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**COMPARING COORDINATED RESPONDING IN  
PAIRS OF RATS WHEN BOTH OPERANTS AND  
AGGREGATE PRODUCTS ARE SELECTED BY  
INTERMITTENT TEMPORAL CONSEQUENCES\***

***COMPARACIÓN DE RESPUESTAS COORDINADAS EN  
PARES DE RATAS CON OPERANTES Y PRODUCTOS  
AGREGADOS SELECCIONADOS POR CONSECUENCIAS  
TEMPORALES INTERMITENTES***

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**Abstract**

Three pairs of rats worked in two adjacent operant chambers separated by a Plexiglas wall. In some experimental conditions, lever-presses were independent operants maintained by either a fixed-interval (FI) or variable interval (VI) schedule. In other conditions, each rat lever-

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press was part of two interlocked behavior contingencies as part of a metacontingency: its aggregate product, a brief flash of light, was maintained either by a FI or a VI schedule of mutual water presentation. The results clearly show that the interlocking of behavioral contingencies in the design of an experimental metacontingency established a pattern of cooperation between the rats.

*Keywords:* Cooperation, metacontingencies, temporal schedules, water, rats

## Resumen

Se colocaron a tres pares de ratas en dos cajas experimentales contiguas, cada una separada por una lamina de acrílico. En algunas condiciones experimentales, las presiones a la palanca fueron definidas como operantes independientes, mantenidas por programas de reforzamiento de intervalo fijo o variable. En otras condiciones, como parte de una metacontingencia, cada presión a la palanca era parte de dos contingencias de comportamiento entrelazadas: la breve presentación de una luz intermitente era mantenida por un programa de IF o IV con la entrega mutua de agua. Los resultados muestran claramente que contingencias de comportamiento entrelazadas, mediante un diseño experimental de metacontingencia, estableció un patrón de cooperación entre ratas.

*Palabras clave:* Cooperación; metacontingencias; programas temporales; agua; ratas.

Cooperation is a traditional field of study within psychology (see Hobbes, 1651/1962, p. 100; Darwin, 1859; Kropotkin, 1902). In behavior analysis, Keller and Schoenfeld (1950) and Skinner (1953) defined cooperation as the combined behavior of two or more organisms needed for reinforcement for either. Recently, Tan and Hackenberger (2016) used pairs of rats to investigate some behavioral mechanisms of mutual reinforcement with a clear specification of the target response

(a definition of metacontingency: Glenn et al., 2016). The use of a reproducible unit, response coordination, which results in an aggregate product (AP), provides a baseline level of performance against which the effects of other variables can be assessed (e.g., Tan & Hackenberg, 2016; Carvalho et al., 2020). One of such variables is the intermittence of consequences.

Experiments using the basic definition of metacontingency usually arrange continuous consequences delivered after aggregate products (e.g., Vasconcelos & Todorov, 2015; de Carvalho et al., 2017). There have been, however, experiments that have investigated intermittent reinforcement in metacontingencies (e.g., Angelo & Gioia, 2015; Soares et al., 2015, 2019). de Carvalho et al. (2018, 2020) have described behavioral effects of Fixed Ratio (FR) on patterns of APs in pair of rats. Moreover, Codina et al. (2020) have recently showed a quantitative relation between Variable Ratio (VR) size and APs. Despite these recent experimental works, a clear demonstration of the effects of Fixed and Variable *Interval* (FI and VI) schedules on APs are still lacking (cf. de Carvalho et al., 2019). Thus, one objective of the present work is to describe APs of the coordinated responding in pairs of rats when lever-presses are maintained by FI and VI schedules of individual (contingency) and mutual reinforcement (metacontingency). It was expected that the mutual reinforcement schedules would maintain higher rates of aggregate products than the individual reinforcement schedules.

In the present experiment, three pairs of rats worked under FI and VI conditions with different response requirements for reinforcer deliveries. In all these conditions, the intervals of both schedules were maintained at equal duration (25 s for FI and a 25 s on the average, for the VI). The rats worked side by side, regardless of the condition, but each condition differed from one another regarding to the response-reinforcer relations: Either by requiring independent responses or coordinated responses or by changing the temporal criterion in the definition of coordination. In the operant individual schedules, reinforcers were programmed to follow independent lever-pressing of

each rat in the pair. In the metacontingencies, reinforcers were contingent on aggregated products (a brief light flash) that resulted from the coordinated responding of the pairs. Coordinated responses in the metacontingencies were defined as two lever-presses, one from each rat, occurring in close temporal proximity of each other.

