

**EFFECTS OF REINFORCER MAGNITUDE VARIABILITY
ON OPERANT RESPONDING AND CHOICE IN RATS**

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Abstract

The current study determined the effects of either a constant-sized (e.g., 2 pellets) or a variable-sized (averaging 2 pellets but ranging from 0-12 pellets) reinforcer on random-ratio responding in rats. Dependent measures of interest included within-session patterns of responding under a two-component multiple schedule, resistance to extinction, and preference under a concurrent schedule. Under a multiple schedule in which the two components alternated every 5 min, the component associated with the variable-sized reinforcer engendered greater responding later in the session. Responding in this component also was considerably more resistant to extinction than responding maintained by a constant-sized reinforcer; in fact, response rates increased considerably and these elevated rates were maintained for four consecutive extinction sessions in some rats. Despite this, under the concurrent schedule, the constant-reinforcer alternative was preferred in all rats. The results are discussed within the context of habituation, the partial reinforcement effect, and implications to gambling.

Effects of Reinforcer Magnitude Variability
on Operant Responding and Choice in Rats

In the United States organized legal gambling can be found in 48 states with over 1.5% of the US and Canadian population considered to qualify as pathological gamblers (Weatherly & Brandt, 2004). Petry (2005) estimated that 94% of Americans gamble during their lifetime with 10 million people in the United States experiencing problem gambling at some point. The analysis of Eadington (2003) of public policy related to gambling yielded results indicating that each problem gambler results in an additional \$15,000 cost to society, aside from the large personal costs of gambling. With these factors combined, the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV TR; American Psychological Association 2000) recognized pathological gambling as a mental disorder. The recent growth in popularity of online gambling has resulted in increasing societal costs. McCormack and Griffiths (2010) indicated that the use of electronic money as well as the indirect nature of online gambling resulted in increased perceptions of the addictive nature of gambling. Whatever the nature of betting, it is clear that pathological gambling is maintained by powerful underlying behavioral mechanisms.

Most gambling games arrange payouts according to random-ratio (RR) schedules of reinforcement. A random-ratio schedule is one in which each response has a fixed probability of paying off (Haw, 2008). These typically engender higher response rates than fixed ratio schedules. To date much of the literature pertaining to the subject focuses on fixed ratio and variable ratio schedules, which result in a reinforcer following

the completion of a certain number of presses or a variable number respectively. Roll and McSweeney (1997) used gerbils as subjects with schedules delivering reinforcement at approximately the same rate and discovered variable-ratio (VR) schedules (a type of RR schedule) engendered more prolonged responding than responding maintained by a comparable FR schedule. Furthering these findings, Christopher (1988) found that pigeons responded on a VR schedule to the exclusion of responding on a concurrently available FR schedule, to the point of incurring detrimental weight loss by not responding on the FR alternative. Kendall (1989) found that pigeons responded at higher rates for a key delivering a 10% probability of a reinforcer and a 90% probability of a long timeout (i.e., a signaled period of time in which no reinforcers can be earned) than the opposing key delivering an assured reinforcer after an FR 30 to the point of a significant food cost increase and weight loss. These studies exemplify that gambling-like schedules serve to engender higher responding despite the potentially negative long-term consequences of doing so.

Using four pigeons as subjects, Madden, Dake, Mael, and Rowe (2005) demonstrated that as the response requirement for reinforcement is increased, the subjects' higher rates of responding for RR over FR schedules grew dramatically. Similarly, Madden, Ewan, & Lagorio (2006) discussed the propensity for higher responding on a random-ratio (RR) schedule as opposed to a FR schedule when the percentage of baseline income decreases; thus, risk taking behavior becomes more likely. This baseline income refers to the initial number of responses per reinforcer, which is reduced when the response requirement is raised. It is because this schedule engenders high rates of play even under aversive conditions, that it is used in gambling.

The effects of RR schedules can also be seen in human studies. Delabbro and Winefield (2011) found that larger wins gave way to larger post reinforcement pausing and vice versa. Weatherly and Meier (2007) studied two groups of human participants, one risking credits worth no monetary value and one risking credits redeemable for currency. This experiment used a game of five-card draw with deuces wild and found that participants risked considerably fewer credits when they were redeemable for cash, demonstrating the difficulty of creating an accurate human model of gambling in a laboratory setting. Due to ethical constraints of having human participants wager their own money as well as the loss in validity when participants wager substitute currency, animal models of gambling help bridge the gap by creating a laboratory setting of gambling in which there is validity for each “wager” (Madden, Ewan, & Lagorio, 2007). Madden et al. (2007) also discussed how decision-making, arousal and arousal might be altered in a human laboratory setting. The animal model of gambling attempts to rectify these problems.

Weatherly and Derenne (2007) created one of the earliest animal models of gambling but were unable to determine that the rats were under the control of stimulus lights. Peters, Hunt, and Harper (2010) created a rat model of gambling using an FR 10 schedule dispensing different size reinforcers, including a “near win” condition. Three lights signaled this near win condition, which was a more similar stimulus to a win (four or five stimulus lights) than the one or two light signals of a loss. This experiment also included a collect lever in an attempt to further the work of Weatherly and Derenne (2007) by determining if the rats’ behavior was under the control of the stimulus lights. In this case an FR 10 was analogous to a spin and the number of lights that appeared to

signal reward was probabilistic. The rats in Peters et al. made more correct responses for wins and “near wins” than for losses, indicating that the rats’ behavior was under the stimulus control of the lights signaling the various outcomes. In addition to this, responding was more prolonged during extinction when the “near win” outcome was present.

As an animal model of slot machine play, one limitation Peters et al.’s (2010) procedure is that it did not manipulate the size of the win. In addition to reinforcing play probabilistically with wins, slot machines also arrange a variety of payout sizes, ranging from probable small wins to highly improbable jackpots. It is not clear to what extent these variations in win size affect gambling persistence.

