Rats' Behavioral adjustment to mutual reinforcement contingencies [1,2]

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Abstract

We study social and individual behaviors as a continuum between different levels of dependence/interdependence of responses/reinforcers. Twenty-four rats were trained to roll a stainless steel ball continuously from end to end of a gutter, a response that can be performed either individually or coordinately. Each pair of rats chose between two concurrent response options. In one option, access to consequences depended exclusively on individual behavior. In another option, both subjects had to coordinate their actions in time and space on the same object -the ball- for access to reinforcers, according to three conditions that differed in the ratio of pellets obtained by each individual of the pair (4:4 - 4:0 - 1:4). All subjects showed a preference for the individual option. The choice of the mutual option did not seem to be controlled only for the reinforcer ratios, the difficulty -probability- to meet the coordination criterion seems to discounts the reinforcer's value. The study represents a promising approach to analyze the effect of the interaction between the amount and probability of the reinforcer on choice behavior in social settings.

Key words: *Social and individual behaviors as a continuum, mutual reinforcement contingencies, choice, rolling-ball response, rats*

Resumen

Estudiamos los comportamientos sociales e individuales como un continuo entre diferentes niveles de dependencia/interdependencia de respuestas/reforzadores. Veinticuatro ratas fueron entrenadas a rodar un balín de acero continuamente de un extremo al otro de un canal, respuesta que podían realizar de

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forma individual o coordinada. Cada par de ratas eligió entre dos opciones concurrentes de respuesta. En una opción, el acceso a las consecuencias dependía exclusivamente del comportamiento individual. En la otra, ambos sujetos tenían que coordinar sus acciones en el tiempo y el espacio con el mismo objeto -el balín- para acceder a los reforzadores, de acuerdo con tres condiciones que diferían en la razón de pellets obtenidos por cada individuo del par (4:4 - 4:0 - 1:4). Todos los sujetos mostraron preferencia por la opción individual. La elección de la opción mutua no pareció estar controlada solo por las razones de refuerzo, la dificultad -probabilidad- de cumplir con el criterio de coordinación descuenta el valor del reforzador. El estudio representa un enfoque prometedor para analizar el efecto de la interacción entre cantidad y probabilidad del reforzador sobre el comportamiento de elección en entornos sociales.

Palabras clave: *Conductas individuales y sociales como un continuo, contingencias de reforzamiento mutuo, elección, respuesta de rodar un balín, ratas*

To improve the understanding of the nature of social behavior in human and non-human organisms, it is important that the tasks could model the adaptation problem facing by the organisms, identifying the change in the proximal functional mechanisms shared by different species, which can lead to the identification of converging evolutionary processes (Segura & Bouzas, 2015). We need to eliminate the technical and conceptual obstacles from the past by widening our perspective of the social-nonsocial dimension of behavior by situating the stimuli and outcomes that control behavior within a continuum (for a review see Hake & Vukelich, 1972; Schmitt, 1998). Behavior can be under the control of either nonsocial stimuli, relations between events and inanimate objects that indicate when and how behavior will grant access to certain types of outcomes; or social stimuli, for example, when the conspecific signals control the situations under which coordinated behavior will produce mutually beneficial results (Tan & Hackenberg, 2016). In one end of the continuum, outcomes are independent of the behavior of other individuals (i.e., access to them depends exclusively on the individual's own behavior); at the other end, outcomes depend solely on the behavior of another individual -receiver of an altruistic act. At an intermediate point, equal reinforcers are interdependent on the behavior of both, what has been called mutualistic cooperation (Hamilton, 1964; Krebs & Davies, 1993).

Activities can also be understood as a continuum; from instantaneous and discrete responses such as pushing a button or pressing a key, up to the execution of a continuous chain of coordinated activities. Among these continua, several settings of the social and nonsocial environment can be represented. The aim of this study was to systematically explore the behavioral adjustment of pairs of rats to environments in which the reinforcement distributions for each individual, and the coordination criteria for intra-pair activities, varied in different levels of dependence and equality. The setting contingencies required responses from both individuals or from only one individual, they included reinforcement for both or for only one of the individuals, they included an equitable or an unequitable distribution of joint action and/or reinforcers. An intra-subject/pair design was used, which replicate the free-operant choice procedure developed by Segura, Clavijo, and Bouzas (2019)- this procedure involves subjects rolling a stainless steel ball continuously from end to end of a gutter, a response that can be performed either individually or coordinately (p. 2). Unlike the sequential intra-pair coordination criterion used by Segura et al. (2019) in the present study, both subjects were allowed access to the ball during the entire mutual response so that the coordination pattern associated with each of the contingencies could be observed and measured.

