

Fixed-ratio performance of *Betta splendens* without an operandum: An analysis of responding with and without an explicit response-location stimulus and a response-feedback stimulus

Thais M. Sales

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Department of Psychology
University of Manitoba

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Abstract

For contacting a virtual cylinder located near the centre of the experimental tank, 4 male Siamese fighting fish (*Betta splendens*) received food reinforcement on a fixed-ratio (FR) 6 schedule. Ten times per second a tracking system recorded, in 3 dimensions, the location of the fish in the experimental tank. For each fish, the number of responses per session, the 2 dimensional swimming patterns, and the response patterns as observed in cumulative response plots were analyzed in 4 experimental conditions. The experimental conditions were: (a) both a response-location stimulus and a response-feedback stimulus were present; (b) neither a response-location nor a response-feedback stimulus were present; (c) only a response-location stimulus was present; (d) only a response-feedback stimulus was present. After experiencing the conditions, 2 fish were exposed to extinction, first with only the response-location stimulus present and then with the addition of the response-feedback stimulus. The combination of the response-location and the response-feedback stimulus and the response-location stimulus alone resulted in the highest number of responses per session and swimming patterns more concentrated in and around the target response location. The absence of a response-location stimulus and a response-feedback stimulus resulted in fewer responses per session and swimming patterns more spread out than in the conditions where the response-location stimulus was present. The response-feedback stimulus alone produced patterns similar to the condition where neither stimuli were present. In neither condition was an FR break-and-run response pattern observed in the cumulative response plots. The addition of the feedback-stimulus to the extinction resulted in a temporary increase in responding for one fish, but not for the other. The results suggested that the response-location stimulus functioned as

a discriminative stimulus and that the response-feedback stimulus functioned as a conditioned reinforcer when combined with the coin, though its role in the absence of the coin was less clear. The characteristics of the response topography and the variability in the location of the consumption response may have contributed to the lack of a break-and-run pattern under FR6 with fish. .

Keywords: fixed-ratio, location stimulus, feedback stimulus, operandum, fish

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Fixed-ratio performance of *Betta splendens* without an operandum: An analysis of responding with and without an explicit response-location stimulus and a response-feedback stimulus

Most basic operant behaviour studies involve the investigation of discrete motor responses defined in terms of the mechanical contact with a device referred to as an operandum (Critchfield & Lattal, 1993; Skinner, 1962). There are two stimuli provided by the operandum. One is a response-location stimulus: as a visual stimulus, the operandum delimits where a response must occur in order to be followed by a reinforcer delivered according to a certain schedule. The other is an exteroceptive response-feedback stimulus: every time the operandum is operated, a stimulus is produced, typically an auditory one (the audible click of a microswitch) in research with mammals and birds (Critchfield & Lattal, 1993).

Most of our knowledge of basic principles of operant behaviour and the response patterns produced by specific schedules of reinforcement was derived from studies in which an operandum was used. However, the roles of the response-location stimulus and the response-feedback stimulus provided by the operandum have received little systematic study.

Nevertheless, there is evidence that discrete motor responses may be conditioned and maintained in the absence of an operandum. Some examples will now be described.

Operant Studies Without an Operandum

Hoffman and Fleshler (1959) increased the frequency of a pigeon lifting its head to a light beam photocell using negative reinforcement (i.e., target responses were followed by the removal of an aversive stimulus resulting in increase in frequency of

responding). Although an operandum was not used in this study, it is possible that the photocell beam provided a response-location stimulus. In addition, although no clear response-feedback stimulus was present in this experiment, the removal of a shock occurred every time a response was emitted. Therefore, a clear consequence was presented immediately contingent on every response.

Pear and Legris (1987) used a real-time automated 3D video tracking system (VTS) to shape the behaviour of pigeons contacting a virtual sphere with their heads. The location of the virtual sphere was selected on the basis of infrequent contacts of the bird's head with that location during baseline. The rate of contacting the target area increased when the shaping procedure was carried out, although the response was not defined in terms of a distinctive operandum. In this experiment, a distinctive response-location stimulus was not present. Despite that, responding was shaped. Although a response-feedback stimulus was not used in this study, the reinforcer occurred after each response.

Using an apparatus similar to Pear and Legris (1987), Chitty (2002) established responding under fixed ratio (FR, every n^{th} response is reinforced, with N being a fixed number) schedules in male *Betta splendens* (Siamese fighting fish) using the fish's mirror image as the reinforcer. The response involved contacting a virtual sphere and there was no distinctive response-location stimulus or a response-feedback stimulus used in this experiment. Although operant responding was maintained under FR schedules, a clear break-and-run pattern of responding (i.e., pauses occur after reinforcement and are followed by a high steady rate of responding) was not established. This point will be discussed further with the literature of operant conditioning with *Betta splendens*.

Schroeder and Holland (1968) modified the frequency of eye movements by humans using signal detection (pointer deflection) as the reinforcer. The response was defined as the intrusion of the corneal reflection in a 4° by 4° square area surrounding one of each of 4 dials mounted near different corners of the apparatus display. Put simply, the subject had to look at one of the dials in order for a response to have occurred. Because there were 4 dials, there were 4 response-location stimuli. A distinctive response-feedback stimulus was not present. The eye movements were reinforced according to a multiple schedule of reinforcement with three alternating components: fixed-interval 2 min, differential-reinforcement-of-low-response-rates 10 s, fixed-ratio 45 (multiple FI 2 min DRL 10 s FR 45). In the FI 2 min component, the first response emitted after 2 min following the previous reinforced response was reinforced; in the DRL 10 s condition, a response was reinforced when it was emitted after at least 10 s had elapsed without responses; in the FR 45 condition, the 45th response that was emitted following the previous reinforcement was reinforced. Each component was signalled by the illumination of a dim green light in a different position near the middle of the apparatus display. It is important to note that the subjects were not informed that their eye-movements produced the pointer deflections that they were instructed to detect.

Results indicated that patterns of eye movement, as shown by cumulative response plots, were similar to the patterns obtained when an operandum is used; that is, a pause after reinforcement followed by a gradual increase in rate occurred under FI (scalloped pattern), a pause after reinforcement followed by a high steady rate occurred under FR (break-and-run pattern), and a low rate with occasional bursts of responding

occurred under DRL. These are typical schedule effects that have been documented in research with pigeons and rats (Ferster & Skinner, 1957; Skinner, 1938).

Important to the present thesis, these patterns have not been clearly demonstrated in non-avian-or-mammalian species, such as fish. The generality of the patterns of response typically observed with mammals and birds under schedules of reinforcement requires further investigation, as differences between species could be indicative of an evolutionary change or could be indicative that elements present in the experimental setting in the research with mammals and birds are necessary in producing those patterns believed to be "typical" of the schedules.

Critchfield and Lattal (1993) studied the role of a response-feedback stimulus in the acquisition and maintenance of operant responding by rats receiving delayed reinforcement. The operant response was defined as interrupting a photocell beam (potential response-location stimulus) located near the top rear of the operant chamber. A response-feedback stimulus (tone) was presented after each response for a group of subjects and not presented for the other group. Results indicated that responding was established and maintained by delayed reinforcement without an operandum or an immediate response-feedback stimulus. However, the presentation of a tone immediately when the photocell beam was interrupted resulted in faster acquisition and a higher reinforcement rate at stability, indicating that the response-feedback stimulus improved response efficiency.

In the experiments described above, operant responding was established and maintained, even though an operandum was not used. However, except for Chitty (2002), the apparatuses seem to have included distinctive stimuli that may have acted either as a

response-location stimulus or a response-feedback stimulus, or may have obscured the potential role of a response-feedback stimulus (i.e., continuous reinforcement - CRF - every response is reinforced). In addition, only Critchfield and Lattal (1993) directly compared the presence versus the absence of a response-feedback stimulus. There were no comparisons of the presence versus the absence of a response-location stimulus.

The above results lead to three questions that are the focus of the present study. First, in intermittent schedules of reinforcement, are there different rates of responding when a response-location stimulus is present versus when a response-location stimulus is not present? Second, in intermittent schedules of reinforcement, are there different rates of responding when a response-feedback stimulus is present versus when a response-feedback stimulus is not present? Third, will a clear break-and-run pattern of responding occur with *Betta splendens* on FR if a response-location or a response-feedback stimulus is present? This question is important because clear FR schedule effects similar to those obtained with pigeons and rats have not been observed in fish. Thus, all three questions are important in the understanding of the generality of the principles of operant behaviour. The third question will be now be discussed in the context of operant studies with fish.

Schedules of Reinforcement with Fish

The research on schedules of reinforcement with fish seems to have been marked by the investigation of the extent to which the findings observed with other species, especially rats and pigeons, apply to fish. According to Bitterman (1975), potential differences found could be interpreted in essentially two ways. One possible interpretation is that the results are indicative of some fundamental evolutionary change.

That is, they are indicative of differences between species. The other possible interpretation is that the different results were a function of methodological differences. That is to say that differences in the experimental setting, deprivation variables, and reinforcement variables account for the different results.

CRF and extinction. Research has established that operant responding can be conditioned and extinguished in fish. Typically, a response-location stimulus was present in this research (e.g., a ring for the fish to swim through, a target for the fish to contact), but there was no response-feedback stimulus.

Gonzales, Eskin, and Bitterman (1961,1962), using food as the reinforcer, trained African mouthbreeders (*Tilapia macrocephala*) to strike a target and then put the response on extinction (i.e., the response was no longer followed by reinforcement). The mean number of responses across fish decreased over sessions with extinction in both studies. Results for the conditioning phase were not presented.

Wertheim and Singer (1964) conditioned Goldfish (*Caracassius auratus*) to enter an alley using food as the reinforcer. The number of responses per session increased during the CRF phase and decreased during the extinction phase for all subjects. A cumulative response plot for the last CRF session for one of the fish showed a constant rate of responding, typical of the CRF performance documented with pigeons and rats (Ferster & Skinner, 1957; Skinner, 1938).

Goldstein and Hall (1990) conditioned Archer Fish (*Toxotes jaculator*) to spit at a target using food as the reinforcer. This species hunts for prey by spitting at airborne insects, an activity that often occurs in social contexts. The number of spits per session

increased during the CRF phase and decreased during the extinction phase for all subjects.

The mirror image or other image of a male *Betta splendens* can reinforce an arbitrary operant response in the male of this species. (In this thesis, all references to *Betta splendens* will be the male of the species unless otherwise specified.) Several studies were conducted with *Betta splendens* using the image of a conspecific, and therefore the opportunity to engage in aggressive display, as a positive reinforcer for operant responses. *Betta splendens* exhibit aggressive reactions when confronted with the image of a conspecific in the form of a conspecific, a mirror image, or a model of a conspecific. These aggressive reactions typically include extension of gill covers, fin erection, deepening of the body and fin coloration, frontal approach with undulating movements towards the opponent, tail beating, and biting. The combination of these responses has been labelled “aggressive display.” A more detailed description of the aggressive display of *Betta splendens* can be found in Simpson (1968).

In the studies with *Betta splendens*, it has been found that the rate of swimming through a ring increases when a mirror, a moving model of a conspecific, or a film of a conspecific displaying aggression are made contingent on this response (Goldstein, 1967; Hogan 1967; Thompson, 1963; Turnbough & Lloyd, 1973). In addition, the increase in rate of responding is a function of the response-reinforcer dependency: when the image of a conspecific is presented on a schedule independent of the fish’s behaviour, the rate of the measured response increases only slightly; however, the rate of responding increases substantially when the same stimulus is presented contingent on the target response (Goldstein, 1967; Hogan 1967). These results have been replicated with female *Betta*

splendens (Elcoro, da Silva, & Lattal, 2008). Responding of *Betta splendens* has also been conditioned when delayed mirror presentations were used as the reinforcer in studies of delayed reinforcement (Elcoro et al., 2008; Lattal & Metzger, 1994).

Although the rate of responding of fish has been shown to increase and be maintained under CRF, the pattern of responding within sessions in the form of cumulative response plots and how it compares to typical patterns observed with pigeons and rats, has only been shown by Wertheim and Singer (1964) in one cumulative response plot for one fish. Goldstein (1967), Hogan (1967), and Thompson (1963) presented results in the form of group range, mean, or median number of responses per session, as opposed to single-subject results. Gonzales, Eskin, and Bitterman (1961, 1962) also presented the results in a group format for the extinction sessions and did not present the results for the CRF sessions. Goldstein and Hall (1990) and Elcoro et al. (2008) presented single-subject results per session, but not within-session responding. Therefore, to date, there was only one demonstration of the typical CRF response pattern with fish (Wertheim and Singer, 1964) and more research is needed to investigate the extent to which different species of fish show the constant rate of responding in single sessions documented in studies with pigeons and rats under CRF (Ferster & Skinner, 1957; Skinner, 1938).

Operant responding of fish may be maintained and modulated by schedules of reinforcement other than CRF. Some schedules of reinforcement that have been investigated with fish are: differential reinforcement of other behaviour (DRO), in which reinforcement is delivered contingent on the absence of responding for a certain interval (Turnbough & Lloyd, 1973); interval schedules, in which reinforcement is delivered

based on an interval between a response and the previous reinforcement, regardless of other responses that occur during the interval, and may take the form of a fixed-interval (FI) or a variable-interval (VI) (Breuning, Ferguson, & Poling, 1981; Eskin & Bitterman, 1960; Gonzales et al., 1962; Higa & Simm, 2004; Talton, Higa, & Staddon, 1999; Rozin, 1965; Wertheim & Singer, 1964); and ratio schedules, in which reinforcement occurs contingent on every n^{th} response, which can be a fixed number of responses (fixed-ratio, FR) or a variable number of responses (variable-ratio, VR) (Chitty, 1999; Eskin & Bitterman, 1960; Goldstein & Hall, 1990; Hogan, Kleist, & Hutchings, 1970; Salzinger, Freimark, Fairhurst, & Wolkoff, 1968; Thompson, 1969).

DRO. Turnbough and Lloyd (1973) obtained fewer responses (swimming into the upper or lower portion of the response chamber located on one wall of the experimental tank) per session when DRO 100 s was implemented after a phase of CRF, using a 10 s film clip of a fish as the reinforcer with *Betta splendens*.

Interval schedules. As described above, responding under FI in pigeons and rats is characterized by a pause after reinforcement followed by a gradual increase in response rate as the interval progresses, called “scalped” pattern. Responding under VI in pigeons and rats is characterized by a moderate steady rate with little or no pausing after the reinforcers (Ferster & Skinner, 1957).

Gonzales et al. (1962) compared responding (striking a target) under extinction after a VI 1 min and a FI 1 min of African mouthbreeders (*Tilapia macrocephala*) using food as the reinforcer in a group design. Although only extinction data were presented, the authors commented on the performance during FI and VI. According to the authors, cumulative response patterns under VI and FI were indistinguishable: both groups

frequently showed a brief pause after reinforcement and occasional scallops. These results were obtained after 25 daily sessions with 20 reinforcements. Therefore, it is unknown whether a longer exposure to the schedules would have resulted in the typical patterns in interval schedules found with pigeons and rats.

Eskin and Bitterman (1960) also reported failure in observing a scalloped pattern of responding (striking a target) under FI 2 min with African mouthbreeders (*Tilapia macrocephala*). The authors reported that brief pauses after reinforcement were observed, but no scalloped pattern. However, cumulative plots were not presented. Again, these results were based on 23 to 27 sessions and it is unknown whether typical patterns would have been observed with longer exposure to the schedules.