In the operant animal literature, previous research utilizing pigeons found that in both multiple and concurrent schedules subjects tended to respond at higher rates for variable-sized reinforcers than for fixed-sized reinforcers (Essock & Reese, 1974). As the range of the variable-sized reinforcer was increased to include larger deliveries, the pigeons’ response rates in this component increased. In this study pigeons responded on fixed-ratio schedules for either a variable or fixed reinforcer presentation. These results support Custer and Milt’s (2005) “big-win” hypothesis on the development of problematic gambling. They hypothesized that large jackpots as well as the probability of experiencing these large sized reinforcers early in one’s gambling career would lead to a greater likelihood of problematic gambling in the face of continued losses.

Aoyama (2004) studied changes in within-session response patterns in rats responding under continuous reinforcement for either constant or variable-sized water deliveries. Aoyama found that the decrease in within-session responding was less for

variable-sized reinforcers. This is also consistent with a habituation account of within-session response patterning in that the rats will habituate much more quickly to fixed deliveries, causing responding and motivation to drop over the course of the session (McSweeney, Weatherly, & Swindell, 1996). This greater resistance to extinction observed in variable-sized reinforcers might be attributed to the partial reinforcement effect stating that resistance to extinction is greater when only some responses are reinforced (Capaldi, 1966).

Not all studies investigating choice between fixed- and variable-sized alternatives have found preference for the variable outcome. Using a concurrent chain schedule, Ito, Takatsuru, and Saeki (2000) varied the weights of their rats and thus their energy budgets. Only when rats were at 80% of their free feeding weight and the variable reinforcement alternative delivered three pellets on average as opposed to a constant alternative of two pellets was this study able to demonstrate a preference for variable-sized reinforcement. At heavier body weights the rats preferred the constant-sized alternative.

Though research has been dedicated to the effects of reinforcer magnitude variability on choice and operant responding, to date, studies have not examined the intricacies of this phenomenon under random-ratio schedules in which each response has an equal probability of yielding a reinforcer, the schedule typically used in slot machine gambling.

The purpose of this experiment was to study rats' responding on multiple and concurrent random-ratio schedules of reinforcement that ended in fixed- or variable-sized reinforcement. Unlike the Peters et al. (2010) animal model of slot machine play, this

experiment both arranged “wins” and “losses” on an RR schedule and probabilistically manipulated the size of the win. In terms of within session response patterns, based on the results of Aoyama (2004) it was predicted that the variable-sized reward component would show less of a decline over the course of the session as well as be more resistant to extinction. While Essock and Reese (1974) would suggest preference for variable-sized reinforcers, Ito, Takatsuru, and Saeki (2000) would suggest the inverse. Though the literature is mixed as to the preference for fixed or variable reward sizes, we hope that this study will serve to better clarify the nuances of this preference.

Method

Subjects

The subjects were five naïve female Long Evans adult rats. The rats were single housed in polyethylene cages in a temperature-controlled environment. They were kept on a 12-hr reverse light-dark cycle with sessions conducted during the dark phase of the cycle. Each rat was fed 8 to 12 grams of 8604 Teklad Rodent Diet per day immediately following the session as well as given access to water in their home cages. This was done in attempt maintain the rats at approximately 85% of their free feeding weight.

Apparatus

Three commercial operant chambers (30 cm × 24 cm × 20 cm; ENV-008; Med-Associates, St. Albans, VT) each were enclosed in sound-attenuating cubicles (ENV-022V) equipped with ventilation fans. Two retractable levers (ENV-112CM) were centered on the front wall, 1.5 cm in from each side and 7 cm above the grid floor. A

food-pellet dispenser (ENV-203M-45) delivered 45-mg pellets (F0021; Bio-Serv, Frenchtown, NJ) to a receptacle centered beneath the two levers. A houselight, centered on the back wall 2 cm from the ceiling, provided general illumination.

Procedure

In the first phase of the experiment, rats lever pressed on a strictly alternating across blocks two-component multiple schedule. The components were signaled by the lever inserted into the chamber and the onset of the stimulus light over the inserted lever. The sessions were divided into 5-min blocks with a 30-s blackout between blocks. One lever dispensed pellets according to a RR 10 schedule in which each response had a 10% chance of delivering 2 pellets for every successfully completed ratio; this was the constant reinforcement component. The other lever dispensed pellets according to an RR 10 schedule delivering 0-12 pellets averaging to 2 pellets; this was the variable reinforcement component. The number of pellets dispensed was selected without replacement from the following list: 0,0,0,0,1,1,1,1,4,12. In both components, a 0.2-s audible tone signaled the delivery of each pellet, including a single tone when 0 pellets were dispensed in the variable reinforcement component to demarcate a ratio completion.

The session began in the constant or variable component with equal probability. Following 5 min of the initial component, there was a 30-s blackout during which both levers retracted and both lights signaling available reinforcement were turned off. After this blackout the lever opposite the initial component was made available, and the light above it signaling available reinforcement was turned on. For the remainder of the session, the components strictly alternated and were separated by a 30-s blackout until the rats had experienced each component six times. Three rats, F1, F2, and F3, experienced

this phase with the left lever delivering constant reinforcement and the right lever delivering variable reinforcements. Two rats, F4 and F5, experienced this phase with the left lever delivering variable reinforcement and the right lever delivering constant reinforcement.

This multiple schedule was employed for 30 sessions and the last 10 sessions were used for analysis. This was followed by 4 sessions of extinction during which completion of the RR response requirement would produce either a constant 2 or variable number of audible tones but no pellets were delivered. All other procedural details remained the same during these extinction sessions. It should be noted that one rat, F6, died during the course of this component and as such this data is not included in the analysis.