Method

Subjects and Housing

Twenty-four experimentally naïve Wistar rats (*Rattus norvegicus*) served as subjects, 12 males and 12 females. Subjects were broods of two female rats mating with the same male. After mating, the male was removed and the two females lived together during gestation and 23 days after parturition (weaning). On weaning day, rats' pups were randomly assigned to two housing conditions: 6 males (♂) and 6 females (♀) were housed individually in translucent plastic cages 25 cm wide, 25 cm high and 40 cm long (25,000 cm^3). The other 12 subjects were housed together by sex (6 ♂ and 6 ♀) in two cages with the following dimensions: 35 cm wide, 30 cm high and 52 cm long (54,000 cm^3). All cages contained food and water dispensers. At 70 days old, the subjects' body weights were reduced to 85%, this condition remained until the end of the experiment; post-session feeding was provided when it was necessary. Rats were maintained on a 12-hr light/dark cycle (light phase beginning at 07:00). Room temperature was 21±2 °C, and relative humidity oscillated between 55 and 65 percent. Sessions were conducted seven days a week at approximately the same hour of the day (11:00 AM). This research complied with Colombian laws and Animal Behavior Guidelines for Laboratory Animal Research (Law nº84/1989).

Apparatus, Task and Reinforcement Contingencies

We designed four experimental chambers to evaluate rats' choice between individual and mutual alternatives as a function of the ratio of reinforcers obtained by each individual of the pair (for a review see Segura, Clavijo, & Bouzas, 2019; Segura & Gutiérrez, 2006). The chambers were made of waterproofed wood and measured 60 cm long, 40 cm wide and 30 cm high. Three transparent acrylic panels, 40 cm long and 30 cm high, divided the chambers into two identical compartments (see Figure 1).

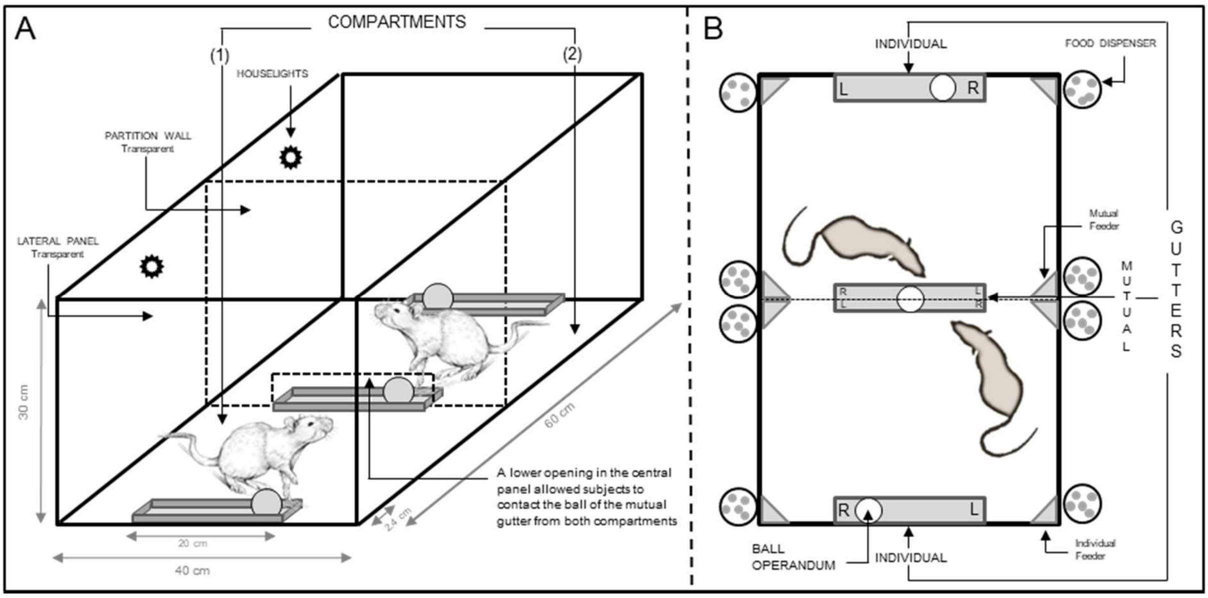

Figure 1. Lateral view (A) and top view (B) of the experimental chamber for the study of choice behavior under mutual and individual reinforcement contingencies.

Figure 1 shows lateral (A) and top (B) views of the experimental chamber. Three aluminum gutters (response options), 20 cm long and 2.4 cm wide, horizontally disposed over the floor without slant. Two gutters were in the lower part of the side panels and the other one was in the center of the chamber -which together with the central acrylic- divided the apparatus into two identical compartments. Thereby, each compartment had a side gutter (individual option) and a central gutter as a mutual option. A lower opening in the central panel allowed subjects to contact the ball of the mutual gutter from its own compartment (see Figure 1A). Each response option was associated with two food dispensers, located 10 cm horizontally from the end of each gutter. Two houselights were situated 3.5 cm below the top of the chamber, at the center of one of the walls of each compartment.

The target response consisted of the rat rolling a stainless-steel ball of 2.25 cm diameter and 55 g weight from end to end of a gutter. Three balls (operandum) were used, one for each response option. Each reinforcer consisted of 40-mg food pellets custom-molded from pulverized rat food (rodent Laboratory Chow, Purina LabDiet®).

Each pair of rats chose between two concurrent response options. Subjects' partnering and assignment to a compartment were randomly established and remained constant throughout the study. In one option, access to consequences depended exclusively on individual behavior (i.e., independent of the behavior of the other subject). In the mutual option, both subjects had to coordinate their actions in time and space on the same object -the ball- to produce the delivery of the reinforcer (for a review see Boesch & Boesch, 1989).

