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***EFFECTS OF RESPONSE-REINFORCER RELATIONS ON
THE MAINTENANCE OF COORDINATED RESPONDING
UNDER SCHEDULES OF SIMULTANEOUS
REINFORCEMENT***

**EFEITOS DE LAS RELACIONES RESPUESTA-
REFORZADOR EN EL MANTENIMIENTO DE
RESPUESTAS COORDINADAS BAJO PROGRAMAS DE
REFORZAMIENTO SIMULTANEO**

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Abstract

The effects of response-reinforcer relations on coordinated responding were investigated. Coordinated responding was defined as two lever presses, one by each rat that occurred within 500 ms of one another. Four conditions were arranged in an ABCB design. Coordinated responding was reinforced according to a fixed-ratio 6 (FR 6) schedule in Condition A. In Condition B, a response by each rat was required, independent of their temporal proximity, to produce water delivery under a variable-interval schedule. Condition C was a replication of Condition B, except that coordinated responding was required for reinforcer deliveries. All conditions involved simultaneous reinforcement, that is the rats received access to reinforcers at the same time. The results extended previous findings by demonstrating that the requirement of coordinated responses to produce reinforcement affected both coordinated response rates and the proportion of such responses relative to the total responses in a session, in that both measures were higher in Conditions A and C than in Condition B. There also was control of the temporal distribution of coordinated responding by the type of schedule (FR or VI): A “break-and-run” pattern was observed under the FR schedule, and a constant response rate was observed under the VI schedule.

Key words: response-reinforcer dependence, temporal coordinated responses, reinforcement schedules, pairs of rats, water

Resumen

Se investigaron los efectos de relaciones respuesta-reforzador en respuestas coordinadas. La respuesta coordinada se definió como dos presiones de palanca 500 ms una de la otra, una por cada rata. Cuatro condiciones se organizaron en un diseño ABCB. La respuesta coordinada se reforzó de acuerdo con un programa de razón fija 6 en la Condición A. En la Condición B, se requirió una respuesta de cada rata, independientemente de su proximidad temporal, para producir suministro de agua bajo un programa de intervalo variable. La condición C era una réplica de la condición B, excepto que se requería una respuesta coordinada para la entrega de reforzadores. Todas las condiciones implicaron refuerzo simultáneo, es decir, las ratas recibieron acceso a los reforzadores al mismo tiempo. Los resultados ampliaron los hallazgos previos al demostrar que el requisito de respuestas coordinadas para

producir alimento afectó tanto a las tasas de respuesta coordinadas como a la proporción de tales respuestas en relación con las respuestas totales en una sesión, ya que ambas medidas fueron más altas en las Condiciones A y C que en la Condición B. También hubo control de la distribución temporal de la respuesta coordinada por el tipo de programa (razón o intervalo): se observó un patrón de “interrupción y ejecución” en el programa de razón, y se observó una tasa de respuesta constante en el programa de intervalo.

Palabras clave: dependencia respuesta-reforzador, respuestas coordinadas temporalmente, programas de reforzamiento, pares de ratas, agua

Coordinated relations between the responding of two or more individuals are considered a unit of behavior because they change as a function of contingencies that occur at a social level (e.g., Glenn, 2004). Free-operant tasks and interdependent procedures are used to investigate functional relations between social coordinated responses and consequences (e.g., Cohen, 1962; Lindsley, 1966; Marwell & Schmitt, 1975; Schmitt, 1984; Skinner, 1962). In the interdependent procedure, mutual reinforcement is scheduled for joint responses of two or more individuals (Hake & Vukelich, 1972). Coordinated responding is commonly defined as two responses, one by each participant, that occur within a specified time interval (e.g., 500 ms) of each other (Cohen, 1962; Lindsley, 1966).

Experiments that have used interdependent procedures with temporally coordinated responses indicate that the reinforcement of coordinated responding maintains such responding at higher levels than under conditions that have no programmed consequences for such responses (Azrin & Lindsley, 1956; Toledo et al., 2015; Vogler, Masters, & Morrill, 1971). Numerous experiments, however, have questioned whether the findings reflect the reinforcement of coordinated responding or whether they are an artifact of reinforcement that occurs at the level of individual responses (e.g., Hake & Vukelich, 1972; Schmitt & Marwell, 1968; Schuster, 2001; Tan & Hackenberg, 2016; Vogler, 1968). In free-operant tasks, a common concern is that responses of individual participants maintained at high rates may reflect coordination that occurs by chance (Schmitt & Marwell, 1968).