The next phase of the experiment consisted of a concurrent schedule in which both levers were available for a 60-min session with the lights above the levers signaling available reinforcement. Both levers delivered reinforcers according to an RR 10 schedule, with one lever arranging constant reinforcement and the other variable, as described above. Twelve sessions were conducted and the last five sessions were used for analysis. Subsequently, the response requirement on the constant lever was increased to an RR 30 and finally to an RR 50; the response requirement on the variable lever remained an RR 10. Due to time constraints each RR parameter was investigated for only six sessions with the last five used for data analysis. Rat F1 died during the course of this session and as such this data is not included in the analysis.

Results

During the first exposure to the multiple schedule, the mean overall session group ($n=5$ rats) response rate in the constant reinforcement component was 10.71 responses per min and the mean response rate in the variable component was 13.62 responses per min. Data from the last 10 sessions of this conditions were used for these analyses. These results are displayed in Figure 1. This difference was not significant with a two-tailed t-test yielding $t(8) = 1.051, p = .9088$.

Figure 2 shows within-session changes in responding in both components. The x-axis is divided into 10 min blocks with 5 min being devoted to responding for fixed-size reinforcers and 5 min devoted to responding for variable-size reinforcers. This graph displays a fairly constant decline in responding across both conditions with a steeper decline when the rats are responding for fixed-size reinforcers. This effect was most evident in 3 of the 5 rats.

Figure 3 displays the proportion of Block 1 responding maintained in the subsequent blocks. The variable reinforcement alternative maintained a larger proportion of responding through all 5 subsequent blocks. This was true for all but one rat.

Figure 4 displays the responding maintained during each of the four sessions of extinction in each of the two components. Visual inspection of the data reveals that for every rat responding in the variable component was more resistant to extinction than responding in the constant component. In some rats, the variable reinforcement component actually yielded higher rates of responding than during the multiple schedule baseline. This is possibly the most significant finding of the study in that response rates actually increased in the variable reward-size component for 2 of the 5 rats and all of the

rats had higher responding during extinction for the variable reward-size component in all or all but the first extinction session. In contrast, responding maintained in the constant component usually decreased across extinction sessions to low levels for all rats except F3. For this rat, constant component responding initially increased in the first extinction session. Although it subsequently decreased thereafter, it continued to occur at rates higher than what was observed in baseline. Critically, however, even for this rat responding in the variable component occurred at higher rates than constant component responding.

The extinction results from Figure 4 are expressed as a proportion of baseline in Figure 5. For every rat and excluding the first session of extinction, responding in the variable component persisted at a higher level, relative to the mean baseline response rates shown in Figure 1, than responding in the constant component.

Figure 6 shows the results from the four extinction sessions are averaged together and within-session patterns of responding are expressed using the block analysis as described above. For all rats the variable reward-size component induced higher responding during extinction with the exception of F4 who was nonresponsive in later blocks.

Figure 7 displays the proportion of total responding devoted to the constant reinforcement alternative during each of the three concurrent schedule phases. In the initial portion of the concurrent schedule phases both levers operated under an RR 10 dispensing fixed and variable reward sizes. Once an initial preference for the constant component was determined, the response requirement on this lever was gradually raised. Only when the constant lever response requirement was raised to an RR 50 while the

variable lever requirement remained an RR 10 did most rats prefer the variable alternative.

Discussion

Under the multiple schedule, the constant and variable reinforcement magnitudes maintained comparable overall response rates. This is inconsistent with previous results found by Essock and Reese (1974).

Although overall response rates did not differ between the constant and the variable sized reinforcers, responding for reinforcers of variable sizes persisted longer throughout sessions. Consistent with our findings, Aoyama (2004) also found that the decrease in within-session responding was less for variable-sized reinforcers. The typical pattern of decline in within session responding shows an exponentially negative slope, as seen in this study. By altering weights and comparing this decline in responding between schedules, Aoyama posited that it is not satiation responsible for these changes but habituation. This habituation occurs more slowly to variable-sized reinforcers.

These findings are consistent with a habituation account of within-session response patterning (McSweeney, Weatherly, & Swindell, 1996). In addition to this these findings could also be explained using Capaldi's (1966) partial reinforcement effect. The variable-sized reinforcement component actually arranges intermittent reinforcement; most of the time 0 pellets are delivered upon completion of the ratio. Intermittent schedules of reinforcement produce responding that is more resistant to extinction. Because 0 pellets was the most frequent outcome, perhaps our rats could not

discriminate extinction in this component; so here you could discuss the discrimination hypothesis of the partial reinforcement effect.

Mellon and Shull (1986) found that responding maintained by a variable delay to reinforcement was more resistant to extinction than responding maintained by a fixed delay to reinforcement. The current research extends these findings to situations involving variability in reinforcer magnitude. Aoyama (2004) also found that resistance to extinction was higher for variable-sized reinforcement .

In addition, it is unclear to what extent the tones functioned as discriminative stimuli and conditioned reinforcers in this study, and how this contributed to the differences in resistance to extinction. In the constant component, the tone always served as a discriminative stimulus for food pellet delivery. This is no longer the case in the extinction sessions. The variable reward-size component often results in a 0-pellet presentation following the tone, making this component more resistant to extinction due to the signals accompanying the schedule.

Our results are consistent with those found by Ito et al. (2000), who were only able to demonstrate a preference for variable reinforcement when motivation levels were increased with increases in food deprivation and the variable reinforcement alternative delivered on average more pellets than the constant alternative. Otherwise, Ito et al. reported preference for the constant alternative. Our study actually found that rats preferred the constant component even when it was more expensive than the variable component (i.e., in the RR 30 condition). Only when the price disparity further increased (i.e., in the RR 50 condition) did preference for the cheaper variable alternative emerge. Using Ito et al.'s results as a reference point, the RR 50 in the constant component

decreased pellets earned and fostered the motivation to switch preference to the richer component.

The choice results found in this study are inconsistent with those found by Essock and Reese (1974). One possible explanation is the nature of the schedule employed in this experiment. In our study the 0-pellet presentation was a common outcome under the variable reward-size component. This, similar to the methods employed by Ito, Takatsuru, and Saeki (2000), could account for the preference for a constant reward-size under a concurrent schedule.