We manipulated the difference in the amount of food obtained in the mutual response, *by each individual of the pair*, in three experimental conditions: (a) both subjects obtained 4 pellets [condition 4:4] if they rolled the ball for the entire journey together; (b) the subject who rolled the ball by itself from one end to the other of the mutual gutter received 4 pellets and its partner 0 [condition 4:0], and (c) the subject who completed the journey by itself obtained 1 pellet and its partner 4 pellets [condition 1:4]. Thus, the mean number of pellets associated with each strategy was: in 4:4 condition (4 + 4) / 2 = 4 pellets; in 4:0 condition (4 + 0) / 2 = 2 pellets; and in 1:4 condition (1 + 4) / 2 = 2.5 pellets. The criterion to coordinate the actions in time and space in the condition 4:4, implied that both subjects roll the ball jointly. In contrast, in conditions 4:0 and 1:4, the coordination criterion implied alternation of mutual responses. The individual reinforcement contingency was roll the ball from one end of the individual gutter to the other end, producing the delivery of 1 pellet, this restriction in the individual option remained constant throughout the three experimental conditions. We analyzed the behavioral adjustment, *the intra-pair coordination*, and the preference, *responses and times assigned to each response option* (individual vs. mutual).

Procedure

Until 23 days old, all pups were raised by their mothers, who provided them the care and food necessary to survive. Both dams remained together through their litters' parturition, gestation, and infancy. After weaning, the subjects were randomly assigned to one of two housing conditions: Individual, or in group of 6 by sex (i.e., 6 ♂ and 6 ♀ were housed together; and 6 ♂ and 6 ♀ were housed individually). This assignment remained constant throughout the study.

At 10 weeks old, food deprivation was established and the subjects received four feeder-training sessions. The first two sessions focused on training the approach response to the individual feeders. The next two sessions focused on training the approach response to the feeders associated with the mutual reinforcement option. Thirty reinforcers were delivered on a VT 20-s schedule per session. At the end of the four sessions, all subjects approached the corresponding feeder when a sound signaled a pellet falling from the food dispenser.

Subsequently, the subjects were exposed to a shaping phase composed of four training conditions. And an experimental phase with three conditions that differed in the ratio of pellets obtained by each individual of the pair, for each successful response at the mutual option (4:4 - 4:0 - 1:4 conditions).

Shaping of rolling-ball response

The target response consisted of each rat rolling the ball from one end of the gutter to the other end, continuously and without interruptions, and exclusively making contact with the ball with its two front legs throughout the entire journey. The method of successive approximations was used to shape the target response. The response criterion -ball displacement distance- was either maintained, increased, or decreased individually as a function of the displacement performed by each subject (see Segura, Clavijo & Bouzas, 2019).

This phase consisted of four training conditions designed by Segura and Gutiérrez (2006); namely, (a) taking the ball from left to right (L→R) in the individual gutter, (b) taking the ball in the opposite direction (R→L), (c) continuously displacing the ball from left to right of the individual gutter and vice versa (L→R / R→L), and (d) continuously displacing the ball in the mutual gutter (L→R / R→L). The response on the mutual gutter was identical to that of the individual gutter. Each successful displacement (e.g., L→R) was reinforced with one pellet (fixed-ratio 1, FR1). Throughout the shaping phase subjects were trained individually. That is, *coordinated actions were never trained.* Each session lasted 10 minutes, during which the houselights constantly remained on.

Experimental conditions

An A-B-A' within-subject/pair design was used with three experimental conditions. Twelve pairs of subjects were randomly assigned: 6 by sex and 3 by each housing condition (see Table 1). The experimental conditions differed in the contingencies of reinforcement associated with the mutual option: the ratio of pellets obtained -*by each individual of the pair*- for each successful response in the mutual option was 4:4 - 4:0 - 1:4. The contingency of reinforcement associated with the individual option remained fixed throughout all experimental conditions; that is, each successful response in this alternative was reinforced with one pellet. As shown in Table 1, each pair of rats experienced one of three reinforcements ratio sequences, following a Latin square: (a) A → B → C [4:4 - 4:0 - 1:4], (b) C → A → B [1:4 - 4:4 - 4:0], and (c) B → C → A [4:0 - 1:4 - 4:4]. All subjects were exposed to each condition for 15 sessions.

Table 1. Sequences of exposure to the experimental conditions for each rat pairs according to the housing conditions and sex.

Housing	Experimental Conditions					
	A → B → C		C → A → B		B → C → A	
	Pair	Rats / Sex	Pair	Rats / Sex	Pair	Rats / Sex
Together	[1]	2-3 / ♀♀	[2]	4-7 / ♀♀	[3]	5-10 / ♀♀
	[7]	2-5 / ♂♂	[8]	4-6 / ♂♂	[9]	1-3 / ♂♂
Individually	[4]	13-16 / ♀♀	[5]	11-12 / ♀♀	[6]	14-15 / ♀♀
	[10]	9-10 / ♂♂	[11]	7-8 / ♂♂	[12]	11-12 / ♂♂

Experimental sessions

Each experimental session comprised four blocks. Namely, two forced-choice blocks (for each response option for each subject) and two 5-min free choice. Blocks were separated by a 10-s blackout, during which the experimenter placed the balls at the midpoint of the gutters. Each forced-choice block was divided into two parts, one for each response option: (a) two balls, one at each individual gutter; or (b) one ball at the mutual gutter. In each session, a random selection (without replacement) determined which response option (individual or mutual) began the first block. This selection was reversed in the second forced-choice block and applied for all 12 subject pairs.