In different experimental conditions, the time interval used to define coordinated responses was manipulated in both FI and VI metacontingencies. The coordinated time requirements had durations of 200, 500 and 800 ms. Thus, in addition to describing behavior under interval schedules, the present study sought to describe how different coordination requirements can modulate this unit of social behavior. As the FI and VI contingencies involved independent reinforcement and the FI and VI metacontingencies involved mutual reinforcement, we will simply refer to the former schedules as *FIi* and *VIi* and to the latter schedules as *FI<sub>m</sub>* and *VI<sub>m</sub>*.

## Method

### Subjects

Ten male Wistar rats, 3 months of age at the beginning of the experiment, were used. The rats were maintained in the vivarium of the Laboratório de Psicologia da Aprendizagem, Universidade Federal de São Carlos (UFSCar), Brazil. The rats were housed in dyads in polypropylene cages (30 cm × 30 cm × 50 cm) and maintained on a 12 h/12 h light/dark cycle with constant temperature (~23°C) and relative humidity (~50%). Free-drinking body weights were recorded for 30 days, starting upon the rats' arrival in the vivarium. The average weight that was recorded over 5 days immediately preceding water deprivation was used as a reference for forming dyads. The dyads were formed according to similarities of their body weight that were obtained during those five days. The conditioning chamber used for two dyads (R50-R51 and R56-R57) had malfunctioning and these dyads were withdrawn from the experiment, remaining the dyads R52-R53, R54-R55, and R58-R59. The rats were water-deprived for ~23 h before each

experimental session and had free access to food in their home cages. Each rat had access to one bottle of water for 5-20 min, 10 min after each session. The rats were separated if they had different durations of access to water. The experiment was approved by local authorities.

### Apparatus

Four standard operant conditioning chambers (24 cm height  $\times$  26 cm depth  $\times$  20.5 cm width) were used in the experiment. A pair of these chamber were excluded due to malfunctioning. The remaining chambers were pair-enclosed in large boxes that were equipped with ventilation fans (chambers were assembled as depicted in Figure 1A) and positioned side by side, separated by a Plexiglas wall so that the response levers were on the same side and visible to each other. Each chamber was equipped with an aluminum response lever (0.3 cm height  $\times$  0.5 cm depth  $\times$  5 cm width), supported by a galvanized wire and placed 13.5 cm from the lateral walls. Access to water was provided through an aperture that was located below each response lever. Water was delivered through a dipper (0.06 ml) for 2 s. A white LED light was installed outside the chamber, 13 cm above the floor, and the chamber had a stainless-steel rod floor. Experimental events were controlled and recorded by an LG computer and a Lenovo laptop, both equipped with Visual Basic 2010 Express and connected to an interface (model ADU208 USB Relay I/O).

### Procedure

The present study had a total of 10 experimental conditions, excluding pre-training sessions. The order of the different scheduling conditions for each dyad are shown in Table 1. Two pairs of rats (R52-R53 / R54-R55) started the experiment at a VI schedule, while the third pair (R58-R59) started at a FI schedule. All dyads started with schedules that required independent responses for reinforcement (i.e., FI*i* and VI*i*). Furthermore, schedules that required coordination at a criterion of 500 ms (i.e., FI*m* and VI*m* < 0.5s) were repeated once to check for reversibility. The characteristics of each interval schedule will

be described next as well as the difference in the response-reinforcer dependence in each of these schedules.