One interesting aspect of the present set of results is that it is the only study to date that demonstrates dissociation between preference and resistance to extinction. Grace and Nevin (1997) demonstrated the typical covariance of preference and resistance to change. If one schedule is preferred to another it is typically more resistant to extinction, which is contrary to the findings in the present study. A likely explanation for this discrepancy being the number of 0-pellet presentations on the variable reward-size component causing it to be more difficult for the rats to differentiate between this schedule and extinction.

This study demonstrated considerably higher responding for the variable reward-size component in the multiple schedule implemented. These variable reward sizes also proved much more resistant to extinction. This demonstrating the ability of both this type of RR schedule as well as varying reward sizes to increase time spent playing in gambling situations. This may very well serve to engender higher rates of gambling amongst those with pathological gambling problems.

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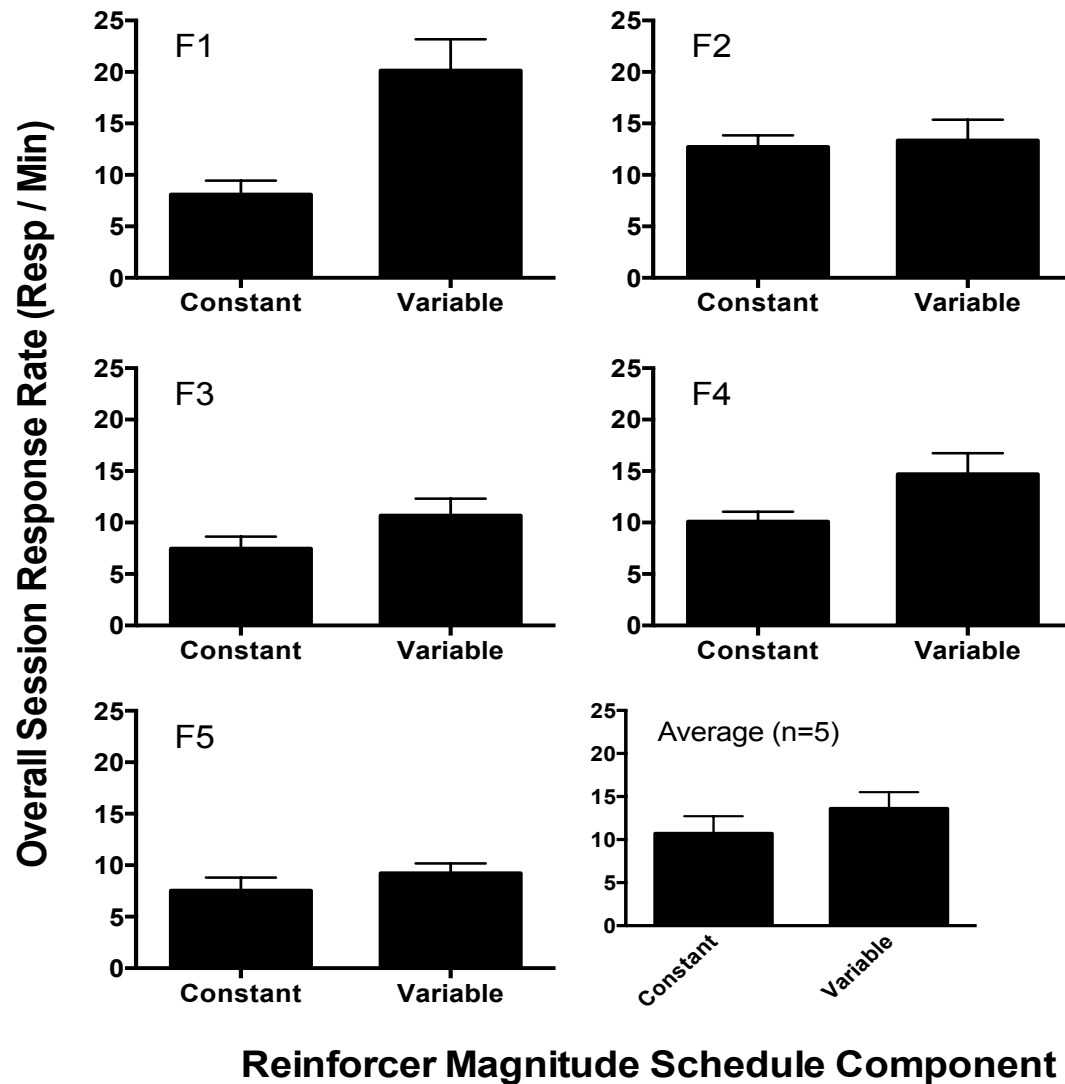


Figure 1. Shown above is the mean (+ SEM) overall response rate (responses/min) engendered by each reinforcer magnitude component for each of the five rats. In the lower right hand panel the mean response rates averaged across all five rats are shown.