Wertheim and Singer (1964) studied the response of swimming into an alley under a VI 50 s schedule in a single-subject design with Goldfish (*Caracassius auratus*), using food as the reinforcer. A cumulative response plot was presented for one fish. Responding under the VI schedule showed occasional pauses after reinforcement and local rate changes. These patterns were observed after 24-10 min sessions. It is unknown whether a longer exposure to the VI would have produced the constant rate of responding typically observed under this schedule with pigeons and rats.

It should be noted that in the preceding three studies (i.e., Gonzales et al., 1962; Eskin & Bitterman, 1960; Wertheim & Singer, 1964), the main goal was to study responding during extinction after a phase of reinforcement using interval schedules. The specific performance during FI and VI sessions was little explored.

Rozin (1965) trained Goldfish (*Caracassius auratus*) to press a lever under an FI 1 min schedule using food as the reinforcer. One cumulative response plot for one fish

was presented and showed a scalloped pattern. The author reported that each of the three fish used in the study presented the scalloped pattern after 30 to 60 sessions of approximately 30 min.

Breuning et al. (1981) examined the FI performance of fish of the species Goldfish (*Caracassius auratus*) under chained and tandem schedules, in which responding in one component results in the next component, with reinforcement occurring at the completion of the last component. In chained schedules the components are correlated with distinctive discriminative stimuli whereas in tandem schedules they are not. The chained and tandem schedules used by Breuning et al. were chained FI 90 s FI 90 s, with two different light intensities as the antecedent stimuli correlated with each component, and tandem FI 90 s FI 90 s, with no differential stimuli correlated with the components. A brief tone was added either to the completion of each component or only to the completion of the first component, in separate conditions. The authors reported that a scalloped pattern was observed in each component of the schedules, although within-session cumulative response plots were not presented. The addition of the brief tone contingent on the completion of both the first and the second component resulted in the highest median response rates in both schedule components for both schedules. The addition of the tone contingent only on the completion of the first component resulted in no change in response rate. The authors concluded that the tone functioned as a conditioned reinforcer when it was paired with food in the completion of the second component. This is relevant to the second question of the present study because, although the tone was not used as a response-feedback stimulus in the sense that it was not contingent on each response, it was used as feedback to the completion of a schedule

requirement when food was not presented and had an effect on responding when it was paired with food.

Talton et al. (1999) investigated the response patterns (pressing a lever) of Goldfish (*Caracassius auratus*) under FI and VI schedules of food reinforcement. The fish were exposed to FI 60 s, FI 240 s, FI 30 s, and VI 60 s. The time of the first 10 responses averaged across all intervals and sessions was presented in a curve for each fish. The curves showed a gradual positive acceleration in the FI 60 s performance, suggesting a scalloped pattern, and no acceleration for the VI 60 s performance, suggesting a constant rate of responding. Despite the evidence that the FI and VI schedules used controlled different response patterns, within-session cumulative response plots were not presented; thus, it is not clear whether typical FI and VI performances were observed within single-sessions.

Higa and Simm (2004) investigated the effects of FI schedules of mirror image (i.e., FI 30 s, 60 s, 120 s, and 240 s) on the response of swimming through a hoop by *Betta splendens*. The authors reported an apparent gradual increase in the rate of responding as the interval approached the end, which, as mentioned above, is the pattern typically found when responding is reinforced under FI schedules in research with pigeons and rats responding on an operandum. However, similar to Talton et al.'s (1999) study, the response curves presented the mean time of a response in an interval based on all intervals and sessions when each FI schedule was in effect. Therefore, it is unclear whether scalloped patterns within a single session for a single fish occurred.

Thus, mixed results have been obtained in studies that used interval schedules. Specifically, Breuning et al. (1981), Talton et al. (1999) and Higa and Simm (2004),

Rozin (1965) reported typical VI and FI response patterns with fish, whereas Gonzales et al. (1962), Eskin and Bitterman (1960), and Wertheim and Singer (1964) did not. Further studies in which subjects are exposed to the schedule for many sessions until reaching a performance stability criteria and in which single-subject response patterns are analyzed in cumulative plots (such as done by Wertheim and Singer, 1964) could possibly help clarify these mixed results.

Ratio schedules. As described above, responding under FR by pigeons and rats is characterized by pauses that occur after reinforcement followed by a high steady rate of responding, called a “break-and-run” pattern. Responding under VR is characterized by a high steady rate of responding with no or little pausing after reinforcement (Ferster & Skinner, 1957). The duration of the pauses after reinforcement observed under FR and VR schedules tends to increase as the ratio requirement increases and is also subject to variations dependent on other variables, such as level of deprivation, the magnitude of the reinforcer, and the range of ratios that comprise the VR schedule (see Schlinger, Derenne, & Baron, 2008, for a review on pausing under ratio schedules). In addition, when the ratio requirement is high in both FR and VR schedules, long pauses occur not only after reinforcement but also after a series of responses have been emitted, even though the response requirement has not been met. This phenomenon has been called ratio strain (Felton & Lyon, 1966; Ferster & Skinner, 1957; Weissman & Crossman, 1966; Wood, Happ, & Adams, 1983).

Eskin and Bitterman (1960) tested the effect of pre-feeding on the FR 20 performance of African mouthbreeders (*Tilapia macrocephala*) striking an aluminum target for food. Pre-feeding resulted in a decrease in the mean responses per minute.

Although the authors reported that pauses after reinforcement occurred, cumulative response plots and single-subject results were not presented. The authors also reported that the decrease in rate of responding could be accounted for both by an increase in pausing after reinforcement and by a decrease in the rate of responding during response-runs. Thus, they suggested that the decrease was not indicative a positive relation between pausing after reinforcement and a decrease in motivation. However, the mean pause after reinforcement at each pre-feeding level was not shown.

Salzinger et al. (1968) studied conditioned reinforcement in Goldfish (*Caracassius auratus*). Three fish were first trained to press a lever under an FR 10 schedule of food reinforcement, which consisted of a worm delivered with water dispensed by an eye-dropper mechanism. Noise produced by a solenoid occurred at the same time that the worm and water were delivered. The fish were then divided into three groups of two and placed on extinction. During extinction, one group received a noise and water from an eye dropper after every tenth response, one group received only the noise after every tenth response, and the remaining group received no feedback at all. It took more sessions for responding to extinguish for the fish receiving both noise and water every tenth response than it did for the two other groups. In addition, the fish that received water emitted more responses in the first extinction session than did the fish that received no feedback. The authors concluded that the noise and water functioned as a conditioned reinforcer for these fish.

Salzinger et al. (1968) presented cumulative response plots of the conditioning phase to compare with the extinction phase. However, they did not comment on whether consistent pauses after reinforcement were observed and the graphs were too small for a

reader to see if pauses occurred. Therefore, although responding was maintained under an FR 10 schedule, it is not clear whether the fish presented a break-and-run response pattern.

Goldstein and Hall (1990), in addition to investigating responding by Archer Fish (*Toxotes jaculator*) examined the spitting response of these fish under VR schedules of food reinforcement (i.e., VR 3, VR 5, VR 8, and VR 10). During the VR schedules for two of the three subjects the spitting response increased as a function of the increase in ratio value, while the number of reinforcements per session remained at the same level, which is expected in low ratio schedules (Hursh, 1980; Powell, 1968). For the other subject, a peak was reached at VR 5 and then the number of responses per session decreased and remained stable despite the further increases in the VR, which caused the number of reinforcements per session to decrease. Cumulative response plots were not presented and it is unknown if a high steady rate of responding with no or little pausing after reinforcement, typically found in VR schedules occurred.

Thompson (1969) reinforced swimming through a channel of *Betta splendens* under FR schedules using mirror image as the reinforcer. Responding was reportedly unstable with FR sizes above 4, except in one case in which responding was maintained on FR 7. In an attempt to improve performance, Thompson introduced a chained FR 1 FR 2 FR 2 FR 2 schedule, where the completion of each response requirement in the chain resulted in change in the colour of a light present during each component (green, yellow, blue, and red respectively). Completing the requirement of the last component resulted in a 2-min mirror presentation.

The rate of responding increased in the chained schedule. The response requirement in each component of the chained schedule was then increased and response rates not only increased again, but a clear break-and-run pattern of responding was observed. The author suggested that the change in the colour of the light present during each component of the chained schedule may have worked as a conditioned reinforcer, thus producing a higher response rate. Although a break-and-run pattern of responding was obtained in this study, it was only when the FR schedule was chained. It is possible that chaining would not be necessary to produce the break-run pattern if a response-feedback stimulus had been used in a simple FR.

Hogan, Kleist, and Hutchings (1970) reinforced the response of swimming through a tunnel on FR 1 to FR 6 for one group of *Betta splendens* with 20 s mirror presentations as the reinforcer. The same was done for another group of fish using food as the reinforcer. For the group that had food as the reinforcer, the mean number of responses in the last two sessions of each schedule increased as a function of the FR requirement, a result similar to Goldstein and Hall (1990)'s study with VR schedules. In addition, the number of reinforcements per session remained relatively constant as the ratio increased. For the group that had mirror as the reinforcer, the mean number of responses in the last two sessions of each schedule remained relatively constant across the different FR requirements and the number of reinforcements per session decreased.

Hogan et al. (1970) suggested that the differences in food and mirror as reinforcers may result from food and mirror depending on different mechanisms for their reinforcing effects. Cumulative response plots were not presented in this study, thus it is

unknown whether any fish presented the break-and-run response pattern typically observed when responding is reinforced according to FR schedules.

Chitty (2002) reinforced the response of *Betta splendens* of contacting a target virtual location in an experimental tank with a 20 s mirror presentation as the reinforcer on FR 1 to FR 6. In contrast to Hogan et al. (1970), the results showed that the rate of responding increased slightly as a function of the increase in the response requirement. Representative cumulative records of single sessions were presented and although they show longer pauses in the higher ratios (FR 6) for all subjects during stability, these pauses did not always occur after reinforcement, so a clear break-and-run pattern of responding was not observed.

The research on ratio schedules suggests that fish's responding can be maintained under ratio schedules and may be sensitive to changes in the ratio value. However, to date, typical ratio response patterns within a session have not been shown. Three studies have presented cumulative response plots with fish responding under FR (i.e., Chitty, 2002; Salzinger et al., 1968; Thompson, 1969) without a clear break-and-run pattern being demonstrated under a simple FR schedule. Cumulative response plots for fish responding under VR schedules have not been shown.

The Absence of Typical Operandums in Research with Fish

In addition to the characteristics of the data analysis in studies with fish, which have included very few examples of single session cumulative response plots, the absence a typical operandum may have contributed to the little evidence of the "typical" response patterns associated with schedules of reinforcement with fish.

The responses reinforced in the experiments thus far reported were swimming through a tunnel, ring, or hoop, swimming into an alley, striking a target, spitting at a target, approaching a target, pressing a lever, and contacting a virtual target. With the exception of Chitty's (2002) study in which the response was contacting a virtual target in the experimental tank, the experiments included a distinctive response-location stimulus. It is not clear whether the studies included an exteroceptive response-feedback stimulus. Given that most operant studies in which a "typical" pattern of responding was obtained under reinforcement schedules with pigeons and rats included an auditory response-feedback stimulus provided by the operandum, it is possible that both a response-location stimulus and a response-feedback stimulus are necessary for the development of patterns of operant responding that are assumed to be "typical".

In studies with fish, there is evidence that feedback contingent on meeting a response requirement may facilitate FR performance in a chained FR schedule (Thompson, 1969) and may delay decrease in responding in a subsequent extinction phase (Salzinger et al., 1968). These results are consistent with results of research on conditioned reinforcement with other species using chained schedules or tests in extinction after intermittent reinforcement (e.g., Hursh, 1977; Kelleher, 1961).

Motivation in *Betta splendens*

One characteristic of the research with *Betta splendens* that may have also contributed to the absence in these fish of the operant response-rate patterns typical of pigeons and rats is the use of an image of a conspecific as the reinforcer. The function of a mirror image (or other types of images of a conspecific) as a reinforcing stimulus presumably derives from its function as an unconditioned elicitor for an aggressive

display. If this is true, variables that affect the effectiveness of mirror image as an unconditioned elicitor could also affect its value as a reinforcer. Two processes that affect the value of a mirror image as an unconditioned elicitor and a potential reinforcer are habituation and prior social history.

The aggressive display of *Betta splendens* tends to wane when the fish are exposed to a mirror repeatedly or continuously. This phenomenon has been described as habituation (Clayton & Hinde, 1958; Peeke & Peeke, 1970; Rhoad, Kalat, & Klopfer, 1975). If habituation occurs, it seems plausible that the value of a mirror image (or image of conspecific) as a reinforcer may decrease, which in part could explain the variability in operant responding in this species when mirror image is used as a reinforcer.

Baenninger (1970) investigated whether prior social history and habituation would change the value of mirror image as a reinforcer for *Betta splendens*. Results obtained suggest that prior history of dominance or submission in pair encounters with conspecifics affects the value of mirror image as a positive or negative reinforcer. Rate of responding reinforced with mirror presentation was higher for the dominant group than for the submissive group. In addition, the fish that had a history of being submissive learned an operant response that removed a mirror when it was continuously present (negative reinforcement).

These results of pair encounters with *Betta splendens* are consistent with a phenomenon that has been observed with several species and has been called the winner/loser effect (see Hsu, Earley, & Wolf, 2006, for a review). Individuals that have won recently tend to be more aggressive and more likely to win again in a next encounter

(winner effect), whereas individuals that have lost recently tend to behave submissively or retreat when challenged and are more likely to lose again (loser effect).

In operant experiments with *Betta splendens* the subjects are typically purchased from local pet stores, and thus there is no control over their previous experimental history. Despite attempts to control motivating operations that may change the value of the image of a conspecific as a reinforcer, such as isolation of the fish in the home tank, the variability in responding observed from session to session of the same subject, when single-subject data are presented, suggests that the control over the variables affecting the value of the mirror image as a reinforcer is not complete at this point.

The use of a mirror and other images of a conspecific as a reinforcer in the experiments described above may, in part, explain the failure in replicating FR break-and-run response patterns with *Betta splendens*. Although Hogan et al. (1970) did not present cumulative response plots of individual fish responding under FR schedules, he indicated that responding was more stable when it was reinforced with food than with mirror image. Therefore, if the generality of the response patterns observed with pigeons and rats is to be tested with *Betta splendens*, it makes sense to start with the use of food as the reinforcer.

Statement of the Problem

Most operant research involves (a) a response-location stimulus, typically in the form of an operandum, and (b) a response-feedback stimulus, typically in the form of an auditory stimulus that occurs when the subject responds on the operandum. It is unknown how or whether the response-location and response-feedback stimuli control operant responding. The present research examines these questions by systematically

manipulating the presence and absence of response-location and response-feedback stimuli in *Betta splendens*. This species of fish provide a simple model for examining these issues. Another question addressed by this research is whether *Betta splendens* show the type of FR responding (i.e., a break-run pattern) that is typical of birds and mammals responding on FR schedules. This is important because data on the responding of fish on various schedules of reinforcement is sparse or nonexistent; thus, it is not known whether fish of any species show the type of schedule behaviour that is typical of birds and mammals.

Method

Subjects

The subjects were four experimentally naïve male *Betta splendens* – F01, F02, F03, and F04 – purchased from a local pet store. The fish were selected on the basis of their: (a) colour; (b) size; (c) fin and gill appearance; and (d) activity level. In regard to their colour, the fish were all dark blue, which allowed detection by the VTS described below (see Apparatus section). In regard to their size, they were the smallest among the other *Betta splendens* available at the pet store, in an attempt to choose young fish that would live for the duration of the experiment. In regard to the appearance of the fins and gills, the fish chosen needed not to have white spots on their gills and their fins had to look intact, in an attempt to buy healthy animals, as white spots could be indicative of a fungal infection and imperfect fins could be indicative of fin rot. Finally, in regard to their activity level, the fish had to be either swimming or staying half way in depth in the bowl where they lived in the pet store, as opposed to staying on the bottom of the bowl or near the top, also in an attempt to select healthy animals.