Different procedures have been used to verify whether reinforcing stimuli affect social coordination (e.g., Łopuch, & Popik, 2011; Schuster, 2001; Schmitt & Marwell, 1968; Toledo et al., 2015; Vasconcelos & Todorov, 2015). One way of assessing

this is by manipulating response-reinforcer dependence (e.g., Kuroda et al., 2013). Tan and Hackenberg (2016, Experiment 1) assessed the effects of response-reinforcer dependence on the reinforcement of coordinated responses in pairs of rats. The authors defined coordinated responses as lever presses by each rat that occurred within 500 ms of one another. All conditions involved simultaneous reinforcement, in which the rats were provided access to reinforcers at the same time. Reinforcement rates were held constant across conditions while they varied the requirement for reinforcer deliveries and schedules under which the consequent stimuli were presented.

Tan and Hackenberg's (2016) reinforced coordinated responding according to a fixed-ratio (FR) schedule in Condition A. In Conditions B and C (which were control conditions), coordinated responding was not required for simultaneous reinforcement. In Condition B, food deliveries occurred independently of responding after variable time intervals. In Condition C, the variable-interval (VI) schedule was not a conventional VI schedule (Ferster & Skinner, 1957). In Tan and Hackenberg's procedure, the first response of either rat that occurred after the VI IRI interval lapsed produced a reinforcer for each of the rats. The proportion and rates of coordinated responding were higher in Condition A than in either Conditions B or C, indicating that the dependence of reinforcement of the coordinated responses of both members of the pair is critical for maintaining coordination.

de Carvalho et al. (2018) further explored the procedure developed by Tan and Hackenberg (2016), exposing rats to intermittent schedules of reinforcement of coordinated responding. de Carvalho et al. (Experiment 3) compared coordinated performance under an FR 6 schedule and a yoked VI control schedule (Tan & Hackenberg, 2016). Coordinated responding was reinforced only when the FR schedule was in effect. There were more coordinated responses during the FR 6 than during the yoked VI schedule, providing evidence of the effect of the response-reinforcer dependency on maintaining coordinated responses when such responses were reinforced intermittently. The results also suggested that different schedules engender different response patterns (FR and variable ratio [VR]). In Experiment 1, the FR schedule controlled a "break-and-run" response pattern and the VR, relatively high and constant responding.

Although in both experiments there were differential effects of the different reinforcement schedules on coordinated responding, at least two methodological issues remained unresolved. The first is that there is a possible side effect of the way that the yoked VI schedules were arranged. In both experiments, the overall response rates of one of the rats in most of the dyads decreased considerably under the yoked

VI. Although both rats could respond when that schedule was in effect, the rat that responded more rapidly was more likely to produce the reinforcer once the VI IRI interval lapsed (e.g., Rat A). This in turn could have systematically arranged a VT for the other rat (e.g., Rat B). Thus, response-independent food or water deliveries could be the reason for the decrease in Rat B's response rate. Therefore, it is unclear whether coordinated responding decreased because of the VT-induced decreases in Rat B's rate or because of the absence of the coordination dependency (cf. Vogler, 1968). The second issue was that in their Experiment 3, de Carvalho et al. (2018) used different reinforcement schedules, comparing an FR 6 with the yoked VI schedule. As FR and VI schedules can engender different coordinated response patterns, evaluation of the influence of coordination-reinforcer dependency is clearer when the same schedule is used (e.g., Kuroda et al., 2013; Zeiler, 1968). The present experiment was designed to compare coordinated performances when reinforcers were either dependent on coordinated responding or occurred independently of such responding and to examine whether different schedules (FR *v.* VI) maintained different temporal distributions of coordinated responses.

Method

Subjects

Eight male Wistar rats, 9 months old at the beginning of the experiment, served as subjects. Four rats R17-R20 were the same as in Experiment 3 in de Carvalho et al. (2018) and formed the same dyads as reported therein. Four other rats (R21-R24) underwent the exact same experimental conditions as the rats used by de Carvalho et al. (Experiment 3) before this experiment began. These four rats were assigned to dyads by pairing them based on their free-drinking body weight.