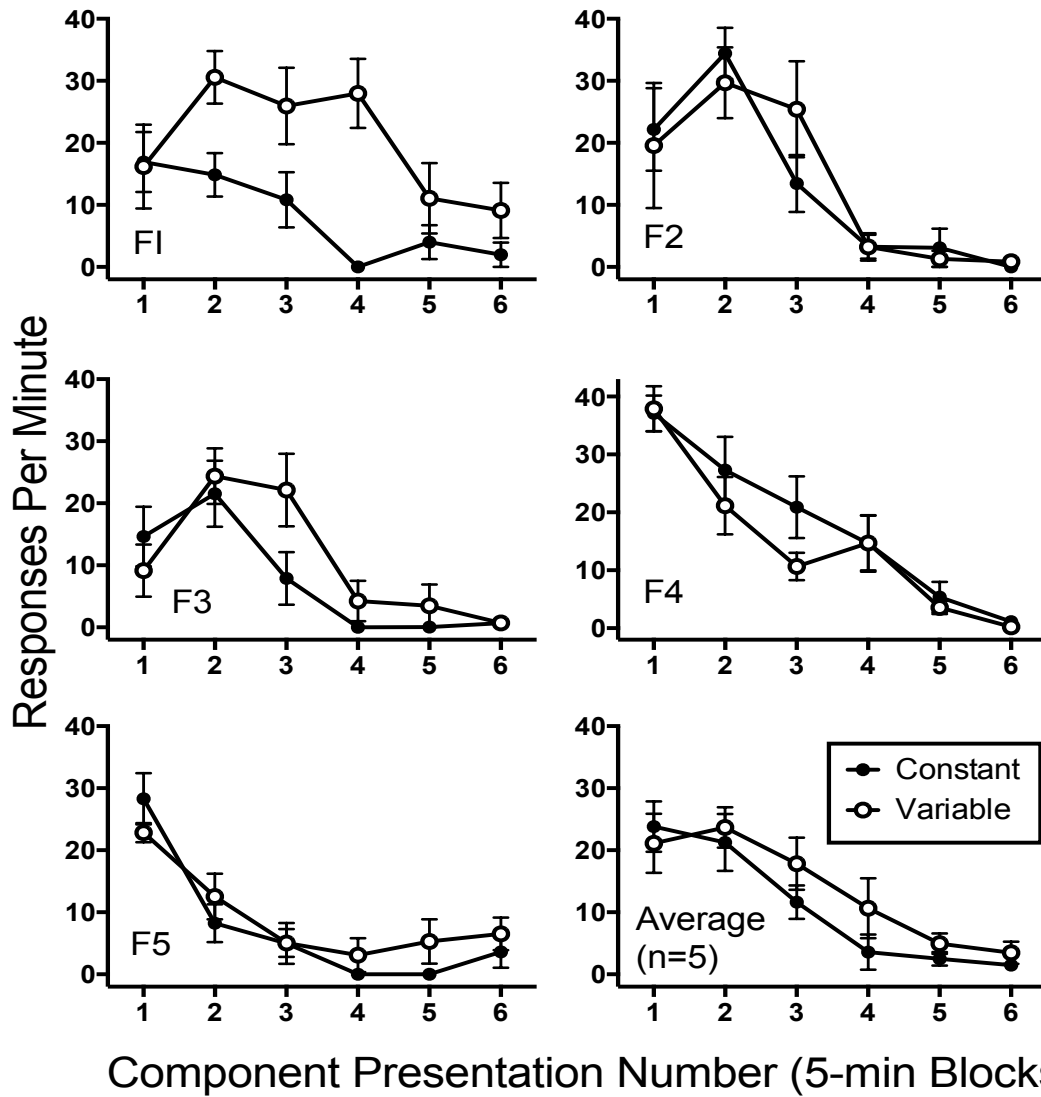


Figure 2. Shown above is the response rate (responses/min) and SEM for each of the five rats, averaged across the last 10 sessions of the multiple schedule condition.

Response rates from the individual 5-min components are shown in consecutive order. A solid black circle denotes the constant reinforcement components and an empty circle denotes the variable reinforcement components.