### **Fixed and Variable Interval schedules**

Lever-pressing of each rat was shaped through differential reinforcement of successive approximations to that final response class. After response shaping, rats were exposed to continuous reinforcement (CRF) for five sessions. From these five sessions to the end of the experiment, rats always responded side-by-side and visible to each other. After the five sessions on CRF, rats were gradually transitioned to either FI or VI schedules of equal interval duration (i.e., 25 seconds). Thus, the value of 25 seconds was used in both FI and VI schedules throughout the experiment. In the fixed-interval schedules, reinforcers were produced by a first lever-pressing that occurred after 25 s since the last reinforcer delivery; whereas in the variable-interval schedules, a first response that occurred after each of 1.17 s, 3.68 s, 6.46 s, 9.59 s, 13.18 s, 17.36 s, 22.40 s, 28.71 s, 37.21 s, 50.29 s, and 84.95 s intervals (25 s on average) since the last reinforcer produced reinforcing stimuli. These 11 intervals were obtained according to the progression of Fleshler and Hoffman (1962). The intervals were assigned randomly within sessions. These intervals were the same for both types of VI reinforcement schedules, either *VIi* or *VI<sub>m</sub>*.

### **Individual reinforcement schedules**

In the individual reinforcement schedules (*FIi* or *VIi*), independent responses were required for reinforcer deliveries, meaning that water was independently delivered to each rat: Responses from a rat only produced its own reinforcing stimuli, having no effects on the contingencies of its partnering rat. However, both rats always responded under the same schedule at the same time, whether *FIi* or *VIi*. For example, consider Rats A and B during the *FIi* and *VIi* of independent reinforcement. The possibility of Rat A to produce a reinforcing stimulus depended on the occurrence of Rat A response after the FI/VI interval that elapsed since the last access to the reinforcing stimulus.

The same occurred for Rat B: reinforcement for this rat under independent reinforcement schedules depended on its own responses and according to the programmed interval schedules. Thus, if Rat A was responding under the *VIi*, so was Rat B; the same occurred for the *FIi*.

### **Mutual reinforcement schedules**

For the schedules that required coordination, reinforcers were always delivered at the same time for both rats (mutual reinforcement, that is, *FI<sub>m</sub>* and *VI<sub>m</sub>*). Moreover, the response required in the mutual reinforcement schedules was the coordinated responding. Therefore, under interval schedules of mutual reinforcement (*FI<sub>m</sub>* and *VI<sub>m</sub>*), reinforcement of Rats A and B depended on coordinated responses that occurred according the schedule requirements (as described above). Coordinated responding was defined as two lever presses, one of each rat, that occurred within a time interval of each other (more on this below).

### **Experimental Conditions**

**Phase 1.** In successive experimental conditions (Table 1), the fixed and variable schedules of individual and mutual reinforcement were arranged. The three dyads started the experiment with independent reinforcement schedules (i.e., *FIi* or *VIi*). Following the first condition of individual reinforcement, the rats were exposed to the schedules of mutual reinforcement. After responding under the independent and mutual *VI* (dyad R52-R53 and R54-R55) or *FI* (dyad R58-R59) the rats were exposed to the other type of schedule under the same reinforcement type (i.e., mutual reinforcement).

**Table 1**

*Order of condition, number of sessions, mean proportion of coordination (Prop.), and mean obtained reinforcement rates (Reinf/min: S+ rates) in the last three sessions of each condition in Phase 1 and Phase 2. Proportions for individual schedules are those for coordination that occurred within 0.5 s.*

	Order	Phase	Reinforcement schedule	Response dependency	# of Sess.	Prop.	S+ rates
<b>Dyads</b>							
52-53	1	1	Vli	Ind	13	0.27	2.11
	2		VIm	(< 0.5 s)	10	0.38	2.11
	3		FIm	(< 0.5 s)	12	0.40	2.14
	4		Fli	Ind	12	0.31	2.18
	5	2	FIm	(< 0.2 s)	11	0.20	2.14
	6		VIm	(< 0.2 s)	11	0.22	2.05
	7		VIm	(< 0.5 s)	10	0.49	2.11
	8		FIm	(< 0.5 s)	10	0.41	2.11
	9		FIm	(< 0.8 s)	12	0.51	2.11
	10		VIm	(< 0.8 s)	14	0.60	2.11
54-55	1	1	Vli	Ind	11	0.25	2.15
	2		VIm	(< 0.5 s)	10	0.41	2.11
	3		FIm	(< 0.5 s)	10	0.34	2.14
	4		Fli	Ind	12	0.40	2.11
	5	2	FIm	(< 0.2 s)	11	0.23	2.11
	6		VIm	(< 0.2 s)	11	0.23	2.02
	7		VIm	(< 0.5 s)	10	0.44	2.08
	8		FIm	(< 0.5 s)	10	0.41	2.14
	9		FIm	(< 0.8 s)	10	0.49	2.14
	10		VIm	(< 0.8 s)	10	0.51	2.05
58-59	1	1	Fli	Ind	10	0.21	2.14
	2		FIm	(< 0.5 s)	10	0.32	2.11
	3		VIm	(< 0.5 s)	13	0.51	2.14
	4		Vli	Ind	15	0.19	2.15
	5	2	VIm	(< 0.2 s)	11	0.28	2.02
	6		FIm	(< 0.2 s)	10	0.26	2.14
	7		FIm	(< 0.5 s)	10	0.39	2.14
	8		VIm	(< 0.5 s)	11	0.44	2.08