Each fish was housed individually in a rectangular shaped 3-gallon tank, filled with dechlorinated water and decorated with aquarium gravel and two plastic aquarium plants. The home tank water temperature was maintained at $27 \pm 1^\circ\text{C}$. The fish were visually isolated from each other in order to minimize potential change in behaviour as a result of seeing a conspecific. The home tanks were located in a room with a 12 h light/dark cycle.

The fish were acclimated to the home tank for 10 to 20 days before the beginning of the experiment, until their eating was stable (i.e., no consistent increasing or decreasing trend for five consecutive days). In addition to acclimatizing the fish to the new home environment, this period served to determine the daily food intake of each fish before the start of the experiment.

*Betta Buffet Pellets*TM manufactured by Omega Sea Ltd. were provided once daily on days without a session at approximately the same time when the session was scheduled to occur. Pellets were given one at a time for 3 minutes. Any pellets that remained in the tank as a result of the fish either not ingesting it, or regurgitating it, were removed from the tank. The fish usually stopped eating the pellets after 2 min.

After FR sessions in which the number of reinforcers obtained was less than the minimum number of reinforcers obtained per session during the CRF Phase, the fish was given the number of pellets needed to complete the minimum number of reinforcers per session obtained during the CRF Phase. For example, if the minimum number of reinforcers per session obtained during the CRF Phase was 6 and the fish received 4 reinforcers during an FR session, 2 pellets were given after the session. Tests conducted prior to the study indicated that, on average, the amount of food received for each

reinforcer was approximately equal to that of one pellet. The pellets were given about 5 min after the session to avoid contiguity between the end of the session and receiving food, with the goal of preventing potential reinforcement of a poor performance during the session.

Aside from the interval between sessions or between feeding and the next session (approximately 24 h), deprivation was not used. Ethical approval for the research was obtained from the appropriate Animal Care Committee of the University of Manitoba (approved protocol number F08-014).

Apparatus

Figure 1 shows a diagram of the tank illustrating the location of the virtual target response (T1), the other virtual cylinders (T2, T3, and T4), the feedback light (all described below) and the region where the food typically fell. Since the feeder was mounted approximately at 122 cm above the water level, the food fell in a somewhat dispersed region when the feeder operated.

Experimental tank. Sessions were conducted in a 20 cm high x 40 cm long x 40 cm wide experimental tank filled with dechlorinated water to a depth of 10 cm. The water was increased to $27\pm 1^{\circ}\text{C}$ (same as in the home tank) by adding water heated using an electric kettle. Since the same experimental tank was used for all fish, the water was changed and the tank was completely dried before each session with the purpose of removing traces from other fish.

Response-location stimulus. The response location was a virtual cylinder extending vertically from the centre of the floor of the experimental tank to above the water line. In the sessions in which a response-location stimulus was present, a Canadian

bimetallic \$2 coin (14 mm radius) was placed in the center of the tank, exactly covering the bottom of the target response location (Figure 1). This stimulus was chosen because of its standard physical characteristics, which facilitates replication, and the fact that it was not detected by the VTS (described below) and thus did not interfere with the data recorded from the fish.

Response-feedback stimulus. In the sessions in which a response-feedback stimulus was presented, a desk lamp containing a 120V 50W red light bulb was placed on one side of the tank, equidistant from the two adjacent corners, and 10 cm away from the tank wall. The bulb was directed toward the centre of the tank (Figure 1). Each operation of the light lasted 1 s.

Feeder. A modified electric pepper mill was used as the feeder. The feeder was mounted on a wooden beam above the experimental tank. The pepper mill was filled with the same type of food used outside of sessions. The feeder ground the food for 1 s when it operated. This resulted in the delivery of a small amount of food, which fell between the limit of the response-location area and one of the walls (Figure 1). Tests conducted prior to the beginning of the experiment indicated that, on average, the amount of food in each 1-s operation of the feeder was approximately equal to one pellet of *Betta Buffet Pellets*TM. In addition, a small LED near the opening of the feeder turned on for 1 s when the feeder operated. The feeder LED in this study was analogous to the feeder lights and feeder sounds in studies with pigeons and rats. The purpose of the feeder LED was to signal the availability of food. It should be noted that, since the LED operated only when the feeder operated and not every time a response was emitted, it does not constitute a response-feedback stimulus as defined in the present study.

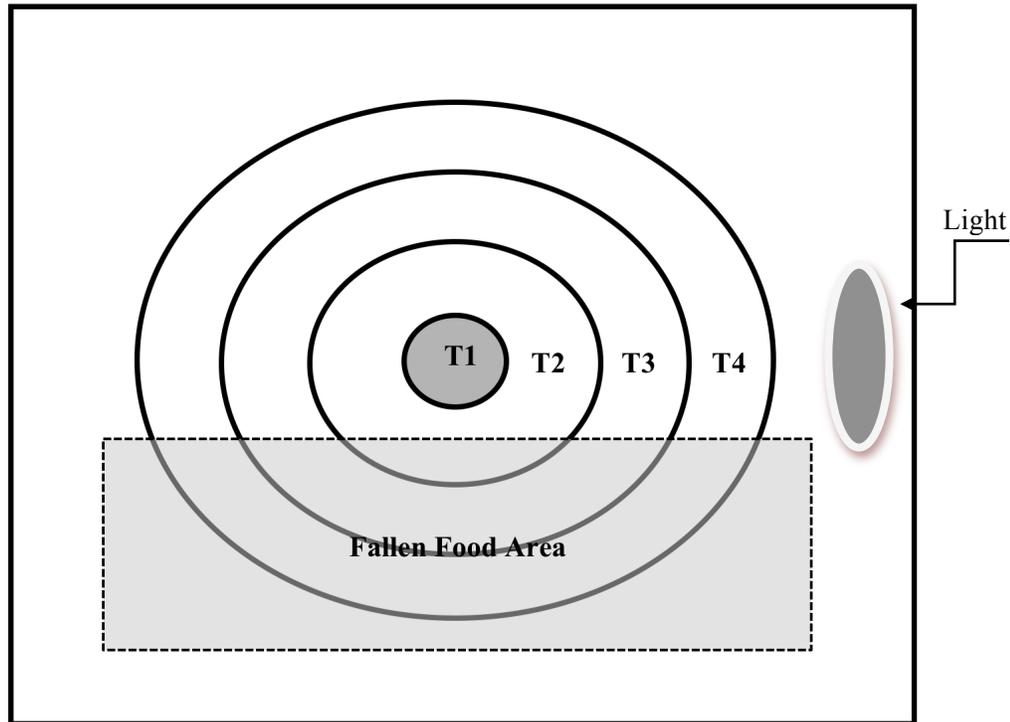


Figure 1. Schematic overhead view of the experimental tank showing the four concentric virtual cylinders. The feedback stimulus (light) was located on the right side of the tank, where the front of the tank (shown at the bottom of the figure) was the side closest to the door to the experimental room. The food fell in the area between the response location and the front wall of the tank.

Video tracking system (VTS). A custom-built VTS, similar to the one used by Pear and Legris (1987), recorded the three dimensional position of the fish 10 times per second during sessions. The VTS consisted of two video cameras, a VTS circuit board connected to an IBM XT computer, a television monitor, and a Windows 2000 computer, containing three pieces of software for collecting and analyzing the data that was received by the IBM XT computer from the VTS. The three pieces of software used to analyze the data were: VirtualDub, V2001, and New Operant Behavior Laboratory (NOBL).

VirtualDub is a free software licensed under the GNU General Public License (GPL) and

the V2001 (programmed by Joseph A. Legris) and NOBL (programmed by Wayne Chan) were custom-made programs.

The video cameras were mounted on the same wooden beam that the feeder was mounted on. They were 31 cm apart and angled toward each other at a combined angle of 14° and were connected to the television monitor and to the VTS circuit board. The two computers and the television monitor were located in a room adjacent to the room containing the experimental tank. The television monitor allowed alternation between the view of the two cameras and its main purpose was to ensure that the cameras were capturing the image of the tank.

The software VirtualDub recorded a video from an overhead view of the experimental tank. It also provided a real-time video view that allowed for the observation of responding while the session was ongoing and allowed checking of whether the apparatus was working properly during the session (e.g., if the response was being recorded when the fish contacted the target location, and if the feedback light was working properly).

The software V2001 combined the input from the two cameras by tracking the location of the first dark region wider than 3 pixels that it detected when analyzing the images from left to right and back (the side farthest from the door of the experimental room) to front (the side closest to the door of the experimental room), and then presenting the centre of this location in three coordinates (three dimensions). This process was repeated 10 times per second, which has been demonstrated in previous studies to be a robust measure of the location of the fish (e.g., Chitty, 2002).

The software NOBL controlled the delivery of reinforcers according to the programmed response requirement and recorded: (a) the occurrence of contacts with four computer computer-defined spatial locations with the shape of four concentric vertical cylinders (i.e., the virtual target location cylinder and the other three virtual concentric cylinders used during shaping); (b) the occurrence of reinforcers; (c) the occurrence of tracking errors (i.e., tracking of more than one object or tracking of no objects – i.e., loss of tracking – were recorded as system errors); and (d) the coordinates of the location of the tracked object 10 times per second. The NOBL software also created a data text file with the preceding information.

The centring of the target-response location (T1) was based on the observation that, during operant level assessment (prior to conditioning), the fish tended to spend most of the time swimming along the walls of the tank and rarely swam into the centre.

T1 was 14 mm in radius (same radius, as already mentioned, of a Canadian bimetallic \$2 coin). The three virtual concentric cylinders (T2, T3, T4) used during shaping were also centred in the tank (same coordinates) and their radiuses were 44 mm, 74 mm, and 104 mm, respectively; that is, each virtual cylinder (T[n]) occupied a larger circular area than the virtual cylinder with the next lower number (T[n-1]) (Figure 1). The difference between each adjacent virtual cylinder was of 30 mm in the radius, which is approximately the length of a fish. This distance was chosen in order to minimize the potential for the fish to be detected entering more than one virtual cylinder at a time.

In order for a hit or contact with a virtual cylinder (response) to be recorded, the fish had to enter that virtual cylinder. In order for a second hit to be recorded, the fish had to leave and then re-enter that cylinder.

Prior to each session, the coordinates of the centre of the tank were re-calibrated to prevent any drift in the target location as measured by the VTS. Tests were also conducted to ensure that the apparatus (i.e., cameras, software, computers, feeder, and light) was working properly. Tests indicated that the coordinates varied slightly (± 2 mm) from day to day, possibly due to variations in humidity, etc., which could affect slightly the angle of the cameras by causing the wooden beam to expand or contract slightly.

Procedure

Measures. Throughout the study, the VTS recorded: (a) the number of times the fish contacted each virtual cylinder (T1, T2, T3, T4); (b) the time of each contact with each of the virtual cylinders; (c) the number of reinforcers delivered in a session; (d) the time of each reinforcer delivery; (e) the centre location of the centre pixel of a dark region wider than 3 pixels (i.e., the approximate position of the fish because everything else in the tank was white or reflective of light) that it detected, which were plotted in two-dimensional swimming trajectories for analyzing the distribution of swimming within a session; and (f) the times of losses of tracking (i.e., tracking errors).

In order to determine the effect that each condition had on responding, the main measures used were the total number of responses and reinforcements per session. Additional effects were analyzed by looking at the two-dimensional swimming trajectories within a session (XY plots; i.e., length \times width collapsed across height). The operant response patterns produced by the FR schedule of reinforcement in each condition were analyzed by viewing cumulative response plots for single sessions.

Sessions schedule and duration. Sessions for each fish occurred 7 days a week, at approximately the same time, and lasted 15 min.

Initial training. During the initial training, the coin and the lamp were present for F02 and F04 and the coin and lamp were not present for F01 and F03. The initial training was composed by four Phases: Operant Level Assessment, Shaping, CRF, and FR increase. Each of these Phases is described below.

Operant level assessment. The fish were placed in the experimental tank. Responses (contacts with each virtual cylinder) were recorded but no programmed consequences occurred (i.e., feeder and lamp were inoperative). Five sessions of operant level assessment were conducted for each fish.

Shaping. Shaping was conducted in three to five stages depending on the performance of the fish during the operant level assessment. In each stage, contacts with a successively closer location to T1 were reinforced, with Stage 1 being the farthest approximation to T1 and Stage 5 being contacts with T1. The lamp operated at the same time of the automatic reinforcer deliveries. Each stage was in effect for one or two sessions. The stages are described below.

Stage 1: shaping to T4. Contacts with T4 were shaped using a manual switch to operate the feeder. Successive approximations to T4 were reinforced until the fish first contacted T4. At this point, the feeder operated automatically after each contact with T4 for the remainder of the session. Fish F02 and F03 started shaping at this stage because they made no hits to T4 on the last session of the operant level assessment.

Stage 2: reinforcement of T4 contacts. Contacts with T4 operated the feeder. Fish F01 started shaping at this stage because during the last session of operant level assessment it made 6 contacts with T4 and no contacts with T3.

Stage 3: reinforcement of T3 contacts. Contacts with T3 operated the feeder. Fish F04 started shaping at this stage because during the last session of the operant level assessment it made 11 contacts with T3, but it made only 5 contacts with T2, being that contacts with T2 were even lower in the previous operant level session (i.e., only 3 contacts).

Stage 4. Reinforcement of T2 contacts. Contacts with T2 operated the feeder.

Stage 5. Reinforcement of T1 contacts. Contacts with T1 operated the feeder.

CRF. Each contact with T1 (hereafter simply called a “response”) was followed by food delivery until responding reached the stability criteria described below.

FR. Over sessions the reinforcement schedule was gradually increased to FR 6, which was the maximum FR value used by Chitty (2002) and Hogan et al. (1970). During the FR sessions, F02 and F04 received the response-feedback stimulus after each response and also received food after each n^{th} response, with n being the number of responses required for reinforcement. F01 and F03 received food after every n^{th} response and did not receive the response-feedback stimulus. The criterion to increase the FR was 2 or 3 consecutive sessions in which responding either maintained within the range observed during the CRF sessions, or was higher than during the CRF sessions. Fish F01 had the reinforcement schedule increased to FR 6 in a total of 12 sessions and the other fish had the schedule increased to FR 6 in a total of 9 sessions each.

Design. Responding was analyzed in each of four conditions:

- Condition CL (coin and light). Both the response-location stimulus and the response-feedback stimulus were in effect (i.e., the coin was at the bottom of the T1 location and the feedback light was operative).

- Condition NN (no-coin, no-light). Neither the response-location stimulus nor the response-feedback stimulus was in effect.
- Condition C (coin only). Only the response-location stimulus was in effect.
- Condition L (light only). Only the response-feedback stimulus in effect.

Table 1 presents a summary of these experimental conditions.

Table 1

Experimental Conditions

	Feedback Light	No Feedback Light
Coin	CL	C
No Coin	L	NN

The experimental conditions were tested in the following order. First, an analysis was conducted, in which the effects of the two extreme conditions, CL and NN, were determined in an ABAB design. In order to control for potential sequence effects the CL condition was tested first for F02 and F04, whereas the NN condition was tested first for F01 and F03.

After the above analysis was conducted, a component analysis was carried out. Either condition C or L was tested first, followed by a return to the last condition experienced in the comparison of CL vs NN and then followed by the other condition. In order to control for sequence effects, the order of the conditions was such that in the

component analysis F01 and F02 experienced condition C first and F03 and F04 experienced condition L first.