The rats were maintained in the vivarium of the Laboratório de Psicologia da Aprendizagem, Universidade Federal de São Carlos (UFSCar). Each paired dyad was housed together in polypropylene cages (30 cm × 30 cm × 50 cm) in a room with a 12 h/12 h light/dark cycle with constant temperature (~23°C) and relative humidity (~50%). The rats had free access to food in their home cages and were water deprived for ~23 h before the experimental sessions. Each rat had access to one bottle of water for 5-20 min, 10 min after each session. Post-experimental session drinking was allowed to maintain the rat's weight within 83-87% of their free-drinking body weight (cf. Tang & Collier, 1971; Treichler & Hall, 1962).

Apparatus

Four standard operant conditioning chambers (24 cm high \times 26 cm deep \times 20.5 cm wide) previously used by de Carvalho et al. (2018) were used. The chambers had steel rod floors and were placed in pairs inside sound-attenuating boxes equipped with ventilation fans. The two chambers in each box were positioned side by side, separated by a Plexiglas wall so that the response levers were on the contiguous side of the chamber and visible to each other. Each chamber contained 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. The response levers were separated by 27 cm, left to right edge. Water was accessible through an aperture located below each response lever. It was delivered through a dipper (0.06 ml) for 2 s. A white light-emitting-diode (LED) was located outside the chamber, 13 cm above the floor. The experiment was controlled by an LG computer and Lenovo laptop, both equipped with Visual Basic 2010 Express and connected to an interface (model ADU208 USB Relay I/O). The experimental space was dark at all times except when the LED was on following a coordinated response (see Procedure section).

Procedure

Rats within dyads were randomly assigned to one of two chambers (left or right) and remained in the same chamber for all conditions. Four conditions were arranged in an ABCB sequence. In Condition A, temporally coordinated responding was reinforced according to an FR 6 schedule to establish and maintain sustained responding and to replicate coordinated responding under this schedule (de Carvalho et al., 2018). In Conditions B and C, the rats responded under VI schedules: B was a yoked schedule during which coordinated responding was not required for reinforcement; C was the critical condition, in which the reinforcer deliveries depended on coordinated responses of the two rats comprising the dyad (see details below). To evaluate effects of the coordinated response-reinforcer dependency, it was important to control for reinforcement rates between the conditions with and without the coordination dependency in place. Without equal reinforcement rates between the two conditions, reductions in coordinated responding in the absence of the dependency could be attributed to reinforcement rate reductions rather than to the absence of the dependency. A VI schedule was used in B and C because it allows constancy in reinforcement rates across a wide range of response rates (but see Neuringer & Schneider, 1968). The design allowed (1) verification of whether requiring responding of both subjects across all conditions would replicate the

effects reported by de Carvalho et al. (2018, Exp. 3); (2) extension of the results of these authors with regard to the effects of schedule types by comparing coordinated performance between FR (A) and VI (C) schedules; (3) use of the same reinforcement schedule (VI) in experimental (C) and yoked (B) conditions; and (4) verification of whether effects observed in Condition C would reverse when the coordinated response-reinforcer dependency was removed during the second exposure to Condition B.

Coordinated responding was defined as two lever presses, one by each pair member, within a 500 ms interval of each other. Each coordinated response turned the LED on for .5 s. Any independent or coordinated response occurring while the light was on extended its duration for another .5 s. The experimental sessions were conducted daily at approximately the same time and lasted for either 45 reinforcer presentations or 1 h, whichever came first. Conditions were changed only when coordinated responding was stable, defined as the absence of increasing or decreasing trends in coordinated ratios and $\leq 10\%$ variation of the mean coordinated ratios over the last three sessions of each condition. Each condition was in effect for a minimum of 10 sessions, and the data from the last three stable sessions were used in the data analysis.

Condition A: FR 6 reinforcement of coordinated responding. In this condition, coordinated responding of the dyads was reinforced according to an FR 6 schedule. In this schedule, each instance of coordinated responding flashed the LED, and each on-off light cycle defined a single response in the FR sequence. Therefore, both animals had access to water at the offset of the LED following the sixth occurrence of a coordinated response.