	Order	Phase	Reinforcement schedule	Response dependency	# of Sess.	Prop.	S+ rates
<b>Dyads</b>							
	9		VI <sub>m</sub>	(< 0.8 s)	10	0.58	2.08
	10		FI <sub>m</sub>	(< 0.8 s)	10	0.47	2.11

*Note.* Reinforcement rates in the individual reinforcement schedules are the largest rates obtained between the two rats (the proportion is also for the same rat). The rates within pairs in these schedules never differed by more than  $\pm 0.2$  reinforcer/min.

The logic behind the procedure of Phase 1 was that when the type of the reinforcement contingency was manipulated (individual or mutual), the type of schedule was maintained (FI or VI); and when the type of schedule was manipulated (FI or VI), the type of the reinforcement contingency was maintained (individual or mutual). The experimental sessions during Phase 1 ended after the rats obtained a total of 45 reinforcer deliveries. Each experimental condition remained in effect for a minimum of 10 sessions and until responses were deemed stable. The stability criterion was the absence of increasing or decreasing trends in the proportions of coordinated responses from the last three sessions of each condition (accessed visually) and that the proportion in each of the three sessions did not vary  $\pm 10\%$  of the average of the proportions of those sessions. It is important to emphasize that although the FI<sub>i</sub> and VI<sub>i</sub> schedules only required independent responding for reinforcer deliveries, responses that would meet the criterion of coordination were recorded and their proportions were also used to measure stability in those schedules.

**Phase 2.** All conditions of Phase 2 involved mutual reinforcement. However, the temporal criterion of the coordinated responding was manipulated, assuming the values of 0.2 s, 0.5 s (to verify reversibility of Phase 1), and 0.8 s. Therefore, the coordinated responses that were required in the mutual reinforcement schedules were defined as two lever-presses, one of each rat, occurring within an interval of 0.2 s, 0.5 s

or 0.8 s of each other, each value separated by a stability criterion (the same as used in Phase 1). The logic for changing the temporal criterion for coordination across conditions was similar to that used in Phase 1: When there was a change in the temporal criterion, the schedule was maintained; when the schedule was changed, the temporal criterion was maintained. It is worth emphasizing that, in this phase, independent reinforcement schedules were not used (see Table 1).

The conditions remained in effect until the stability was reached according to the same criteria as described in Phase 1. The sessions ended after the rats produced 45 reinforcers. Contrary to what happened in the previous phase, two dyads started Phase 2 under the FI schedules, while the third dyad started Phase 2 under the VI schedule. All pairs started this phase with the same coordination criteria (i.e.,  $< 0.2$  s).