For fish F04, the component analysis was extended because the coin did not seem to have the same effect as for the other fish. It was hypothesised that the lack of effect of the coin was due to a breaking of the contingency between the response and the reinforcer, as a result of many sessions with very low number of responses and reinforcements. Therefore, first the CL condition was reinstated for this fish to try to recover responding. Then, because responding did not recover, re-training was conducted with the coin and feedback light. During this retraining, F04 was placed on CRF and, over sessions, the FR was gradually increased, as during the initial training. Once F04's responding recovered, another CL condition on FR 6 was conducted for this fish followed by a C condition.

For both F03 and F04, the effects of the feedback light were also tested in extinction. First, extinction was conducted with only the coin present. When the number of responses had decreased to 10 or less per session for three sessions, the feedback light was introduced while the coin was still present. The purpose of this test was to assess whether the feedback light had acquired a conditioned reinforcing effect.

Table 2 shows the sequence of experimental conditions for each fish. The numbers next to the conditions in the table indicate the repetition of that condition. For example, NN1 was the first time that fish experienced the condition NN, whereas NN2 was the second time. The conditions that were experienced only once were not numbered.

Table 2

Sequence of Experimental Conditions for each Subject

Subject	CL vs. NN (ABAB design)	Component Analysis (CBD design)	Additional Analyses
F01	NN1-CL1-NN2-CL2	C-CL3-L	
F02	CL1-NN1-CL2-NN2	C-NN3-L	
F03	NN1-CL1-NN2-CL2	L-CL3-C	Ext ^b C-ExtCL
F04	CL1-NN1-CL2-NN2	L-NN3-C1- CL3- RT ^a -CL4-C2	ExtC-ExtCL

^a RT stands for re-training ^b Ext stands for extinction

Stability criteria. The criterion for changing experimental conditions was met if one of the following occurred:

- Five sessions in which the total number of responses in each of the five most recent sessions was not greater than or less than the average of the total number of responses in the same sessions and there was no discernible upward or downward trend in these sessions.
- Fifteen sessions in which there was no discernible upward or downward trend (as defined above) in the last five sessions.

A discernible trend was defined as three consecutive sessions in which the number of responses increased or decreased consistently. Therefore, a minimum of four sessions was required to determine a trend.

Results

The results will be reported in two subsections. In the first subsection, the main effects of the conditions on the number of responses and reinforcements over sessions and on the two dimensional swimming plots (XY plots) will be analyzed. In the second subsection, the response patterns within sessions in each condition will be analyzed through cumulative response plots. Summarized results of the Shaping and CRF Phases can be found in Appendixes A and B, respectively.

Main Effects of the Conditions

Table 3 shows the mean number of responses of each fish in the last five sessions each time a given condition (described below) was in effect, with the range of the number of responses per session in parenthesis below the mean. The first four columns show the results of the CL vs. NN comparison. The first two columns show the mean number of responses in the last five sessions of the CL1 and CL2 conditions. The next two columns show the mean number of responses in the last five sessions of the NN1 and NN2 conditions. (See Appendix C for a figure presenting a graphical summary of the data in Table 3.) It can be seen from the table that the CL condition controlled a greater number of responses on average than did the NN condition for each fish. As seen in Table 3, this result was replicated the second time the CL and NN conditions were in effect (CL2 and NN2). Note that, in this analysis, order was controlled for in that the conditions were presented in an ABAB design, with two fish starting with the NN condition (F01 and F03) and two fish starting with the CL condition (F02 and F04).

Table 3

Mean Number of Responses in the Last Five Sessions of Each Condition (CL = Coin and Light; NN = No Coin, No Light; C = Coin Only; L = Light Only), with the Range of Responses per Session in Parenthesis Below the Means

	CL vs. NN				Component analysis		
	CL1	CL2	NN1	NN2	C1	C2	L
F01	75.8 (74-81)	68.6 (53-84)	22.4 (13-30)	28.8 (23-33)	56.6 (36-75)	-	35.2 (20-54)
F02	30.8 (23-43)	44.0 (26-66)	5.4 (3-9)	9.0 (2-16)	23.0 (11-46)	-	7.8 (6-9)
F03	38.0 (35-45)	38.2 (35-41)	15.4 (5-24)	14.4 (10-19)	38.4 (31-48)	-	6.0 (4-11)
F04	46.2 (40-60)	46.2 (42-51)	9.2 (6-11)	15.6 (10-21)	10.2 (6-12)	32.2 (30-35)	8.2 (7-14)

The last three columns in Table 3 show the mean number of responses for the last five sessions of the C condition and the L condition in the component analysis. The C condition (C1 in the table) controlled a greater number of responses than did the L condition for all fish, regardless of the order in which the conditions were experienced.

F04 was somewhat of an exception to this statement, in that this fish emitted a relatively low number of responses (i.e., 10.2 is not much different from 8.2, which was the mean number of responses in the last 5 sessions of the L condition) the first time the C condition was in effect. F04 was exposed to the C condition a second time (C2) and, this time, the mean number of responses in the last five sessions was roughly 3 times higher than that in the L condition, thus clearly replicating the results found with the other three fish.

Comparing responding in the CL condition to responding in the C condition in Table 3, for three fish (F01, F02, and F04), the mean number of responses in the last five sessions of the CL condition was higher than the mean number of responses in the last five sessions of the C condition. The exception was F03, whose mean number of responses in the CL condition and the C condition were approximately equal.

Comparing responding in the NN condition and in the L condition in Table 3, the mean number of responses in the last five sessions in the NN condition was greater than in the L condition for two fish (F03 and F04), lower than in the L condition for one fish (F01), and similar to the L condition for one fish (F02), if the performance in the two NN conditions is averaged (see Appendix C). It is interesting that although the L condition produced lower or similar responding to the NN condition for all but one fish (F01), the CL condition produced higher responding than the C condition for all but one fish (F03). This suggests that the light by itself had little effect on responding but did have a stronger effect when it was combined with the coin.

Figures 2, 3, 4, and 5 show the total number of responses and reinforcements over sessions during the CL vs. NN comparison and the component analyses (i.e., the comparisons between the L and C conditions). Figure 2 shows the total number of responses and reinforcements over sessions during the main experimental conditions for F01. The CL vs. NN comparison followed the sequence NN-CL-NN-CL. As was seen in Table 3, the number of responses per session in the NN condition was lower than in the CL condition. A few overlapping data points can be observed the first time the NN and CL conditions were in effect, with the increase in the number of responses from the NN to the CL condition being gradual. The second time the conditions were in effect, the

change in the number of responses per session was abrupt, suggesting better discrimination between the conditions.

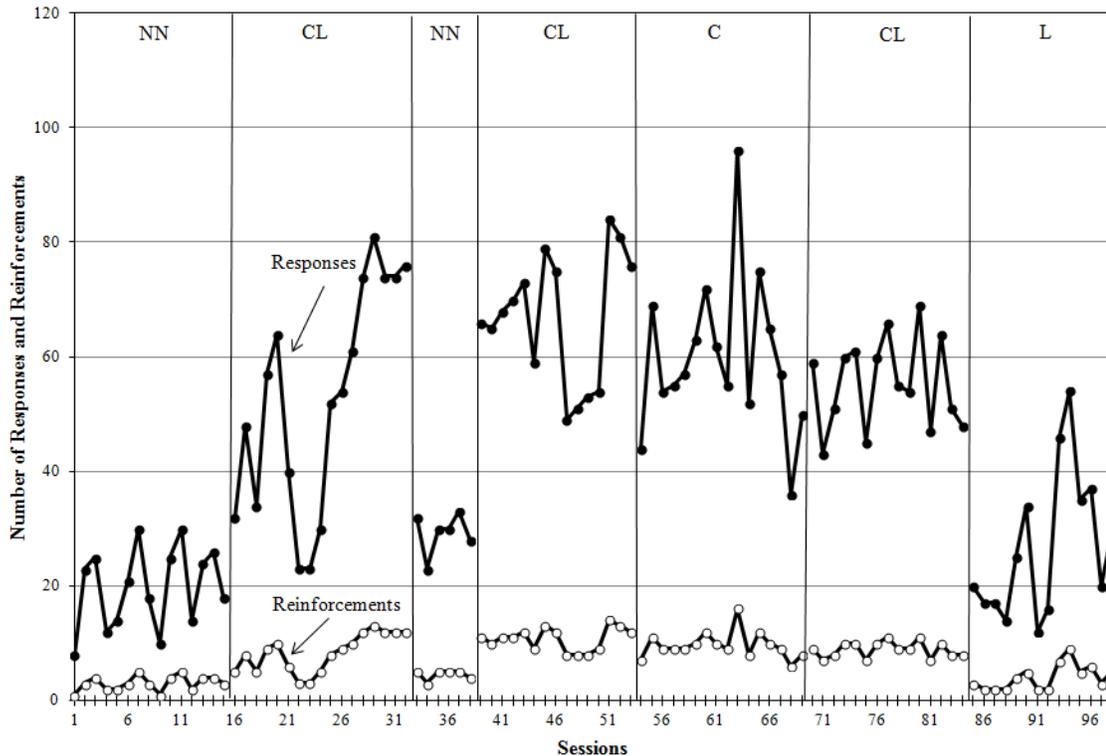


Figure 2. Total number of responses (dark circles) and reinforcements (white circles) over sessions for subject F01 in each experimental condition (CL = coin and light; NN = no coin, no light; C = coin only; L = light only).

Figure 2 also shows the component analysis for F01, which followed the sequence C-CL-L. It can be observed that responding remained at about the same level in the C and CL conditions, dropping abruptly when condition L came into effect. The number of responses per session increased over a few sessions during the L condition, with two data points overlapping with the level of responding observed in the CL condition that was in effect immediately prior to the L condition. However, the number of responses per session reached the stability criteria at a lower level than in the CL and C conditions.

Figure 3 shows the total number of responses and reinforcements over sessions in the CL vs. NN comparison for F02. The CL vs. NN comparison followed the sequence CL-NN-CL-NN and responding was also higher in the CL condition than in the NN condition during the last five sessions in each condition, when responding was considered stable, as seen in Table 3. However, for F02, the change in responding when conditions were changed seemed to happen more gradually than for F01.

In the component analysis for F02, also shown in Figure 3, responding gradually increased in the C condition after the last NN condition of the CL vs. NN comparison and gradually dropped again when the NN condition was reinstated. When the L condition came into effect, the number of responses was initially maintained at the same level as the number of responses observed in the NN condition that was previously in effect. Then, the number of responses per session gradually increased in the L condition suggesting that the light was gradually acquiring control over responding. Because there seemed to be a gradual increase in responding, though not a trend as defined in the Method section, a decision was made to extend the condition for longer than 15 sessions. Interestingly, after this gradual increase, responding dropped, increased again, and then reached the stability criteria of 5 sessions without a trend at a level of responding similar to the one observed in the NN condition.

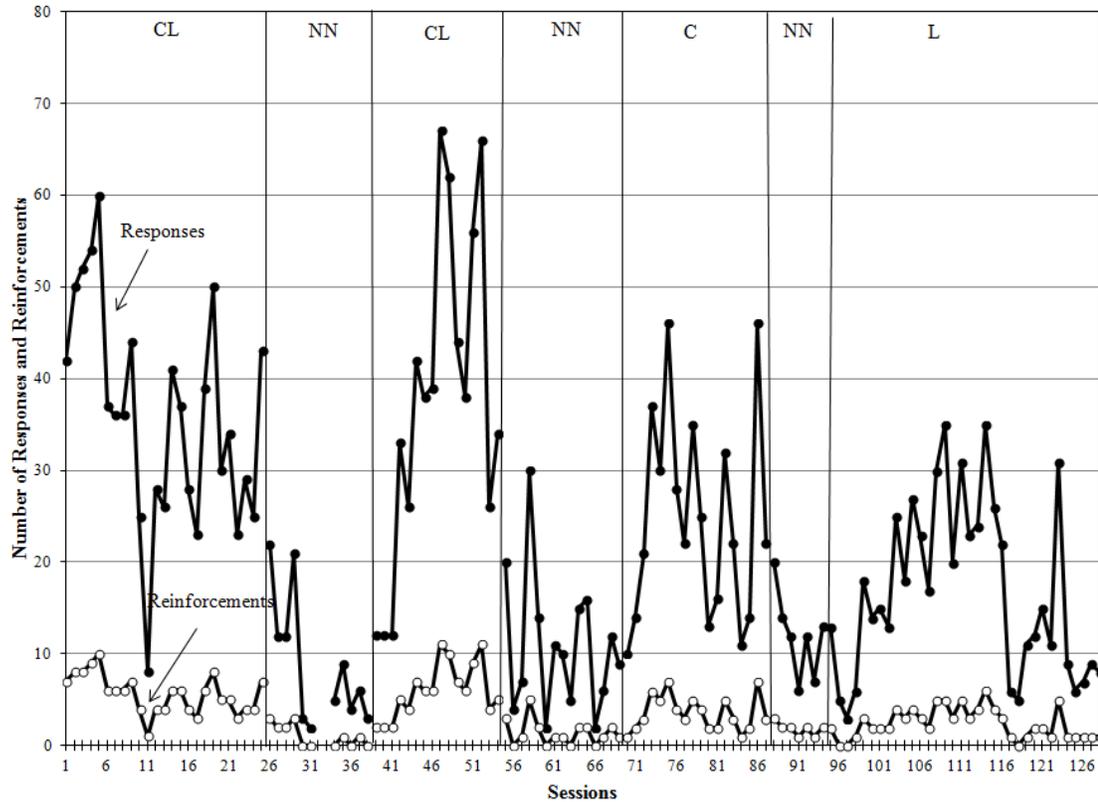


Figure 3. Total number of responses (dark circles) and reinforcements (white circles) over sessions for subject F02 in each experimental condition (CL = coin and light; NN = no coin, no light; C = coin only; L = light only).

Figure 4 shows the total number of responses and reinforcements over sessions in the CL vs. NN comparison, in the component analysis, and in the additional analysis for F03. The CL vs. NN comparison followed the sequence NN-CL-NN-CL. As seen in Table 3, responding at stability for this fish as for the other 3 fish was higher in the CL condition than in the NN condition. It should be noted that the number of responses per session initially dropped for F03 when the condition was first changed from NN to CL. Observing the video of the session, it seemed that the fish engaged in an approach/avoidance pattern towards the coin in that session (see Appendix C for the XY plot of that session). In order to avoid the total loss of the behaviour, a decision was made

to conduct two sessions of CRF with the coin present to expose the fish to the coin and pair the coin with reinforcement. After these two sessions, the number of responses per session under the CL condition, with FR 6, increased gradually. In the second change between conditions – the change from CL to NN under FR 6 – there was an abrupt decrease in the number of responses.