In the free-choice blocks, subjects could choose any option at any time. Free-choice blocks began with one ball in the middle of each gutter (i.e., 10 cm from each end). Thereby, before any successful journey (L→R or R→L), the subjects had to rolling the ball to one of the two ends of the gutter (i.e., ends L or R of the gutters, see Figure 1). This was done to eliminate the experimenter's intervention in the free-choice blocks. Given the continuous nature of the target response, subjects could abandon a journey at any time, leaving the operandum at any point different from one of the gutters' ends and/or switching between response options.

Results

The frequency of successful responses, time allocation, and reinforcers (R, T, and r, respectively) was obtained for each subject for each response option -Mutual ($_1$) and Individual ($_2$)- session by session. From these data, we calculated the response rates (R_1 and $R_2/_{\text{TOTAL TIME SESSION}}$), the relative response rates (R_1/R_1+R_2), the relative time spent in each alternative (T_1/T_1+T_2) and the relative reinforcer rates (r_1/r_1+r_2). The mean of these data pooled across rats, and according to the housing conditions and sex, are shown in Figure 3. Also, response ratios, time ratios, and reinforcer ratios were computed and transformed into base-10 logarithms to evaluate, for each subject, if response ratios and time ratios were a function of log reinforcer ratios (Figure 2). Table 2 compares bias, sensitivity, and the goodness of fit for the equations presented in Figure 2. These data were obtained from the last five sessions of each experimental condition (stable state), allowing the calculation of measures of central tendency and variability.

Since Herrnstein (1961) discovered that the proportion of responses at an alternative is a function of the proportion of reinforcement obtained from that alternative, the Matching Law has been evaluated in a wide variety of phenomena, environments, species, responses, and reinforcers (see Baum, 1993; Wearden & Burgess, 1982). The generalized matching law proposed by Baum (1974) treats preference as extended time scale, suggesting that choice is a continuous process:

$$Log\ \frac{B1}{B2} = s\ Log\ \frac{r1}{r2} + Log\ b, \quad (1)$$

Where B_1 and B_2 are behavior allocations, measured in time or responses, to alternatives 1 and 2, r_1 and r_2 may be food rates or food amounts (pellets) obtained from alternatives 1 and 2, *s* represents the sensitivity of the behavior ratio (B_1/B_2) to the food ratio (r_1/r_2) variation; and *b* represent bias toward one alternative arising from factors other than r_1 and r_2.

We describe our data in terms of the matching law as a first step to explain the behavioral adjustment in a choice context in which two subjects choose between an alternative under the control of mutual reinforcement contingencies (both subjects had to coordinate their actions in time and space to obtain the reinforcer) and another alternative that provides individual sources of reinforcement (independent of the behavior of the other subject). For this purpose, we analyze the data from this study using Equation 1.

Figure 2 shows, in logarithmic coordinates, response and time ratios plotted against reinforcer ratios, across sessions and conditions, rat by rat. The direct proportionality between B_1/B_2 ratios would be represented as a straight line with *s* equal 1.0, and if ratios equaled, as the matching law proposes, the slope line 1.0 would pass through the origin (i.e., the value of $b = 0$). The straight lines were fit to the data points following Equation 1, by the method of least squares. The Equations for responses and time allocations as a function of reinforcers are shown in the graphs.

Figure 2 shows that the lines fitted from responses and from time allocations are different. The response ratios were proportional to reinforcer ratios, the slope of the line fitted to mean data for all subjects was 0.99 across all sessions and 1.03 for the last 5 sessions of each condition. For all subjects, the responses fitted line had a negative intersection, the mean value for bias (-0.99 calculated for all sessions and -0.83 for the last five) favors the individual alternative, all subjects showed negative b values, close to one. The goodness of fit for the averages $r^2 = 0.77$ (all subjects) and 0.82 (last five sessions) showed that response ratios and reinforcer ratios approached to a single straight line.

In contrast, analysis of time ratios as a function of reinforcer ratios were quite different. Figure 2 shows that the slopes of time ratios for all subjects were less than 1 (undermatching) and that the individual variability (values of *s* between 0.93 and 0.24 for all sessions; and between 1.02 and 0.28 for the last 5 sessions of each condition, see Table 2) was greater than the variability observed for responses.