Condition B: Yoked VI without coordinated responding. In Condition B (hereafter labeled the yoked VI), water was available to both rats simultaneously provided each rat responded at least once after the end of each IRI interval. Although one rat could respond more than once after the intervals, reinforcement was delivered to both animals only after a response of each was recorded. Therefore, the interreinforcement intervals in the yoked VI schedule were always the same for rats within dyads. Reinforcers could follow temporal coordinated responses, but they were not required for reinforcer deliveries. Each coordinated response flashed the light, as in the FR condition, but the rats had access to water independently of the light. The mean value of the VI schedule for each dyad was the mean interreinforcer (IRI) interval obtained in the FR condition. Using this mean, 9 IRI intervals were generated using the Fleshler and Hoffman (1962) progression, from which we

Table 1. Mean reinforcement rates (per minute) for each dyad during the last three sessions of each experimental condition. The number in parentheses is the number of sessions that a given condition was in effect.

Dyad	Condition			
	FR6	Yoked VI	Coordinated VI	Yoked VI
R17-R18	3.2(11)	2.5(13)	2.4(11)	2.3(26)
R19-R20	2.3(13)	2.0(10)	1.8(11)	1.9(11)
R21-R22	1.8(10)	1.5(14)	1.6(10)	1.6(21)
R23-R24	2.5(11)	2.1(12)	2.1(10)	2.1(10)

created five separate lists. Each list included all nine values, for a total of 45 interval durations. Each list was presented in random order. For each dyad, the obtained IRI means and standard deviations were: R17-R18 ($M = 19.6$ s, $SD = 4.7$ s), R19-R20 ($M = 27.2$ s, $SD = 5.2$ s), R21-R22 ($M = 34.1$ s, $SD = 5.8$ s), R23-R24 ($M = 24.5$ s, $SD = 7.5$ s).

Condition C: VI with coordinated responding. In this condition (hereafter labeled the coordinated VI), coordinated responding was reinforced according to a VI schedule. For each dyad, the nine intervals and programming of the lists of VI schedules were the same as in Condition B. Each coordinated response flashed the LED, as previously described, but reinforcement were provided to both rats simultaneously only at the light offset that was associated with the first coordinated response that occurred after the end of each IRI interval. Therefore, this contingency was the same as in Condition B, except that water deliveries depended on coordinated responding.

Results

Table 1 shows the mean reinforcement rates and number of sessions for each dyad for each condition. For each of the four dyads, reinforcement rates were higher under FR than under VI schedules. Rates during the VI differed slightly between the dyads (between 1.5 and 2.5 reinforcers per minute), but for each dyad the reinforcement rates were about the same across the two yoked and the coordinated VI conditions.