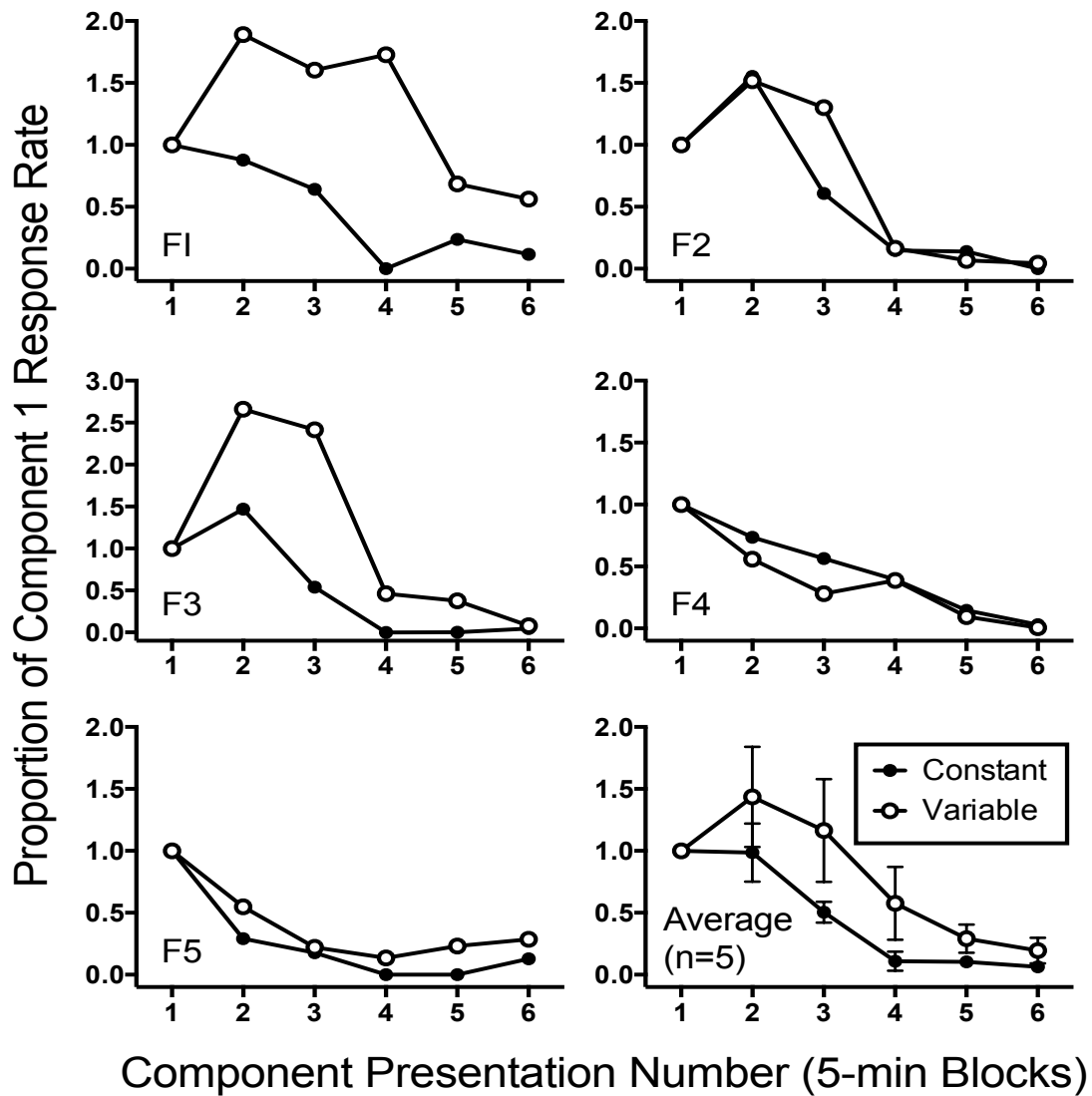


Figure 3. Shown above is the proportion of Component 1 responding (response rate) maintained during each of the five following components. The data point at Component 1 is represented at 1.0 with the responding in later components displayed as a proportion of this. This analysis was conducted for responding in both components (constant or variable) and the data are averaged across the last 10 sessions of the multiple schedule condition.

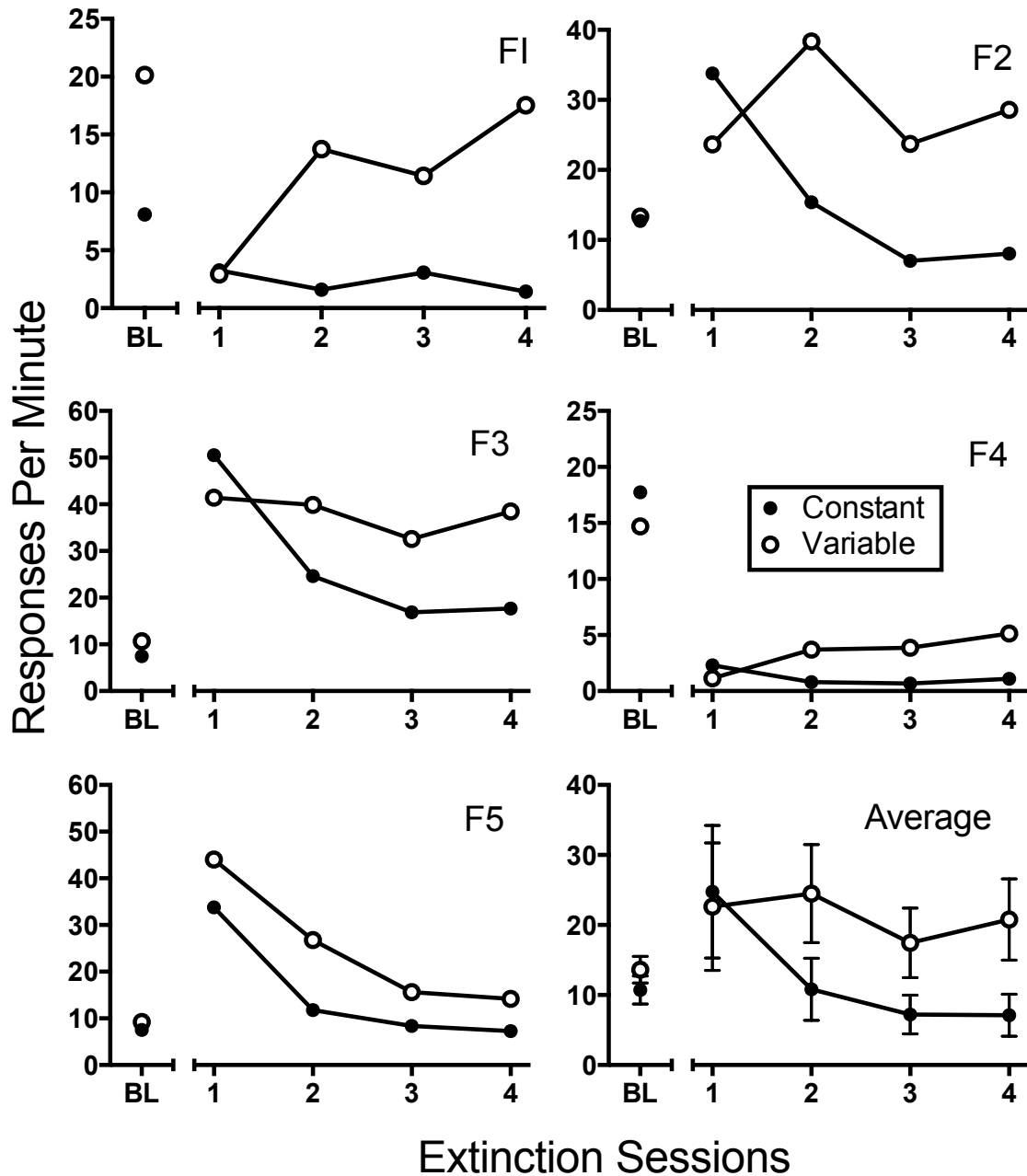


Figure 4. Shown above are the response rates for each of the five rats as a function of the four extinction sessions. Baseline response rates for each reinforcement condition (constant or variable) are displayed in the far left of each graph above the marker labeled BL.