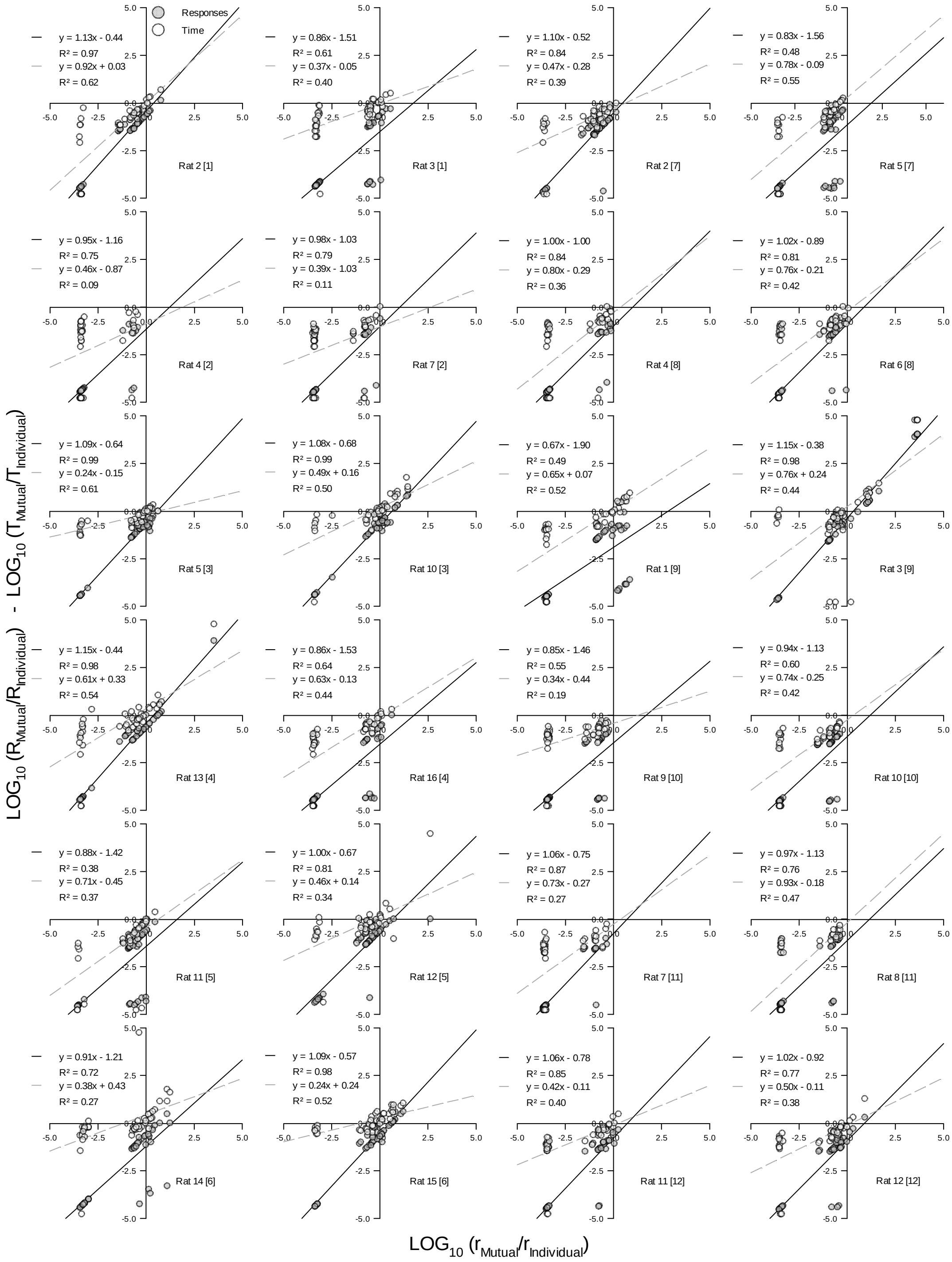

Figure 2. Choice relations for individual rats. Logarithm of response and time ratios as a function of reinforcer ratios on the mutual and individual options per session. Each point represents one session, fifteen points per condition. The straight lines were fit to the data points following Equation 1, by the method of least squares. The Equations for responses and time allocations as a function of reinforcers are shown in the graphs. Data from female rats are shown in the first two columns on the left and data from males in the two columns on the right (pairs of rats for each row).

Table 2. Sensitivity, bias, and goodness of fit (r^2) for fits of Equation 1 shows in Figure 2. These data were obtained from all sessions and from the last five sessions (*) of each experimental condition. Parameters are shown for each rat's data, and the bottom rows show arithmetic means across rats according to the housing conditions and sex.