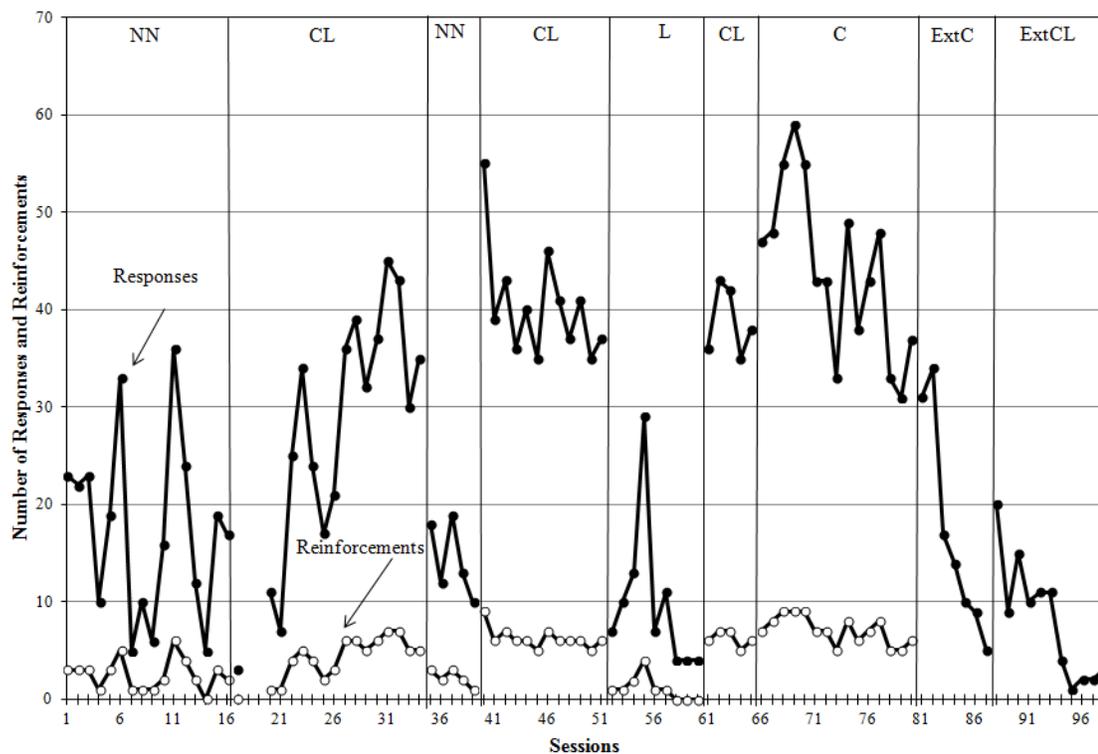


Figure 4. Total number of responses (dark circles) and reinforcements (white circles) over sessions for subject F03 in each experimental condition (CL = coin and light; NN = no coin, no light; C = coin only; L = light only).

The component analysis for F03 is also shown in Figure 4. The number of responses immediately dropped for this fish when the condition was changed from CL to L. Responding gradually increased in the L condition after that, but then dropped again reaching the stability criteria at such a low level that no reinforcers were delivered in the

last three sessions. When the CL condition was reinstated, the number of responses per session immediately increased. The C condition followed and was accompanied by an immediate increase in the number of responses, to a higher level than the CL condition. The number of responses in the C condition then gradually decreased and stabilized at a level similar to the CL condition immediately prior to it.

The additional analysis of extinction conducted with F03 is also shown in Figure 4. During the extinction with the coin present (ExtC), the number of responses per session dropped gradually. When the light was introduced (ExtCL), the number of responses immediately increased in the first session, then decreased again in the following sessions. This suggested that the light had become a conditioned reinforcer.

Figure 5 shows the total number of responses and reinforcements over sessions in the CL vs. NN comparison, in the component analysis, and in the additional analysis for F04. The CL vs. NN comparison followed the sequence CL-NN-CL-NN. The number of responses per session was higher in the CL condition than in the NN condition, as with the other fish, with changes in responding occurring abruptly when conditions were changed.

In the component analysis for F04, which followed the sequence L-NN-C, the number of responses per session remained low throughout, with a slight increase in the first three sessions of the C condition. After re-training F04 and reinstating responding under the CL condition, a new C condition was conducted. Responding in the C condition this time was higher than in the L condition, similarly to what had been observed with the other three fish.

The results of the additional test in extinction conducted with F04 are also shown in Figure 5. First, extinction with the coin present was carried out and responding decreased. When the light was added to the extinction, an increase in responding did not occur, unlike the case with F03.

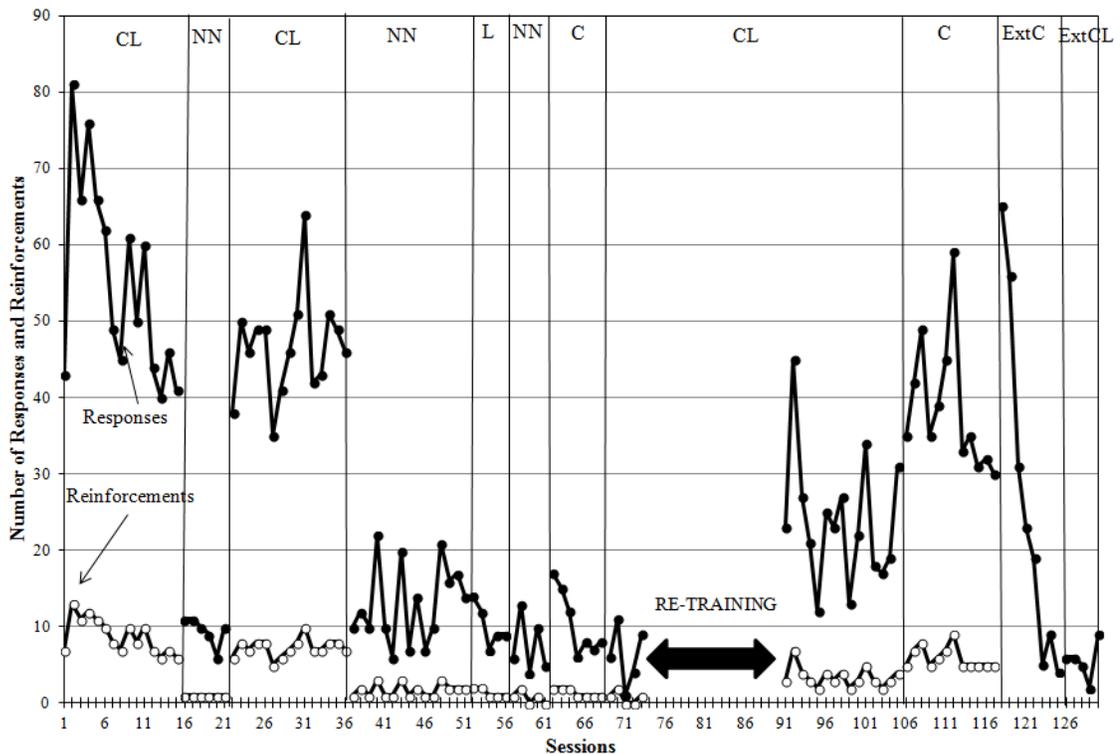


Figure 5. Total number of responses (dark circles) and reinforcements (white circles) over sessions for subject F04 in each experimental condition (CL = coin and light; NN = no coin, no light; C = coin only; L = light only).

Figure 6 shows the XY swimming plots of each fish on the last session that the conditions CL and NN were in effect for the first time, with the CL condition displayed on the top and the NN condition on the bottom. Overall, a cluster of data points can be seen in and around the target response area in each plot. However, swimming remained more concentrated in this area during the CL condition than during the NN condition.

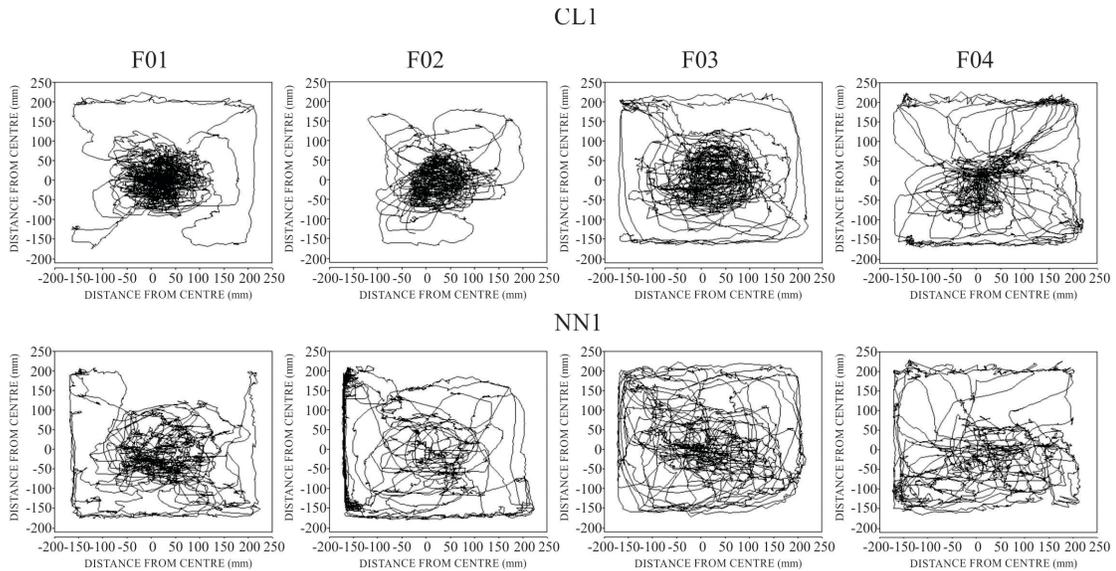


Figure 6. XY plots of the last session of the first time the CL (coin and light) and NN (no coin, no light) conditions were in effect for each fish, with the CL plots on the top and the NN plots on the bottom.

Figure 7 shows the XY plots of the last session of the CL and the NN condition the second time each of these conditions was in effect for each fish. Similarly to the first time these conditions were in effect, a cluster of data points can be seen in and around the target response location, with the cluster of points being more concentrated in the CL condition than in the NN condition.

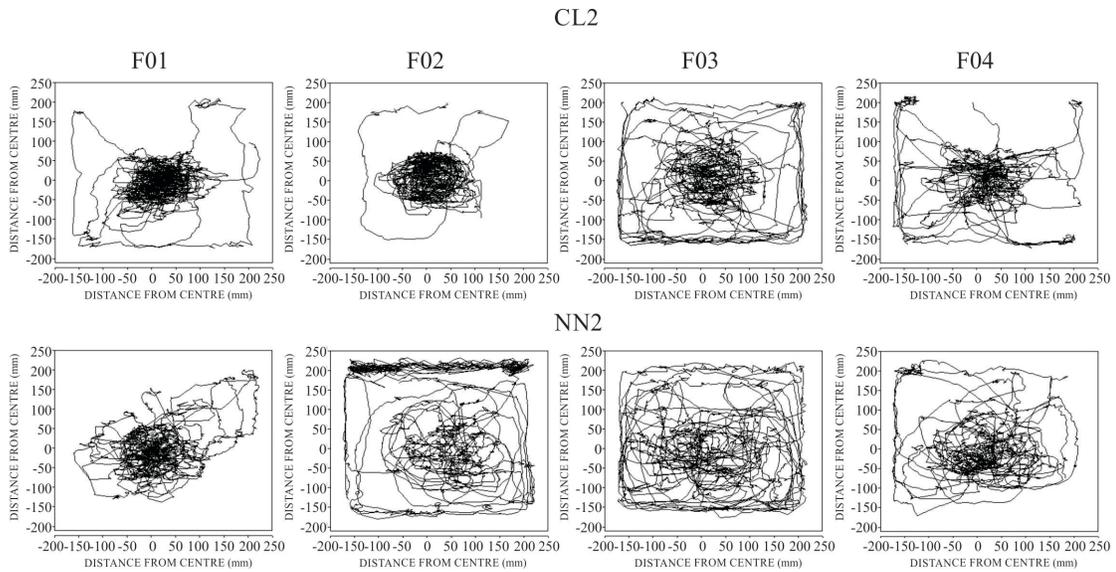


Figure 7. XY plots of the last session of the second time the CL (coin and light) and NN (no coin, no light) conditions were in effect for each fish, with the CL plots on the top and the NN plots on the bottom.

Figure 8 shows the XY plots of the last session of the C and L conditions for each fish. For F04, the last session of the C condition after re-training was plotted. Although a cluster of data points can be observed in and around the response location during the L condition (bottom graphs) for F01, F02, and F04, this cluster is more concentrated during the C condition (top graphs) for all four fish. In the plot of the last session of the L condition for F03 (third graph on the bottom), a cluster of data points near the centre of the tank can barely be seen.

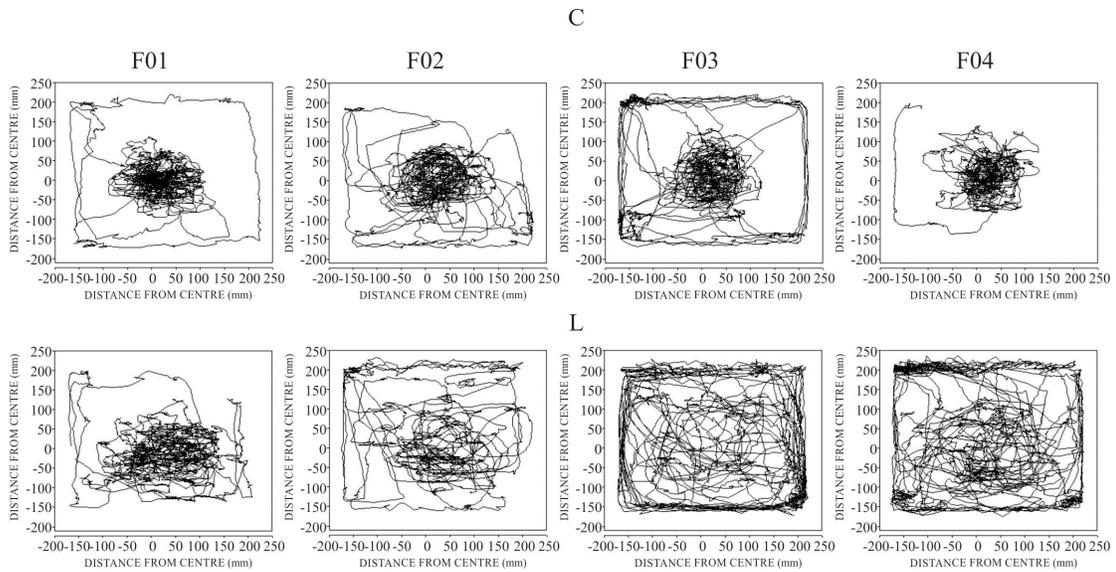


Figure 8. XY plots of the last session in which the C (coin only) and L (light only) conditions were in effect in the component analysis for each fish, with the C plots on the top and the L plots on the bottom. For F04 the second C condition was plotted.

Figure 9 shows the XY plots of F04's swimming from the last session of the NN condition to the first session of the C condition, prior to re-training. Swimming in and around the target location deteriorated gradually during the L condition and the subsequent NN condition, going from being concentrated in and around the target response location to being more spread out throughout the tank. When the C condition came into effect (last graph on the bottom right), a small cluster of data points occurred in and around the target location, but nothing as concentrated as observed the other times when the coin was present.