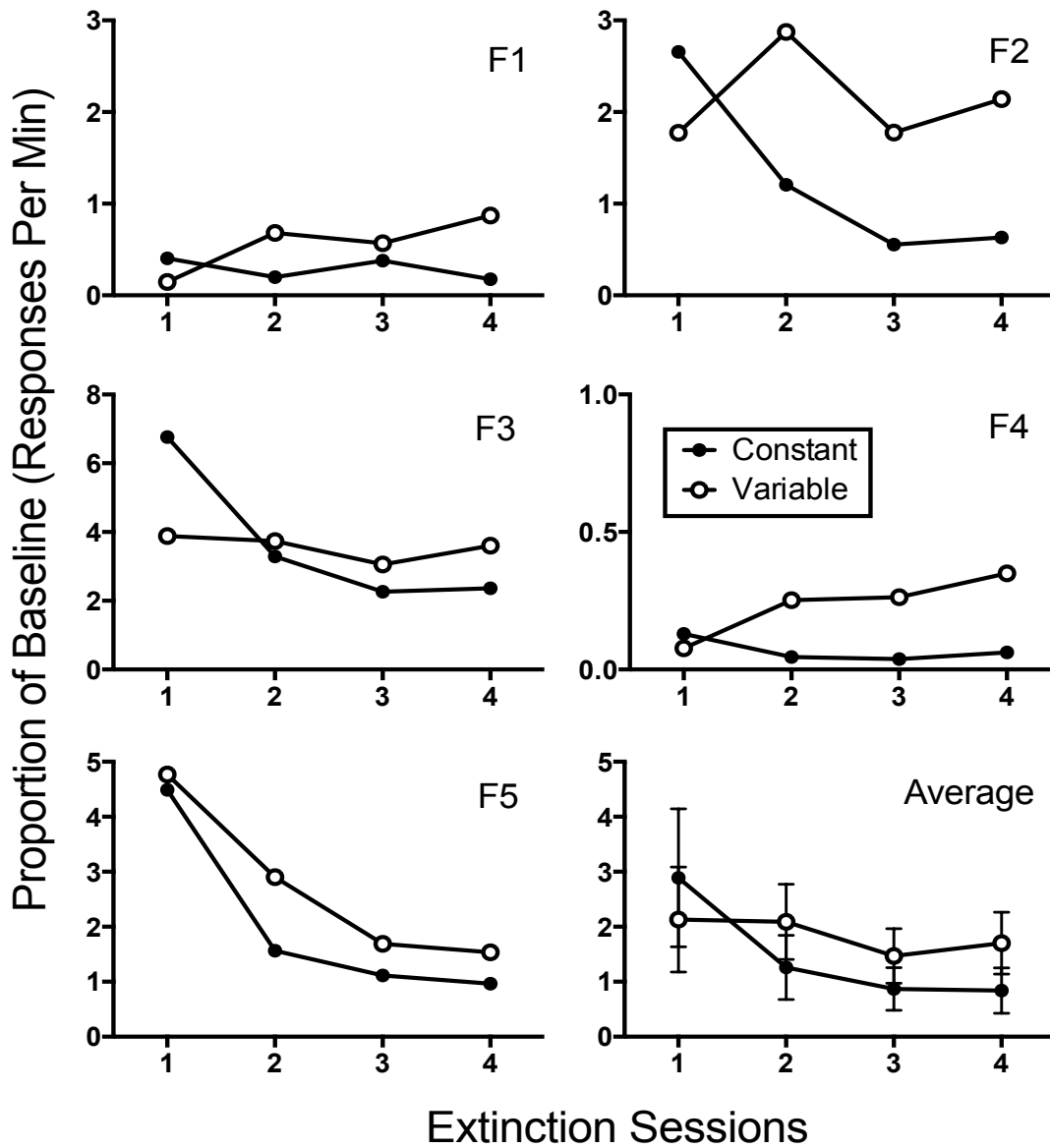


Figure 5. Shown above is the proportion of baseline responding (responses/ min) maintained during each of the four extinction sessions in the constant and variable components. The baseline response rates used in this analysis are shown in Figure 1.