Rats	Responses						Time					
	s		*b*		r^2		*s*		*b*		r^2	
Housed together (♀)		*		*		*		*		*		*
R2	1.13	1.12	-0.44	-0.54	0.97	0.99	0.92	0.83	0.03	-0.05	0.62	0.66
R3	0.86	0.98	-1.51	-1.10	0.61	0.80	0.37	0.28	-0.05	-0.21	0.40	0.39
R4	0.95	1.14	-1.16	-0.54	0.75	1.00	0.46	0.42	-0.87	-0.65	0.09	0.09
R7	0.98	1.13	-1.03	-0.54	0.79	1.00	0.39	0.38	-1.03	-1.16	0.11	0.09
R5	1.09	1.08	-0.64	-0.07	0.99	0.99	0.24	0.35	-0.15	-0.17	0.61	0.75
R10	1.08	1.10	-0.68	-0.65	0.99	0.99	0.49	0.34	0.16	0.06	0.50	0.54
Arithmetic *M*	1.02	1.09	-0.91	-0.57	0.85	0.96	0.48	0.43	-0.32	-0.36	0.39	0.42
Housed individually (♀)												
R13	1.15	1.15	-0.44	-0.43	0.98	0.98	0.61	0.72	0.33	0.55	0.54	0.76
R16	0.86	0.91	-1.53	-1.37	0.64	0.67	0.63	0.71	-0.13	-0.10	0.44	0.56
R11	0.88	1.13	-1.42	-1.20	0.38	0.11	0.71	1.02	-0.45	-0.09	0.37	0.95
R12	1.00	0.83	-0.67	-0.75	0.81	0.81	0.46	0.69	0.14	0.51	0.34	0.59
R14	0.91	1.07	-1.21	-0.70	0.72	0.98	0.38	0.85	0.43	0.66	0.27	0.38
R15	1.09	1.09	-0.57	-0.63	0.98	0.98	0.24	0.29	0.24	0.28	0.52	0.62
Arithmetic *M*	0.98	1.03	-0.97	-0.85	0.75	0.75	0.51	0.71	0.09	0.30	0.42	0.64
Housed together (♂)												
R2	1.10	1.11	-0.52	-0.47	0.84	0.97	0.47	0.66	-0.28	-0.16	0.39	0.53
R5	0.83	0.95	-1.56	-1.26	0.48	0.64	0.78	0.81	-0.09	-0.02	0.55	0.64
R4	1.00	1.08	-1.00	-0.71	0.84	0.99	0.80	0.61	-0.29	-0.71	0.36	0.24
R6	1.02	1.16	-0.89	-0.45	0.81	1.00	0.76	0.94	-0.21	-0.05	0.42	0.55
R1	0.67	0.68	-1.90	-1.79	0.49	0.49	0.65	0.82	0.07	0.09	0.52	0.64
R3	1.15	1.13	-0.38	-0.41	0.98	0.98	0.76	0.74	0.24	0.31	0.44	0.68
Arithmetic *M*	0.96	1.02	-1.04	-0.85	0.74	0.85	0.70	0.76	-0.09	-0.09	0.45	0.55
Housed individually (♂)												
R9	0.85	0.91	-1.46	-1.28	0.55	0.59	0.34	0.35	-0.44	-0.39	0.19	0.21
R10	0.94	0.87	-1.13	-1.35	0.60	0.54	0.74	1.01	-0.25	-0.05	0.42	0.62
R7	1.06	1.17	-0.75	-0.35	0.87	0.97	0.73	0.49	-0.27	-0.67	0.27	0.27
R8	0.97	0.90	-1.13	-1.37	0.76	0.64	0.93	0.92	-0.18	-0.15	0.47	0.56
R11	1.06	1.02	-0.78	-0.93	0.85	0.77	0.42	0.55	-0.11	-0.11	0.40	0.28
R12	1.02	0.99	-0.92	-0.93	0.77	0.70	0.50	0.51	-0.11	-0.24	0.38	0.38
Arithmetic *M*	0.98	0.98	-1.03	-1.03	0.74	0.70	0.61	0.64	-0.23	-0.27	0.35	0.39
All subjects Arithmetic *M*	0.99	1.03	-0.99	-0.83	0.77	0.82	0.57	0.64	-0.14	-0.11	0.40	0.50

These results indicate that the time ratios were not proportional to the reinforcer ratios (mean value of s = 0.57 for all subjects and 0.64 for the last five sessions) unlike responses, time allocations analysis did not show a particular bias for one of the alternatives. Although *b* values among subjects vary, the mean bias values were close to zero (see Table 2). It is possible that the little range of variation between time ratios and reinforcer ratios explains the poverty of the fit $r^2 = 0.40$ and 0.50. The general results pattern shows that all subjects, across all experimental conditions, spent more time in the mutual alternative but their successful responses displayed a smaller proportion than the matching law predicts. Subjects showed a strong preference for the individual option and it was more pronounced for responses than for times. This difference between response ratios and time ratios may be due to the lower probability of success at the mutual option, the intra-pair coordination of activities is costly it requires longer visits and a greater number of attempts (failures) to obtaining the reinforcer.

Figure 3 presents the mean of responses per minute for each alternative; and relative responses, time allocations, and reinforcer ratios pooled for all subjects (first column) and for housing conditions and sex (second to the fifth column). Pooled data of subjects (first row) show that the response rate per minute to the individual option was *M* = 2.29, varied little across experimental conditions (*M* = 2.42, 2.27 and 2.18) and it was higher in males (M = 2.64) than in females (*M* = 1.84). It is important to clarify that the reinforcement contingency on this option remained constant during all the experimental conditions. In contrast, the response rate for all subjects to the mutual option across conditions was *M* = 0.13 responses per minute and varied depending on the changes in reinforcement ratios associated with this option (*M* = 0.09, 0.17 and 0.13, conditions 4:4 → 4:0 → 1:4, respectively). A very interesting finding is the discrepancy in responses per minute between alternatives, the mean ratio across subjects and conditions was 18:1 –i.e., for each successful response in the mutual option, the subjects made an average of 18 successful responses in the individual option. The maximum value for this discrepancy was 79 to 1 when the reinforcer ratio associated with the mutual option was 4:4; and the minimum ratio was 8:1when the reinforcer ratio was 4:0. Even though the reinforcers ratio programmed always favored the mutual option (4:4, 4:0, 1:4) over the individual option (1 pellet), the difficulty [probability] associated with meeting the criteria for intra-pair coordination of activities to accomplish a successful journey, decreases the value of the mutual option.