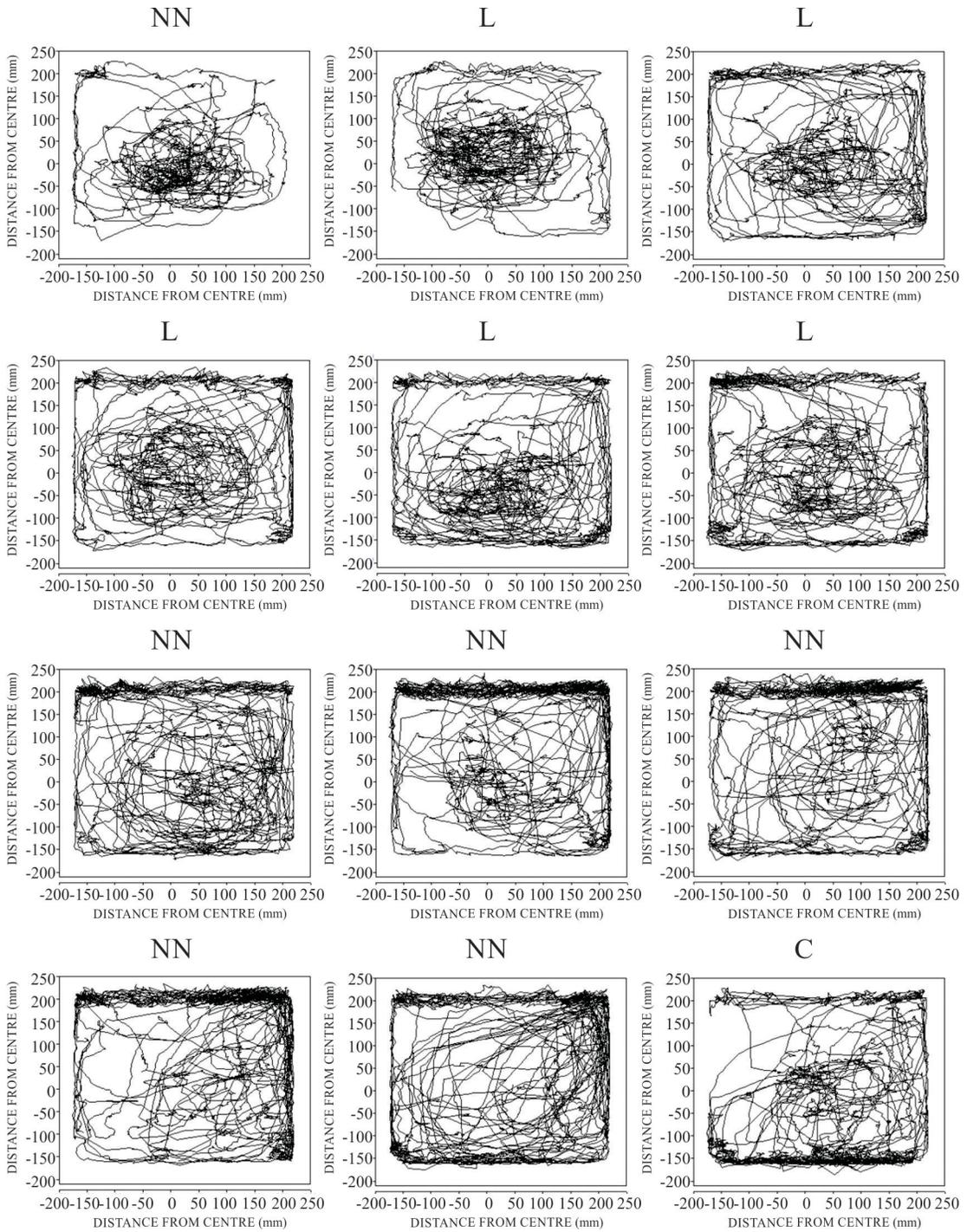


Figure 9. XY plots of the deterioration of F04's responding from the last session in the NN2 condition (CL vs. NN) to the first session in the first C condition (component analysis), before re-training, following the sequence NN-L-NN-C.

Figure 10 shows the XY plots during the first session of extinction with the coin present (first graphs), the last session of extinction with the coin present (second graph), and the first session of extinction with both the coin present and the light operative (third graph) for F03 and F04 (top and bottom graphs, respectively). Looking at the first and second graph for each fish, it can be seen that the cluster of data points observed in and around the response location in the first session of extinction with the coin present was mostly dissipated by the last session of extinction with the coin present. Looking at the third graph for each fish, when the response-feedback stimulus was reintroduced, a small cluster in and around the response location can be seen for F03 but not for F04.

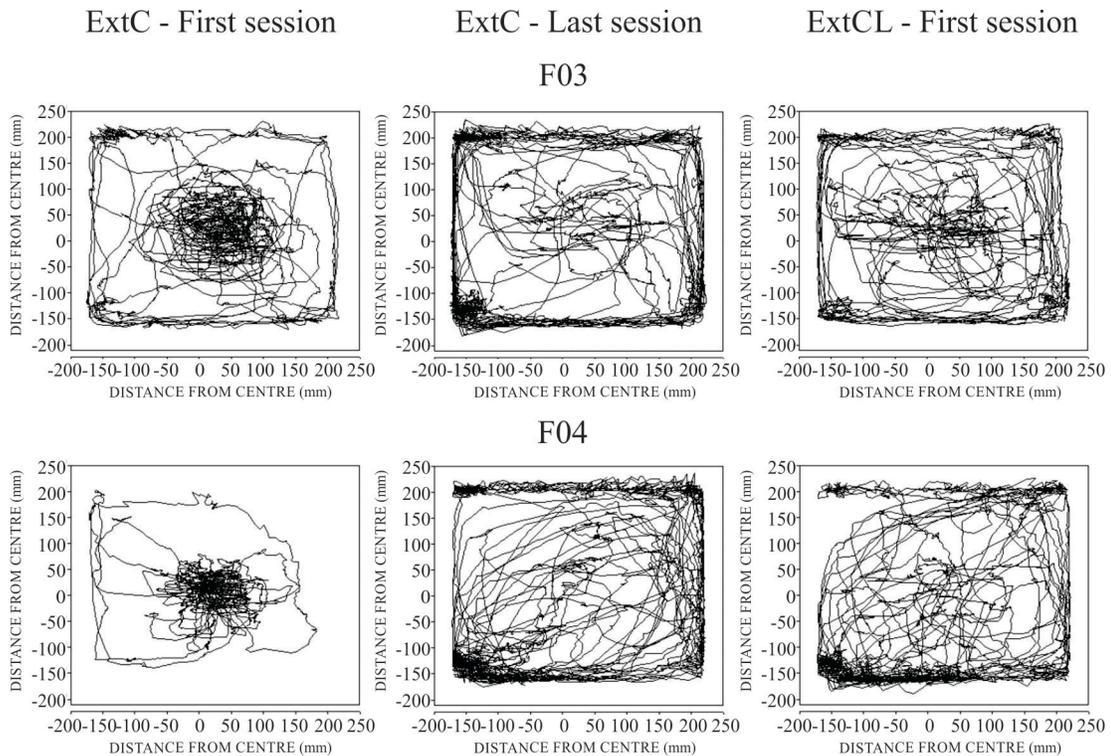


Figure 10. First and last sessions of the ExtC (extinction with coin only) and first session of ExtCL (extinction with coin and light) for F03 and F04.

Overall, all four fish emitted more responses and their swimming was more concentrated in and around the target location in the CL condition than in the NN condition. The results of the component analysis suggest that the response-location stimulus (coin) played an important role in producing the effect of a high number of responses per session and overall greater concentration of swimming in and around the response location.

The effects of the light as a response-feedback stimulus were less clear. The results suggest that the light by itself had little effect on responding. However, for three of the four fish, responding during stability was higher in the CL condition than in the C condition, suggesting that the response-feedback stimulus may have played a role in increasing the number of responses when combined with the response-location stimulus. In addition, the results of the extinction test suggest that for one fish, the response-feedback stimulus may have become a conditioned reinforcer.

Cumulative Records Analysis

Figures 11, 12, 13, and 14 show the cumulative plots of the last session of the second exposure to the CL and the NN conditions and the only or second exposure to the C and L conditions for F01, F02, F03, and F04, respectively.

Figure 11 shows that F01's response rates were lower in the NN and L conditions than in the CL and C conditions. Response rate was highest in the CL condition, followed by the C condition, NN condition, and finally the L condition.

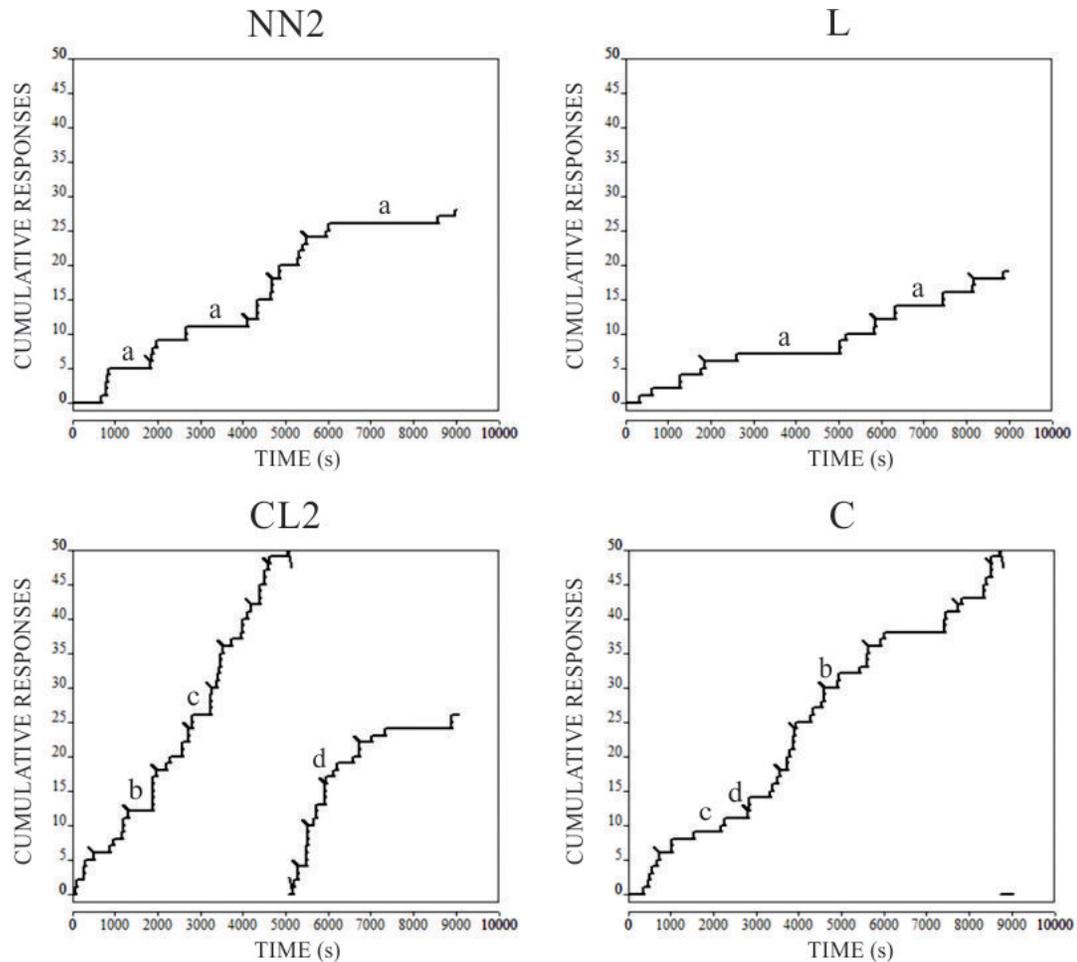


Figure 11. Cumulative responses of F01 in the last session of the NN2 (no coin, no light second exposure), L (light only), CL2 (coin and light second exposure), and C (coin only) conditions, with the NN2 and L plots on the top and the CL2 and C plots on the bottom. The small upward deflections or “tick marks” in the lines indicate reinforcer deliveries. The small case letters exemplify: “a” = long pauses throughout the session; “b” = pauses after reinforcements; “c” = pauses after responses; and “d” = responses after reinforcements.

Figure 11 shows that pauses in responding occurred for F01 in all four conditions, though pauses in the NN and L conditions were on average longer than in the CL and C conditions and occurred at various points in the session (see the regions labelled “a” for examples). In the CL and C conditions, two types of pauses can be observed in these plots: a pause that occurred immediately after a reinforcer delivery (see the regions labelled “b” for examples) and a pause that occurred after a response that was not

followed by a reinforcer delivery (see the regions labelled “c” for examples). In addition, responses can be observed after reinforcement, in some occasions (see the regions labelled “d” for examples); that is, on occasion, no pauses were observed after reinforcer deliveries. Therefore, Figure 11 shows that, for F01, a typical break-and-run pattern of responding was not observed in any of the four conditions.

Figure 12 shows that F02’s response rates were highest in CL, followed by C, and were lowest in NN and L, which produced similar response rates. Pauses can be seen throughout the sessions in all four conditions, with a pattern similar to the one observed for F01: long pauses can be seen throughout the session during NN and L (see regions labelled “a” for examples), and during CL and C, pauses can be seen both after reinforcer deliveries (see regions labelled “b” for examples) and after responses not followed by reinforcer deliveries (see regions labelled “c” for examples). In addition, responses were observed after reinforcer deliveries (see regions labelled “d” for examples).

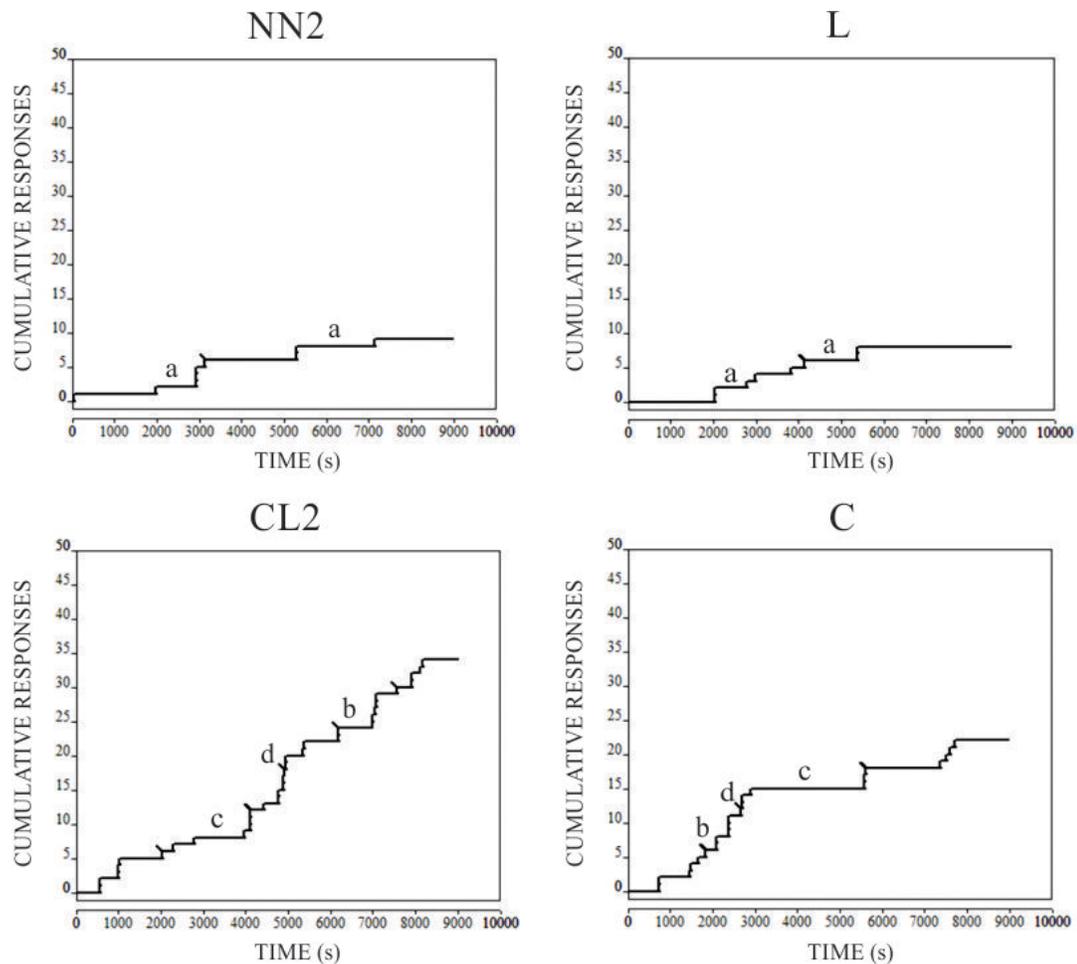


Figure 12. Cumulative responses of F02 in the last session of the NN2 (no coin, no light second exposure), L (light only), CL2 (coin and light second exposure), and C (coin only) conditions, with the NN2 and L plots on the top and the CL2 and C plots on the bottom. The small upward deflections or “tick marks” in the lines indicate reinforcer deliveries. The small case letters exemplify: "a" = long pauses throughout the session; "b" = pauses after reinforcements; "c" = pauses after responses; and "d" = responses after reinforcements.