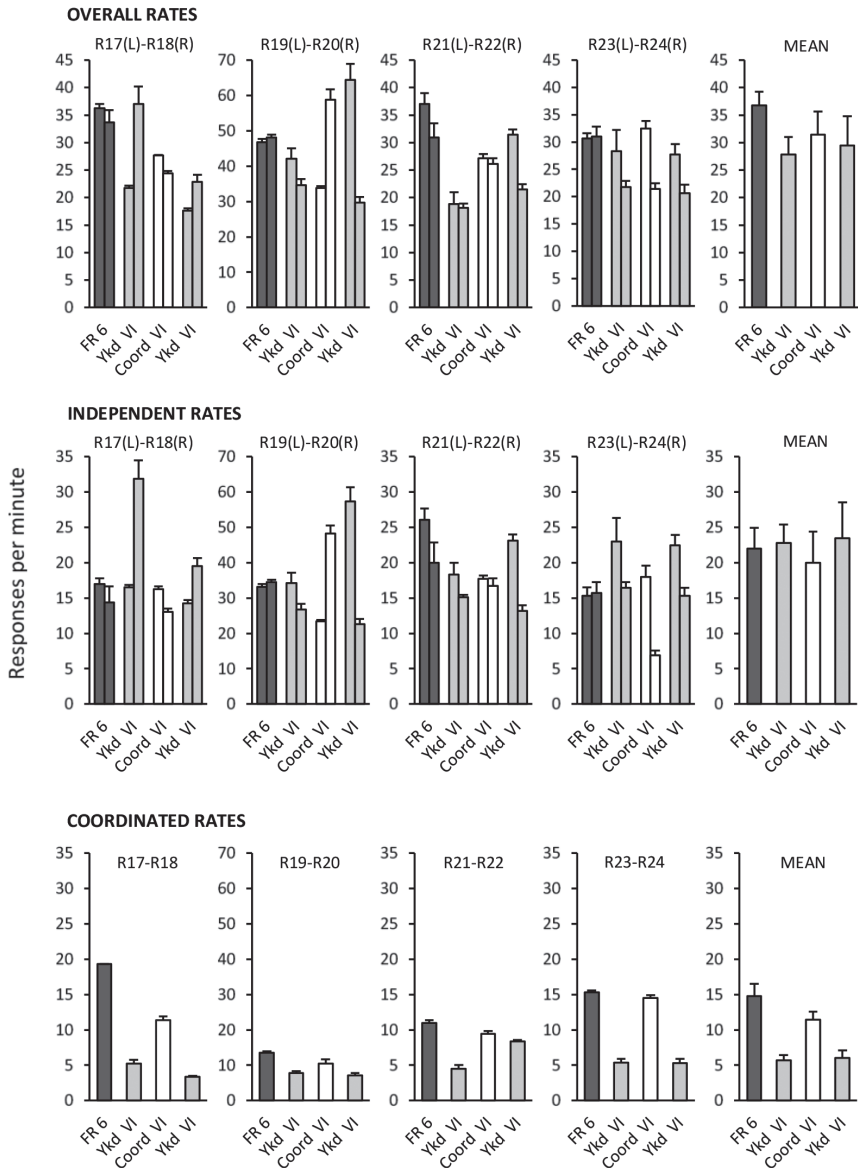


Figure 1. Mean overall (upper panel), independent (middle panel), and coordinated (lower panel) response rates per minute for each rat and dyad during the last three sessions of each condition. The letters L (left) and R (right) after each rat's number in the top two graphs identify which of the two bars shown for each condition is associated with which pair member. The graphs on the right show between-rats means for each dependent measure in each condition. Error bars indicate the standard error of the mean.

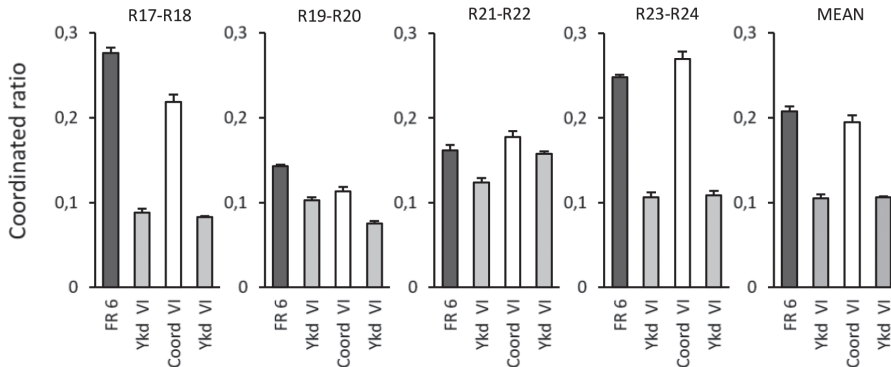


Figure 2. Mean coordinated response ratios (coordinated responses / overall responses) for each dyad in the last three sessions of each condition. Errors bars indicate the standard error of the mean.

The top row of graphs in Figure 1 show the mean overall response rates for each rat in each condition. The last graph in each panel shows the averages across rats. Notice the different y-axis for dyad R19-R20. Overall response rates were calculated by dividing overall lever presses (both coordinated and independent responses) by session duration. Overall rates typically were high across conditions. Although there was considerable variation across rats, overall rates tended to be higher during the FR 6 than during the yoked and coordinated VI schedules. There was no systematic difference in these rates during the yoked and coordinated VI schedules.