The relative rates of responses, times and reinforcers allow observing the interaction between reinforcers amount and the difficulty to obtain them, over the subjects' preference for alternatives of mutual or individual reinforcement (see rows 3, 4 and 5, Figure 3). In a general way, all subjects showed a preference for the individual option and this preference was greater for responses than for times. These results are consistent with the individual analyses presented in Figure 2 and provide additional details of subjects' performance across the experimental conditions (column 1, rows 3, 4 and 5). For example, when the mean reinforcers ratio associated with the mutual option was 4 pellets for each individual in the pair [condition 4:4, mean ratio = (4 + 4) / 2] the response, time and reinforcer relative rates were lower (*M* = 0.05, 0.21, 0.13, respectively) compared with the relative distributions for the other two conditions (4:0, *M* = 0.12, 0.25, 0.22; and 1:4, *M* = 0.07, 0.27, 0.22, R, T and r, respectively).

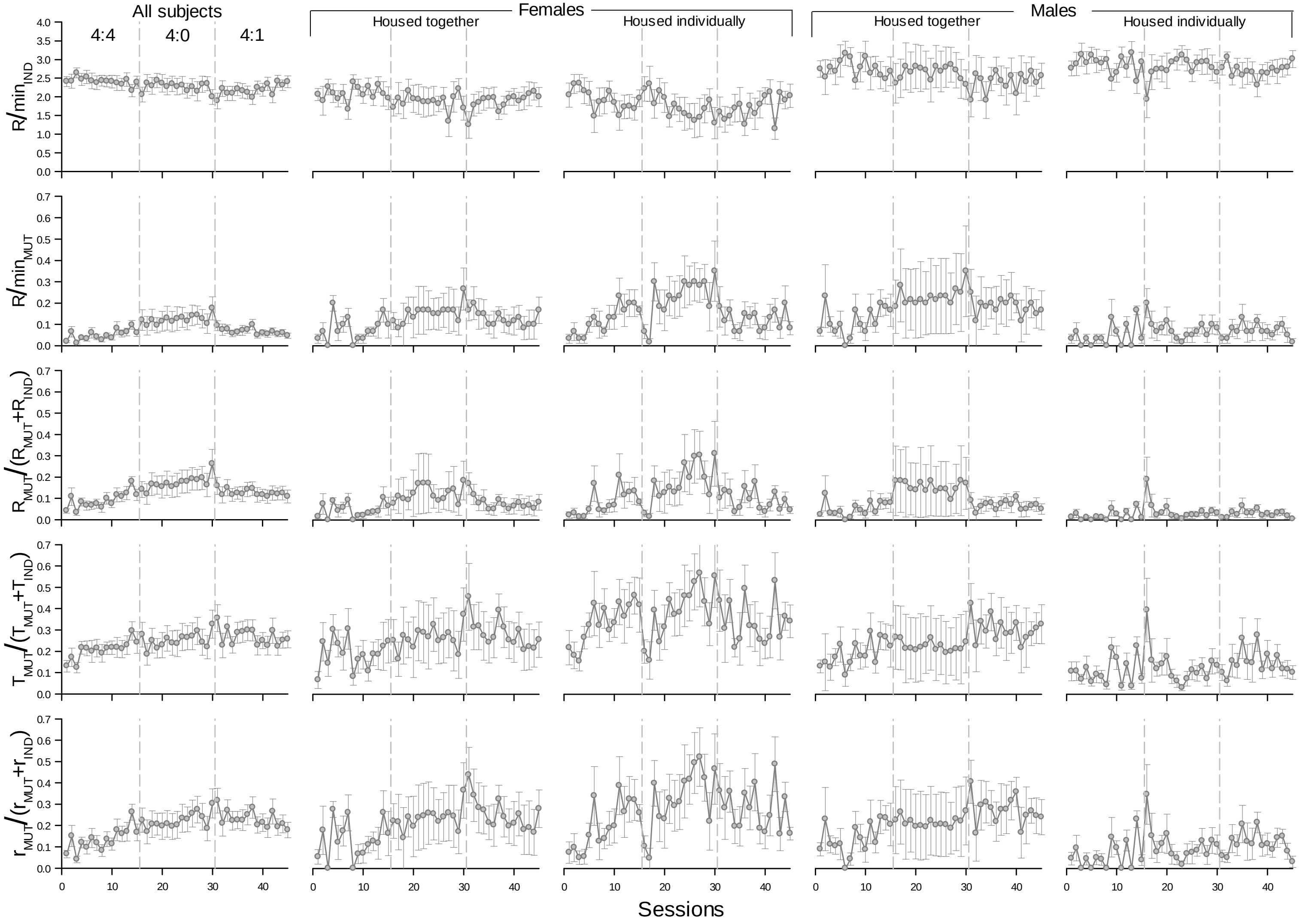

Figure 3. Mean of responses per minute for each alternative; and relative responses, time allocations, and reinforcer ratios pooled for all subjects (first column) and for housing conditions and sex (second to the fifth column). The bars show the standard error of the mean. The sessions were organized by experimental condition and were separated by dashed vertical lines according to the sequence A → B → C, corresponding to the three reinforcement ratios on the mutual option [4:4 → 4:0 → 1:4].