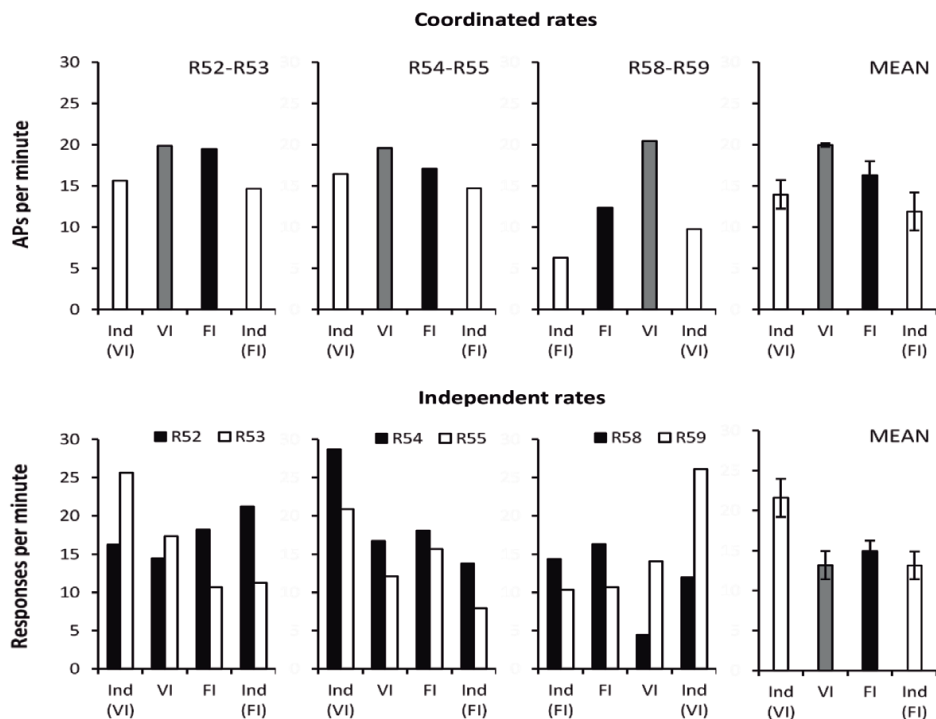
**Data analysis.** Each on-off LED cycle defined the AP (the production of the light contingent on coordination, that was followed by water delivery). Rates of aggregate products were calculated by dividing the total number of APs by session duration. Independent responding was defined as all lever presses that were not part of a coordinated episode. Independent response rates were calculated for each individual rat by dividing the total independent response that occurred in a session divided by session duration. The proportion of coordination was calculated using the total coordinated responses of a session divided by the sum of the independent responses (independent of Rat A + independent of Rat B) + coordinated responses. Although the production of reinforcers in the independent FI and VI schedules did not depend on coordinated responses, the responses that met the coordination criterion ("pseudo" coordination) were recorded, and their proportions were used to measure stability in these schedules as well. The analyses were performed considering the data from the three stable and final sessions of each condition.

The "pseudo" coordinated responding obtained during the individual reinforcement schedules (FI<sub>i</sub> and VI<sub>i</sub>) of Phase 1 were used for comparisons with mutual schedules during both Phase 1 and Phase 2. For comparisons in Phase 1, coordinated responses in the individual

schedules were analyzed as those responses of the rats that occurred in an interval  $< 0.5$  s of each other. For these comparisons, coordinated responding in the individual schedules was similarly defined to the coordinated responses that were required during the mutual schedules of Phase 1. For comparisons in Phase 2, coordinated responses in the independent schedules were analyzed considering the three types of temporal criterion of coordination, that is,  $< 0.2$  s,  $< 0.5$  s and  $< 0.8$  s. These three ways of analyzing the coordinated responses in the individual FI and VI schedules enabled a direct comparison with each of the coordination requirements used in Phase 2.

## Results and Discussion

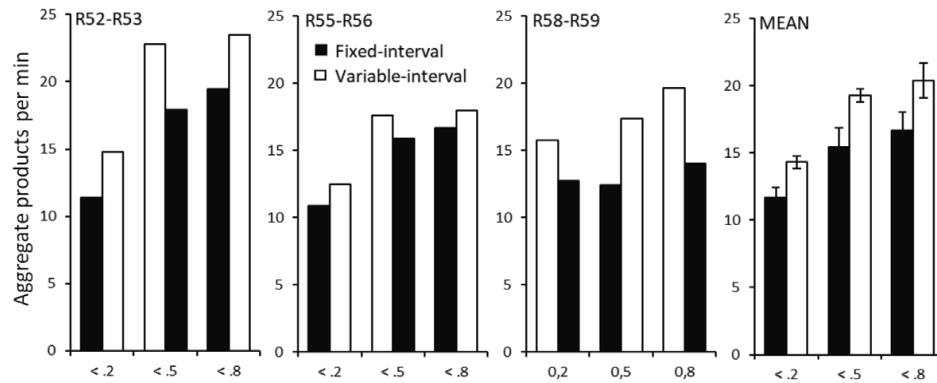
Figure 1 shows the results of independent and coordinated response rates in each reinforcement schedule of Phase 1. The data for the individual responses did not show systematic changes as a function of either schedule (FI and VI) or reinforcement type (independent or mutual). For AP rates, there was a systematic effect of both the schedule (FI or VI) and reinforcement types (individual or mutual). Rates of coordinated responses were higher under both mutual reinforcement schedules than in the individual reinforcement schedules. Moreover, there is an indication that the VI schedules maintained higher rates of coordination than the FI schedules.