The middle row of graphs in Figure 1 shows independent rates for each rat in each condition. Independent responses were all lever presses that were not coordinated responses. Independent response rates were calculated by dividing the total independent responses of a rat by session duration. Similar to overall rates, independent rates did not vary systematically by condition. There was, however, a tendency (five of eight rats) toward lower independent rates during the coordinated VI schedule as compared to those during the yoked VI and FR schedules.

The lower row of graphs in Figure 1 show the coordinated response rates, which varied more systematically as a function of conditions. Although the level of coordinated response rates differed between dyads, within dyads the coordinated response rates were generally higher in the FR schedule than in the other conditions (except for R23-R24) and higher in the coordinated VI schedule than in either yoked VI schedule.

Mean coordinated ratios in the last three sessions of each condition for each dyad are shown in Figure 2. These ratios differed between dyads, with a consistent

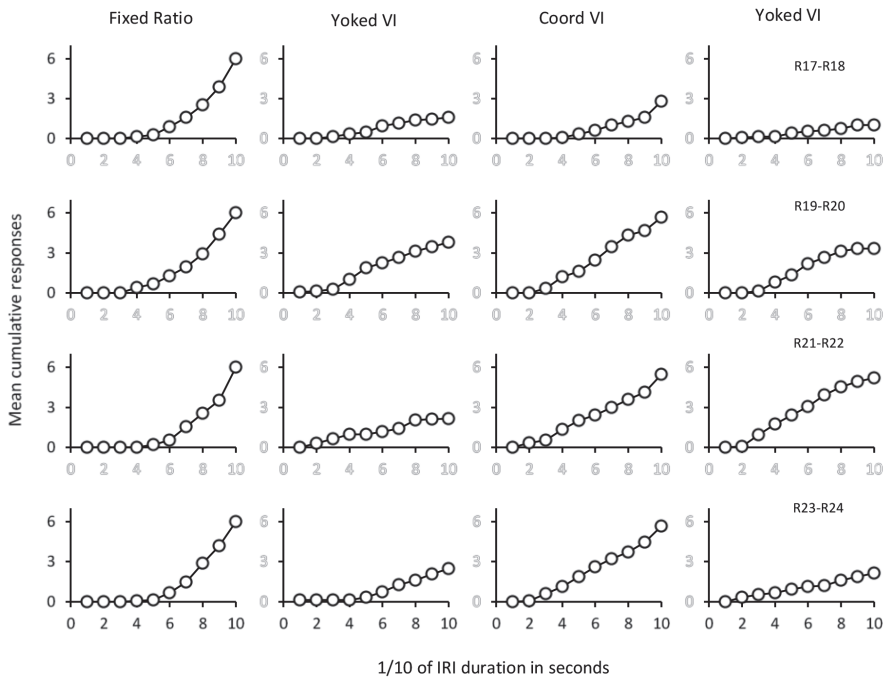


Figure 3. Temporal distributions of coordinated responding (IRTs < 500 ms) in each tenth of selected IRI (see text for explanation). Each data point is an average of responses for each dyad in the indicated interval of each condition of the experiment. Coordinated-response distributions in the VI schedules consisted of five IRIs in each session that were closest to the mean values.

effect of conditions. Ratios were higher in both coordinated schedules (FR 6 and coordinated VI) than in both yoked VI schedules. The dyads also had slightly higher ratios in the FR condition than in any other condition.

Figure 3 shows coordinated-response distributions for each dyad during the last three sessions in each condition of the experiment (FR 6, yoked VI, and coordinated VI). The intervals of the VI and yoked-VI schedules selected for analysis were the five IRIs in each session that were closest to the mean values. Five IRIs, using the same criterion for choosing interval durations, were selected in each session of the FR condition (based on a procedure described by Kuroda et al., 2013). In the FR schedule, coordinated responding of the dyad presented a typical FR response pattern (i.e., pausing and low rate at the beginning of the IRI, followed by a high response rate; pause duration was approximately half the interval). Although pauses

generally appeared in both VI conditions (yoked VI and coordinated VI), they were shorter than those occurring when the FR schedule was in effect. The VI and yoked VI schedules controlled similar patterns of responding, characterized by a constant response rate throughout the interval (in some cases after short pauses), which is a typical pattern of responding for these schedules. As did the data in Figure 2, the Figure 3 data show that coordinated-response rates were higher under the VI than the yoked VI schedule.