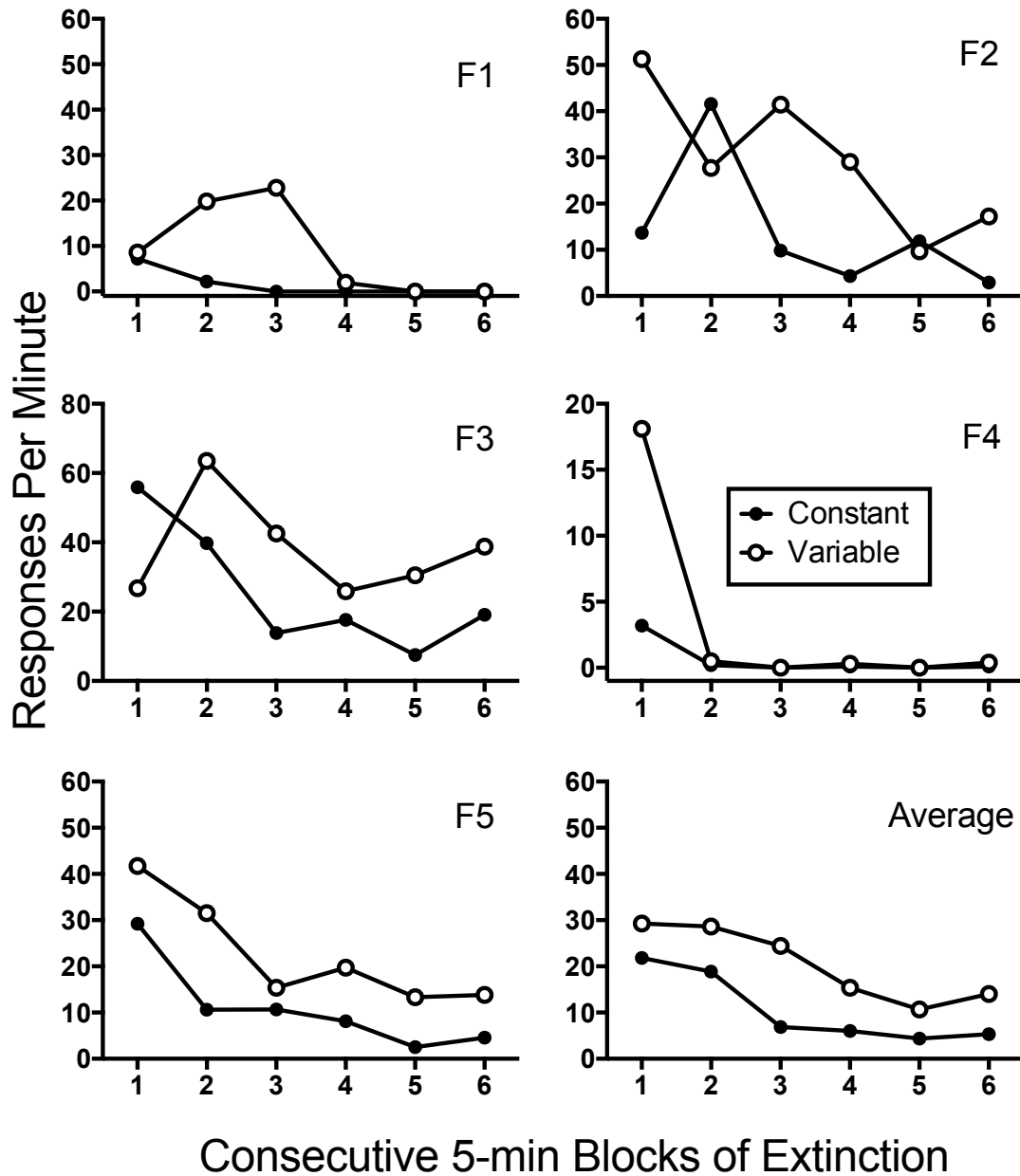


Figure 6. Shown above is the response rate for each of the five rats during consecutive 5-min component presentations across the session. The response rates are averaged across the four sessions of extinction.

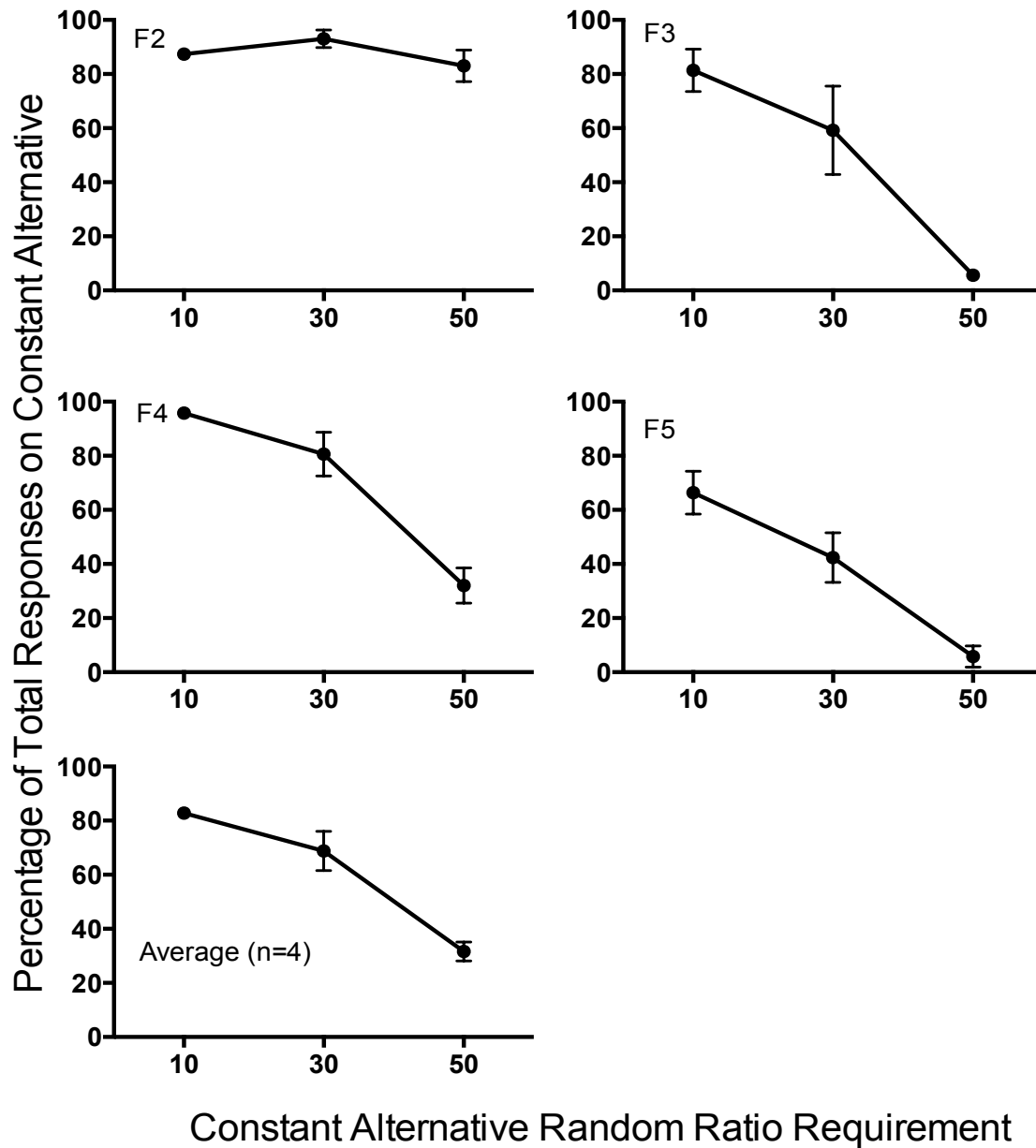


Figure 7. Shown is the percentage of responding devoted to the constant reinforcement alternative on the concurrent schedule as a function of its RR requirement. The RR requirement for the variable reinforcement component always was an RR 10. These results are averaged across the last 5 sessions of each RR parameter. Data from F1 is excluded due to poor health; it died shortly after this condition.