**Figure 1***Mean Coordinated AP's and Independent Response Rates*

*Note.* Mean coordinated aggregate products (AP) and independent response rates for all rats/dyads in each condition of Phase 1. Errors bars shows  $\pm$  standard error of the mean.

The black and white bars in Figure 2 show AP rates in each schedule (FI and VI) and in each coordination criterion ( $< 0.2$  s,  $0.5$  s, and  $0.8$  s) for the three pairs during Phase 2. The figure shows that, regardless of the schedule type (FI or VI), the longer the temporal coordination criterion, the higher the rate of coordinated responses. Although this relationship is characteristic of both schedules, the response rates in the VI were consistently maintained at a higher level than those maintained under FI for all pairs and across most coordination criteria.

**Figure 2**  
Mean AP rates



*Note.* Mean aggregate products (AP) per minute in each schedule and in each coordination requirement for all rats/dyads of Phase 2. Experimental conditions are displayed in the order that it was conducted for each pair (except for the mean graph).

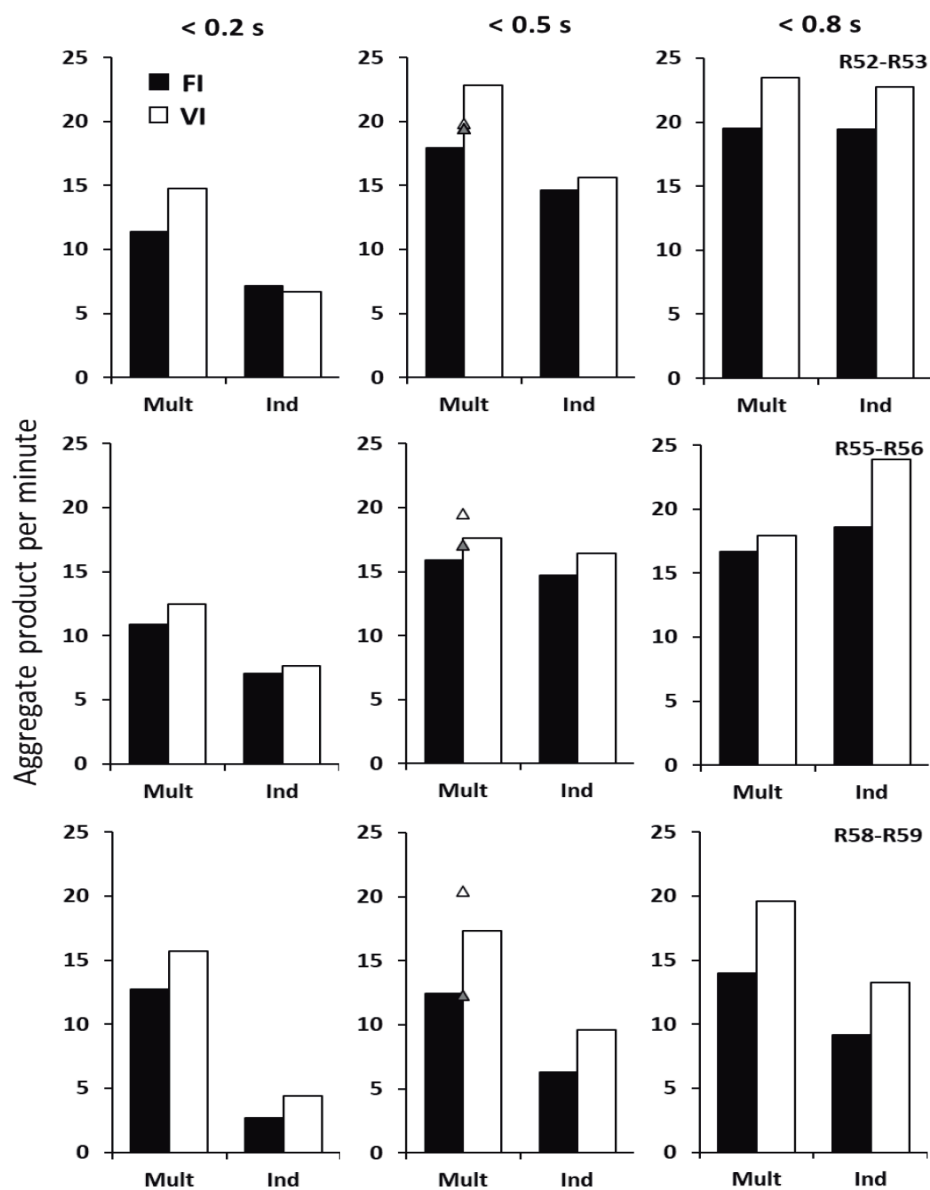
Figure 3 shows APs rates during mutual and independent FI (black bars) and VI (white bars) schedules in the  $< 0.2$  s (left panel),  $< 0.5$  s (middle panel), and  $< 0.8$  s (right panel) criterion for the three pairs. The AP rates in the independent FI and VI schedules (FI<sub>i</sub> and VI<sub>i</sub>) showed a similar function to that observed during the mutual reinforcement schedules (FI<sub>m</sub> and VI<sub>m</sub>), that is: The higher the coordination criterion considered in the analysis, the higher the obtained AP rates. This means that when coordinated responses for the FI<sub>i</sub> and VI<sub>i</sub> were analyzed utilizing a criterion of  $< 0.8$  s, the coordination rate was higher than when the criteria used in the analysis was either  $< 0.5$  s or  $< 0.2$  s. For analysis using a criterion of  $< 0.5$  s, the AP rate with this criterion was higher than that of the  $0.2$  s criterion.