Discussion

The issues raised in Tan and Hackenberg (2016: Experiment 1) and de Carvalho et al. (2018: Experiment 3) were resolved in the present experiment because changes in coordinated responding occurred without systematically lower levels of overall responding across conditions (see Figure 1). The high overall response rates of all rats were likely attributable to the requirement of responding of both pair members. Moreover, differences in coordinated rates reported by de Carvalho et al. cannot be explained by differences in reinforcement schedules, because the present preparation used the same schedule (VI) with both response-dependent and response-independent reinforcement. These results also replicate the FR pattern and further demonstrates typical patterns of coordinated responding in VI schedules (see Figure 4).

The present findings are similar to those of experiments that investigated effects of response-reinforcer relations on individual operant responses (e.g., Kuroda et al., 2013; Zeiler, 1968). Coordinated rates, more than temporal patterns of coordinated responding, were altered by changes in response-reinforcer relations in the VI schedules (see Kuroda et al., 2013). Similar to the conclusions drawn by Kuroda et al., coordinated response patterns were probably attributable to the relatively constant (FR) or variable (VI) distribution of reinforcers in time (Kuroda et al., 2013; Zeiler, 1968).

Although the present experiment overcame some previous methodological issues, some points should be emphasized. First, only a VI schedule was used in the yoked conditions. Future experiments might investigate the effects of response-reinforcer dependence across FR schedules (see Neuringer & Schneider, 1968). (b) Another issue is the possible role of contingent relations between light presentation and coordinated responding in the yoked VI. Light presentations could have affected coordinated responses because of their temporal contiguity with that responses,

and occasionally with water deliveries. Although the effects of the contiguity of coordination and water deliveries could have been reduced by conducting more sessions in the yoked schedules (e.g., Catania, 2005), another option would be to control for the rate of light presentations in pairwise comparisons (i.e., experimental condition *v.* control condition) and program them to be independent of responding in the yoked schedules. (c) The chamber was dark mostly of the time, which make it difficult to conclude whether response of a rat served as visual stimuli for the response of the other. Tan and Hackenberg (2016) could not find decrement in levels of coordinated responses in a condition in which rats had no visual access to their partners. Łopuch and Popik (2011) found a positive correlation between frequency of coordinated responses and “happy” calls in pairs of rats. Tan and Hackenberg suggested that the sound may be the source of stimulus control, and Łopuch and Popik asserted that “happy” calls facilitated coordinated responses. Although it is not possible to isolate all of the procedural variables contributing to coordination in this experiment, it is noted that in the present procedure both visual and auditory stimuli may play a role in the control of coordinated responses.

Kuroda et al.’s (2013) preparation can be used to provide further evidence of the reinforcement of coordinated responses. Kuroda et al. varied the percentage of food deliveries that were dependent on the pigeons’ key-pecking (i.e., from 0 [completely independent] to 100% [completely dependent] and then from 100% to 0%). There was a positive association between response rates and the percentage of response-dependent food deliveries. By combining the strategy of Kuroda et al. (2013) and the design of the present study, future experiments could investigate the effects of varying the percentage of food deliveries that are contingent on temporally coordinated responding. This would not involve, however, completely response-independent food deliveries, but rather food deliveries that are programmed independently of *coordinated* responses (as in the present yoked VI condition). In a hypothetical 50%-50% condition, for example, food deliveries would depend on coordinated responding half of the time. The other half of the time, the food deliveries would depend on responses of both animals, but without the temporal coordination requirement. Using this procedure, one might examine the functional relations between the type of responding (independent or coordinated) and the proportion of reinforcers delivered for each type of responding.

The present experiment showed that increases in coordinated response rates does not occur simply as the outcome of a collection of individual response rates (see, e.g., Schuster, 2001, Vogler, 1968). Therefore, two critical properties for the

definition of coordinated responding were highlighted. One regards the formal relation in the contingency: simultaneous reinforcement that depends on coordinated responses. The second concerns the effects of the schedule of reinforcement in determining the frequency at which coordinated responding occurs. These properties may have implications for applied situations in which coordinated responding (e.g., temporally, spatially defined, etc.) of two or more individuals are required to produce consequences for the group members that would otherwise not be produced.

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