Figure 13 shows that F03’s response rates in the CL and C condition were similar. Response rates in the NN and L conditions were lower than in the CL and C conditions, with the response rates in the L condition being the lowest. The pattern of pauses observed for this fish is similar to that observed for F01 and F02: see regions labelled "a" for examples of long pauses throughout the sessions in the NN and L conditions, see regions labelled “b” and “c” for pauses both after reinforcer deliveries and after responses

that were not followed by reinforcer deliveries in the CL and C conditions, and see the regions labelled “d” for examples of responses after reinforcer deliveries (absence of pauses) in the CL and C conditions.

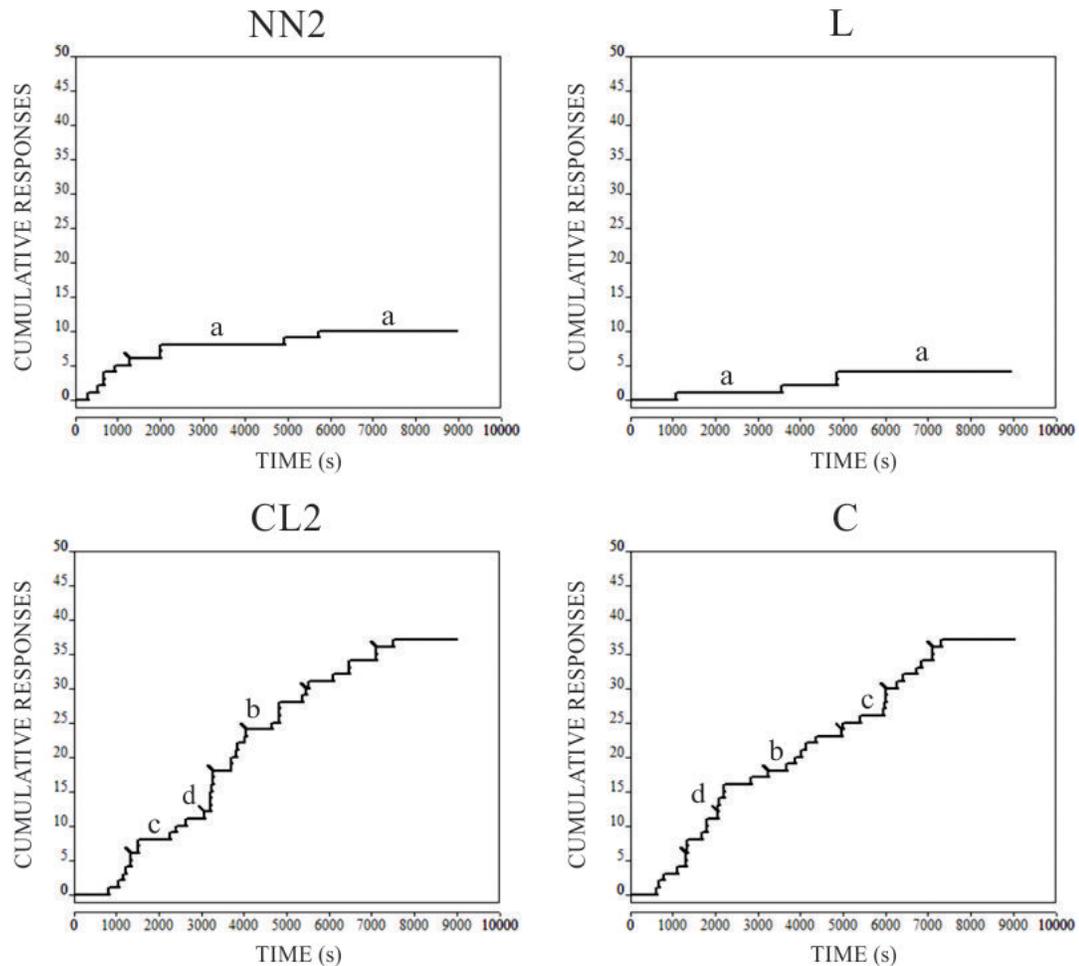


Figure 13. Cumulative responses of F03 in the last session of the NN2 (no coin, no light second exposure), L (light only), CL2 (coin and light second exposure), and C (coin only) conditions, with the NN2 and L plots on the top and the CL2 and C plots on the bottom. The small upward deflections or “tick marks” in the lines indicate reinforcer deliveries. The small case letters exemplify: “a” = long pauses throughout the session; “b” = pauses after reinforcements; “c” = pauses after responses; and “d” = responses after reinforcements.

Figure 14 shows that, for F04, rates of responding were highest in the CL condition, followed by the C, NN, and L conditions. The pattern of pauses was similar to that observed for the other fish: long pauses throughout the session during the NN and L conditions (see the regions labelled “a” for examples), pauses both after reinforcer deliveries (see the regions labelled “b” for examples) and after responses not followed by reinforcement (see the regions labelled “c” for examples) in the CL and C conditions, and responses occurring after reinforcer deliveries (see the regions labelled “d” for examples) in the CL and C conditions.

Therefore, a clear break-and-run pattern of responding was not observed in any of the experimental conditions for any of the subjects in this study.

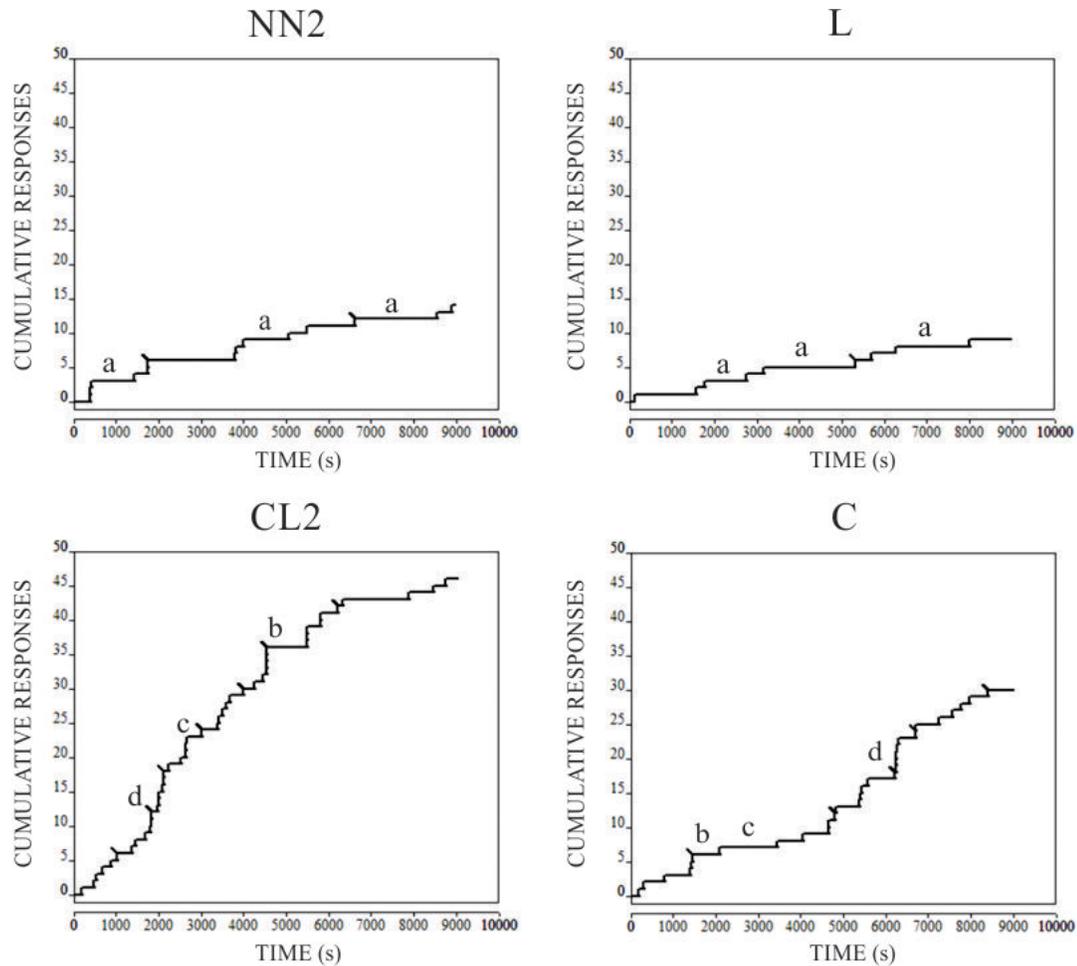


Figure 14. Cumulative responses of F04 in the last session of the NN2 (no coin, no light second exposure), L (light only), CL2 (coin and light second exposure), and C2 (coin only second exposure) conditions, with the NN2 and L plots on the top and the CL2 and C2 plots on the bottom. The small upward deflections or “tick marks” in the lines indicate reinforcer deliveries. The small case letters exemplify: "a" = long pauses throughout the session; "b" = pauses after reinforcements; "c" = pauses after responses; and "d" = responses after reinforcements.

Discussion

The purpose of the present study was to investigate the role of a response-location stimulus (coin) and an exteroceptive response-feedback stimulus (1 s of light) on a spatially defined motor response by *Betta splendens* under an FR schedule of reinforcement. The experiment was an attempt to analyze the effect of two types of

stimuli that are typically provided by an operandum on the FR behaviour pattern widely reported in the operant behaviour literature.

The results indicated that neither a response-location stimulus, nor a response-feedback stimulus were necessary for the conditioning and maintenance of spatially defined responses under an FR6 schedule. This is consistent with findings by Chitty (2002), who conditioned *Betta splendens* to respond under FR schedules having neither a response-location nor a response-feedback stimulus.

Despite not being necessary for conditioning and maintenance of responding under FR, the response-location stimulus and the response-feedback stimulus did have an effect on responding.

The Role of the Response-Location Stimulus

The response-location stimulus had an impact on the accuracy and distribution of responding for all four fish. A greater number of responses per session, reinforcements per session, and responding more tightly concentrated in and around the response location were observed when the response-location stimulus was present (i.e., the CL and C conditions). The response-location stimulus seemed to serve a discriminative stimulus function, evoking more accurate responding to the target location. In the two conditions in which the response-location stimulus was not present (i.e., NN and L conditions), less effective responding was observed: swimming in and around the target location was more spread out, suggesting more response generalization.

In the two conditions where a response-location stimulus was not present, longer "pauses" in responding were observed in the cumulative plots. These were not pauses in the sense of the fish staying still somewhere in the tank, which can be inferred by looking

at the XY plots for the NN and L conditions that show more swimming trajectories along the walls of the tank than in the CL and C conditions, in addition to swimming near the target location mentioned above. As a matter of fact, what is called a "pause" in responding in cumulative plots is not necessarily a pause in the sense that the animal is staying still, as cumulative plots do not provide data on what animals are doing while not engaged in the target response.

Therefore, during the "pauses" observed in the cumulative plots in this study, the fish could be either swimming near the target location without meeting the requirement for a response (i.e., "trying" to make a response) or swimming along or closer to the perimeter of the tank (i.e., "not even trying" to make a response). As mentioned above, the behaviour of "trying" to make a response is being interpreted as response generalization.

The behaviour of swimming near or along the perimeter of the tank may be interpreted as ratio strain. Ratio strain refers to irregular "pauses" occurring between responses in cumulative plots of FR schedules, which are typically observed in high ratio requirements (Felton & Lyon, 1966; Ferster & Skinner, 1957; Weissman & Crossman, 1966; Wood, Happ, & Adams, 1983). It is possible that, given the absence of the response-location stimulus, the response effort to meet the ratio requirement increased (i.e., more swimming near the target location was necessary for a reinforcer to be produced) and thus the contingency experienced by the fish was one of a high ratio requirement.

I did not find other studies on spatially defined responses that directly manipulated the presence versus absence of a response-location stimulus in the literature

reviewed for this study. In previous studies, a potential response-location stimulus was either present during the entire experiment (Critchfield & Lattal, 1993; Hoffman & Fleshler, 1959; Schroeder & Holland, 1968) or absent during the entire experiment (Pear & Legris, 1987; Chitty, 2002). More studies are warranted to investigate the role of response-location stimuli on the accuracy of responding maintained under different schedules of reinforcement with different species. Studies on varying the features of a response-location stimulus and fading (i.e., gradually introducing or gradually removing) a response-location stimulus could be promising in investigating how it is possible for a location apart from the stimuli within it to control responding.

The one exception to the effects of the response-location stimulus observed was the low number of responses per session emitted in the first time F04 was exposed to the C condition. Given that the results for F04 in the C condition differed from the results from the other fish, it was hypothesised that the sequence of sessions with little to no reinforcement resulted in a breaking of the contingency between responding and reinforcer delivery and a deterioration of the reinforced behaviour. The sequence of conditions for this fish was such that, immediately prior to the C condition, it experienced 3 conditions (total of 25 consecutive sessions) in which responding was low (range 4 to 22 responses); thus, the number of reinforcers obtained per session was also low (range of 0 to 3 reinforcements per session), with 14 out of the 25 session containing 0 or 1 reinforcer deliveries.

After F04's responding reached the stability criteria following re-training, a C condition was again conducted. This time, responding first increased then decreased in the C condition, stabilizing at a level similar to the highest data points in the immediately

preceding CL condition. Thus, the hypothesis that the performance observed the first time the C condition was in effect for F04 was due to a breaking of the contingency between responding and reinforcement was supported.

It is possible that two methodological choices contributed to the breaking of the contingency between responding and reinforcement for F04. The first methodological choice was the criterion for session termination, which was based on time (i.e., 15 min sessions). It is possible that, had the session termination criterion been based on the number of reinforcers per session, the fish would not have experienced so many sessions with little to no reinforcers. The second characteristic of the method that may have contributed to this result was the stability criteria, which required a minimum of five sessions, regardless of the number of reinforcers received in the session. Perhaps had the stability criteria specified an earlier termination of the condition in case of more than a number of sessions with no reinforcement, the contingency would not have been broken resulting in the deterioration of the reinforced responding. Future studies should consider different session termination criteria and stability criteria in order to avoid such deterioration in responding.

In studying the presence versus absence of a response-location stimulus, care should be taken to prevent an avoidance response when the response-location stimulus is first introduced. In the present study, when the coin was first introduced in the experimental tank in the CL condition for F03, this fish's responding dropped abruptly. It was hypothesised that an unplanned avoidance contingency was responsible for this effect. Supporting this hypothesis, the two CRF sessions conducted in the presence of the coin worked to eliminate the avoidance behaviour and allowed the experimental

condition to operate. Future studies could conduct a few sessions during baseline with the response-location stimulus present in an attempt to expose the subject to the response-location stimulus prior to the relevant experimental conditions and prevent the avoidance behaviour that was observed.

The Role of the Response-Feedback Stimulus

The response-feedback stimulus used in this study had a much less clear effect on responding than the response-location stimulus. The discussion on the effects of the response-feedback stimulus will be divided into two main analyses: the effect of the response-feedback stimulus when the response-location stimulus was present and the effect of the response-feedback when the response-location stimulus was absent.

The response-feedback stimulus with the response-location stimulus present.

The effect of the response-feedback stimulus when the response-location stimulus was present can be analyzed by comparing the performance of the fish in the CL condition to the C condition and by looking at the results of the test on extinction, which first included only the coin and then the coin and the light. In these conditions, the response-location stimulus was always present and the presence of the response-feedback stimulus was manipulated.

