provides further evidence in favor of this explanation by demonstrating that extending the temporal context of responding in a situation of food accumulation increases the response rate even when the periodicity of reinforcement is eliminated to hinder the establishment of a behavior sequence.

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