A point worth noting is that the longer the temporal criterion for coordinated responses in the metacontingencies, the lesser the difference between the rates in the metacontingencies and the rates of coordinated responses that occurred “by chance” in the operant contingencies during Phase 1. This may be interpreted as the  $< 0.2$  s criterion being the best criterion for coordination, as it shows a clearer difference between responses that were actually coordinated from “pseudo” coordinated responses that occurred independently of the reinforcement contingencies for those responses. Figure 3 also shows

a replication of the FI and VI schedules of mutual reinforcement with coordination criterion at  $< 0.5$  s. Coordinated rates in the FI $m$  and VI $m$  during Phase 2 produced similar levels as those obtained in Phase 1 (FI: gray triangles, VI: white triangles).

**Figure 3**

*Mutual and Individual Average AP's Comparisons*



*Note.* Comparisons of average AP rates between mutual reinforcement schedules and individual reinforcement schedules for each coordination requirement.

The present results clearly show that the interlocking of behavioral contingencies in the design of an experimental metacontingency established a pattern of cooperation between the rats. The aggregate product, signaled by a brief discriminative stimulus and maintained by FI or VI schedules of reinforcement, was the unit of behavior maintained by intermittent consequences. In the recording of “pseudo units”, when in independent individual schedules, a lever-press by a rat would be closely followed by a bar press from the other animal of the pair, but these rates were generally lower than rates obtained in the mutual reinforcement schedules. This observation is consistent with the comparisons between independent and mutual reinforcement contingencies performed by Conde-Moro et al. (2019) and Tsoory et al. (2012), using different tasks, and by other control procedures that involved similar tasks (e.g., de Carvalho et al., 2019; Łopuch & Popik, 2011; Tan & Hackenberg, 2016). Furthermore, the present experiment has consistently shown that variable-interval schedules produce higher coordinated rates and proportions than fixed-interval schedules—such findings are consistent with comparisons between variable- and fixed—ratio schedules (cf. de Carvalho et al., 2018).

### **Concluding remarks**

In view of these results, it is possible to conclude that the requirement of joint responding between subjects directly influenced the results obtained, especially when observing differences in the AP rates between the schedules in which coordination was required at an interval  $< 0.2$  s and APs (pseudo) rates obtained “by chance” in the individual reinforcement schedules. Therefore, although both schedules (individual and mutual) produced responding that met the coordination criterion, it was possible to observe that the programming of a specific reinforcement contingency (individual and mutual) was a condition that significantly altered the occurrence of coordinated responses.

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