In sum, the proportions of responses and times allocated to the mutual option, for all subjects, were quite low in the first 5 sessions (i.e., at the beginning of condition 4:4) with subsequent increase in the sessions' second third and little changes towards the end of the condition. The other two experimental conditions showed less variable choice pattern within conditions, but more variability across subjects. This pattern of behavior change (responses and times) depending on the reinforcers obtained is also observed in pooled data by housing conditions and sex (columns 2 to 5, Figure 3). The variability across subjects was greater when the mean reinforcer ratios obtained, for each individual of the pair, for each successful response in the mutual option was 2 pellets (i.e., the subject of the pair who rolled the ball from one end to the other of the mutual gutter received 4 pellets and the other received nothing). Finally, the housing and sex conditions did not have a great impact on preference, the only exception was the consistent preference for the individual option observed in male rats housed individually.

Discussion

The overall pattern of results obtained suggests the following: first, the choice of the mutual option did not seem to be controlled only for the reinforcer ratios; the difficulty *-probability-* to meet the coordination criterion seems to discounts its value. Although the reinforcers mean ratio for each successful response always favored the mutual option, all subjects showed a preference for the individual option in all experimental conditions (see Figure 3). Second, the discrepancy between the successful response and time ratios observed in Figure 2 suggests that the intra-pair coordination of activities was costly, subjects required longer visits and a greater number of attempts to obtaining the reinforcer. Third, the continuous nature of the target response- rolling the ball from end to end of a gutter- allowed to compare the pattern of activities associated with individual and social responses. The coordination task is a useful tool to identify the subjects' preference for alternatives that are under the control of mutual reinforcement contingencies in a choice context that provides individual sources of reinforcement -i.e., independent of the behavior of the other subject. Finally, our results indicate that housing conditions and sex are neither necessary nor sufficient condition for rats' sensitivity to mutual and individual reinforcement contingencies. However, the discrepancy between males and females in response rates to the individual option, and the consistent preferences (responses/times) for the individual option observed in males housed individually, deserve to be empirically evaluated.

This experimental protocol represented a development and refinement of the coordination task proposed by Segura, Clavijo, and Bouzas (2019). It allows to capture the subjects' behavioral adjustment to environments in which distribution of reinforcers -for each individual of the pair- and the coordination criterion for access to reinforcers, varied in their levels of dependence and equality. At one end of the continuum, access to reinforcers was independent of the behavior of the other subject (individual choice). At the other end of the continuum, the access to a richer source of food depended entirely on the partner behavior (condition 1:4) or depended solely on individual behavior (condition 4:0). At an intermediate point, the reinforcers were equally distributed and depended on the coordinated actions of both subjects (condition 4:4).

Confronting organisms to choose between response options which vary in levels of dependence/equity between responses/reinforcers, as was done in this study, constitutes an important methodological advance in the understanding of the variables that control social behavior. As Hake and Vukelich (1972) point out, the best indications of behavioral control by the mutual reinforcement are: (a) that the behavior of each subject is under the control of the behavior of the other subject (i.e., coordination of intra-pair activities), and (b) that the procedure increases the numerical correspondence between the responses and/or the reinforcers of both individuals (correspondence that was evaluated from the analyses following the matching law). These two types of control would be indicative of the social and reciprocal nature of the cooperative behavior.

All cooperation research can be placed into two major categories: performance procedures and choice procedures. The former measures cooperative behavior itself; the second, the selection of a solution (Hake & Vukelich, 1972; Segura et al., 2019). The experimental protocol presented integrates both procedures into one task, allowing to: (a) evaluate the selection of a strategy based on the reinforcers associated with the individual and mutual alternatives, and (b) identify the pattern of behavior associated with both solutions. To advance in the understanding of social behavior -cooperation, competition, altruism- it is necessary to develop choice experimental protocols that, like our task, allow to capture the structure that defines each social environment, -i.e., behavioral control by mutual contingency relations, evaluating the behavioral adjustment to different dependence, independence, and interdependence levels between the behavior and the symmetry/equality levels in the reinforcers ratio obtained by each individual in each social episode. However, we still need to know the effect of the interaction between reinforcer amount and probability on an organism's choice behavior in social contingencies. In the mutual options, the reinforcer obtained depends on the coordination of intra-par activities, its value would be a function of both the amount and the probability to its receipt and their interaction. We need to quantify the cost of coordinating.

This view, that the study of social and individual behaviors as a continuum, in which individuals choose between an alternative with different levels of dependence/interdependence of responses/reinforcers intra-pair; and an individual option, which is independent of the behavior of the other subject, eliminates the technical and conceptual obstacles from the past that led the study of social behavior from two different perspectives: some focusing on strategy selection and the consequences associated with it (Baker & Rachlin, 2002; Gardner, Corbin, Beltramo, & Nickell, 1984; Wood, Kim, & Li, 2016); and others focusing on execution, on the behavioral signals when coordinating (Drea & Carter, 2009; Łopuch & Popik, 2011; Tan & Hackenberg, 2016).

The results from this study support the idea of quantitative rather than qualitative differences in social behavior –i.e., differences in degree throughout a continuum. To advance in the understanding of social and non-social behaviors we need to identify the variables of which these behaviors are a function, the variables that control the preference for mutual/individual reinforcement alternatives in a choice context.

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