Comparing the performance of the fish in the CL to the C condition, it was observed that, at stability, three fish (F01, F02, F04) emitted a greater number of responses per session and received more reinforcers per session in the CL than in the C condition. This suggests that the efficiency of responding was improved by the response-feedback stimulus. Critchfield and Lattal (1993) found that efficiency of responding was

also improved when a response-feedback stimulus was used in a schedule of delayed reinforcement.

The exception to the result of more efficient responding when the response-feedback was present was F03, whose number of responses in the C condition during stability was at the same level as during the previous CL conditions. Before concluding that the light had no effect for this fish, one should analyze the course of responding during the C condition and the results of the extinction test conducted.

Looking at F03's responding during the C condition, there was an immediate increase in the number of responses per session followed by a decrease. It is possible that the light for this fish either had a mild suppressive effect, so that responding increased when it was removed, or had a conditioned reinforcer effect, so that a pattern similar to an extinction burst was observed in the first sessions of the C condition.

The interpretation of whether the light for F03 had a mild suppressive effect or a conditioned reinforcer effect is clarified by the results of the extinction test. After the extinction without the light operative, the introduction of the light resulted in an immediate increase in the number of responses, suggesting that the light had a conditioned reinforcer effect for this fish.

The results of the extinction test for F04 did not suggest a conditioned reinforcer function of the light for this fish, though the comparison of the number of responses per session in the CL condition to the C condition did. Therefore, the analyses of the effects of the response-feedback stimulus when the response-location stimulus was present suggest that the feedback-stimulus may have functioned as a conditioned reinforcer for all four fish.

The response-feedback stimulus without the response-location stimulus present. The effect of the response-feedback stimulus when the response-location stimulus was not present can be analyzed by comparing the performance of the fish in the NN condition to the L condition because the response-location stimulus was not present in these two conditions.

For one fish (F01), the number of responses per session was greater in the L condition than in the NN condition, suggesting an effect of the light in increasing responding when the response-location stimulus was not present. For two fish (F03 and F04) the number of responses per session was lower at stability in the L condition than in the NN condition, suggesting that the light may have had a mild suppressive effect for these fish; however, the extinction test suggested differently for at least one of them (F03). For one fish (F02), the number of responses per session was similar in the NN condition and the L condition, suggesting that the light, without the response-location stimulus, had no effect on responding for this fish.

For F02, even though the results of responding at stability suggested a lack of effect of the response-feedback light, the course of responding during the L condition did suggest some effect. In the L condition, F02 presented with a process that was not observed with the other fish: responding first increased as though the fish was learning to use the light as feedback in the absence of the response-location stimulus. However, responding subsequently decreased and stabilized at a level similar to the level observed in the NN condition. It is not clear what may have caused this change in the course of responding.

I did not find other studies that compared the effect of an exteroceptive response-feedback stimulus in the absence of a response location stimulus in the literature reviewed. The results obtained in the present experiment suggest that more research is needed on the circumstances under which a response-feedback stimulus may affect responding when no response-location stimulus is present.

FR Response-Patterns with Fish

One contribution of the present study was to expand the research on schedules of reinforcement with fish. The study attempted to determine whether the typical break-and-run FR pattern observed with other species would be observed with fish. In order to do this analysis, cumulative records for single sessions and single subjects, which had been presented in only three other studies found in the literature on FR schedules with fish (Chitty, 2002; Salzinger et al., 1968, Thompson, 1969), were presented.

The importance of analyzing single session cumulative records of species other than birds and mammals relies on the fact that the documented response patterns on schedules were described using single-session, single-subject cumulative records. Therefore, if one is to investigate whether there may be differences between species in responding under specific schedules of reinforcement, one must analyze single-session, single-subject cumulative records.

A typical break-and-run response pattern was not observed in the present study. Despite that, the conclusion that fish cannot present with the break-and-run response pattern observed with birds and mammals would be premature. A number of variables, derived from differences between the current study and most studies on schedules of reinforcement with other species, must be investigated before such conclusion can be

drawn. The investigation of the variables described below would not only add to the comparison between species, but to the very knowledge of the conditions under which those documented response patterns can be observed.

First, the spatially defined response used in the current study is less discrete than the responses in the studies with an operandum. Although some variability in the topography of the response is possible in studies with typical mechanical operandums, it seemed that the variety of topographies that were possible in the present study was much greater. The fish could initiate a response from anywhere in the tank and could contact the virtual cylinder from any direction. In fact, the observation of the videos and the XY plots of the sessions indicated that the fish greatly varied their topography of responding. Future studies should investigate the relation between the amount of variability in the response topography and schedule patterns.

Second, the location of the food delivery in the present study was not as precise as in most studies with birds and mammals (Figure 1), which allowed for variability in the location of the consumption response. This may have had an impact on the schedule pattern by causing the fish to travel lesser or greater distances to consume the food, depending on where it fell in relation to the position of the fish when the reinforcer was delivered. Roper (1975) found that response rate was inversely related to operant-reinforcer distance in a study using CRF. Given that the response-reinforcer distance varied throughout the sessions in the present study, it is possible that the irregular pauses observed were due, in part, to the variation in the distance between the response and the reinforcer. Future studies should investigate the relations between restricted and variable consumption locations with the response patterns on schedules of reinforcement.

Third, the pauses after reinforcement in the present study may have been in part confounded with the time the fish spent engaged on the consumption response. Future studies should attempt to control the consumption response duration in order to study pauses in responding (pauses here are being defined as periods in which the animal is not engaged in the experimentally programmed tasks, which are the target response and the consuming response). This could be done by limiting the duration of a consumption response, as it is often done in research with pigeons, in which the food is available for a limited time.

Another way to investigate the pauses after reinforcements controlling for the time spent consuming the reinforcer would be to use different FR schedules with higher response requirements, given that the average time spent consuming the reinforcer would supposedly remain the same in different FR values. Post-reinforcement pauses tend to increase in length as the FR ratio requirement is increased (Felton & Lyon, 1966; Ferster & Skinner, 1957; Powell, 1968; Schlinger et al., 2008). Comparing the length of pauses in higher versus lower ratios could add to the investigation of pausing by fish under ratio schedules.

A potential difficulty in studying higher ratios would be whether responding would be maintained. The choice for the ratio requirement used in the present experiment was due to reports in the literature of difficulty in maintaining responding by *Betta splendens* with ratios higher than FR 6 (Thompson, 1969; Hogan et al., 1970; Chitty, 1999). In fact, one fish in the present study (F04) showed deterioration of responding after a sequence of sessions without a response-location stimulus.

In conclusion, the present study contributed to the knowledge about the conditioning and maintenance of spatially defined responses under FR schedules of reinforcement. It also expanded the research on schedules of reinforcement with fish. Finally, the present study pointed to several avenues of research to increase our understanding of operant behaviour maintained under intermittent schedules of reinforcement.

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Appendix A

Shaping

Figures 1A, 2A, 3A, and 4A show the XY plots of the last session of Baseline, the last session of each Shaping step, the first session of CRF (CRF1), and the last session of CRF (CRF) for F01, F02, F03, and F04, respectively. Figure 1A shows that swimming of F01 occurred mostly along the walls of the tank during Baseline. Shaping and CRF produced a change in the distribution of swimming, so that at the end of the CRF Phase, concentration of swimming in and around the centre of the tank was observed. This same processes can be observed in Figures 2A, 3A, and 4A for the other subjects.

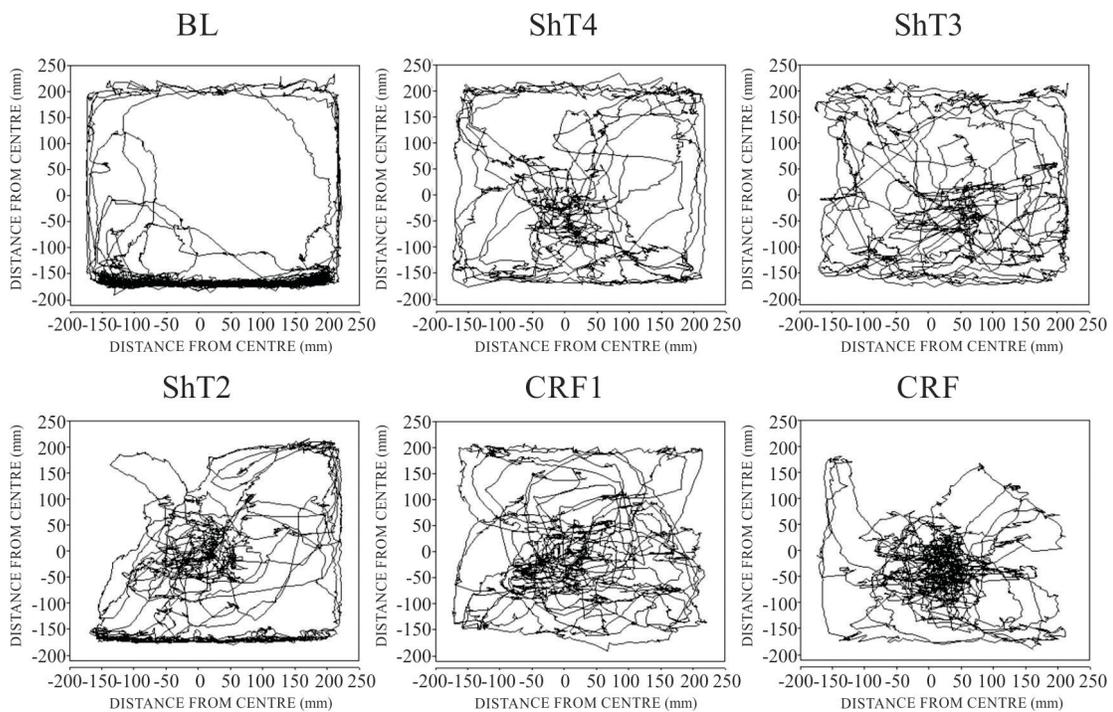


Figure 1A. XY plots of the last session of baseline (BL), the last session in each shaping step (ShT4, ShT3, ShT2), the first session of CRF (CRF1), and the last session of CRF (CRF) for F01.

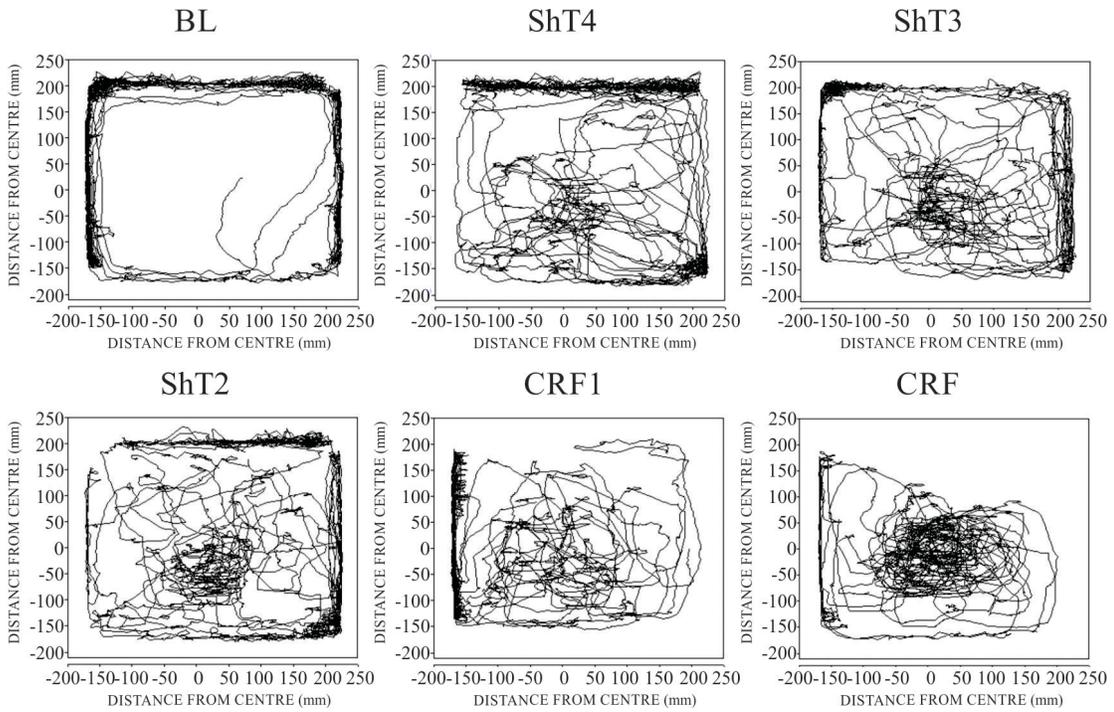


Figure 2A. XY plots of the last session of baseline (BL), the last session in each shaping step (ShT4, ShT3, ShT2), the first session of CRF (CRF1), and the last session of CRF (CRF) for F02.

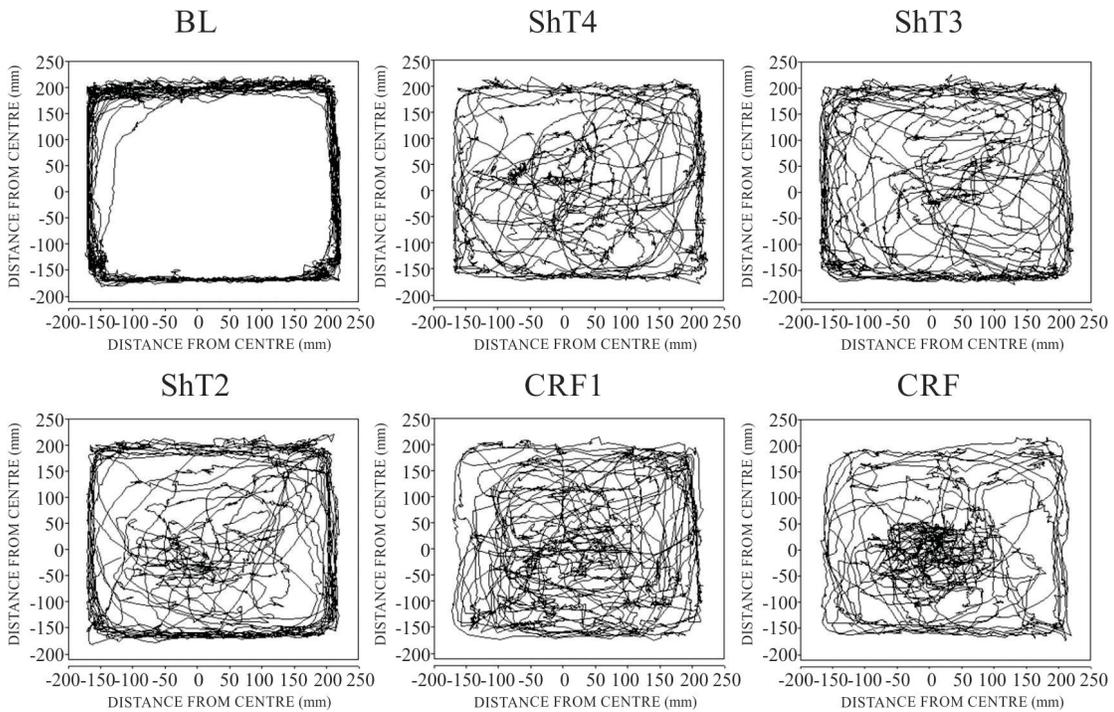


Figure 3A. XY plots of the last session of baseline (BL), the last session in each shaping step (ShT4, ShT3, ShT2), the first session of CRF (CRF1), and the last session of CRF (CRF) for F03.

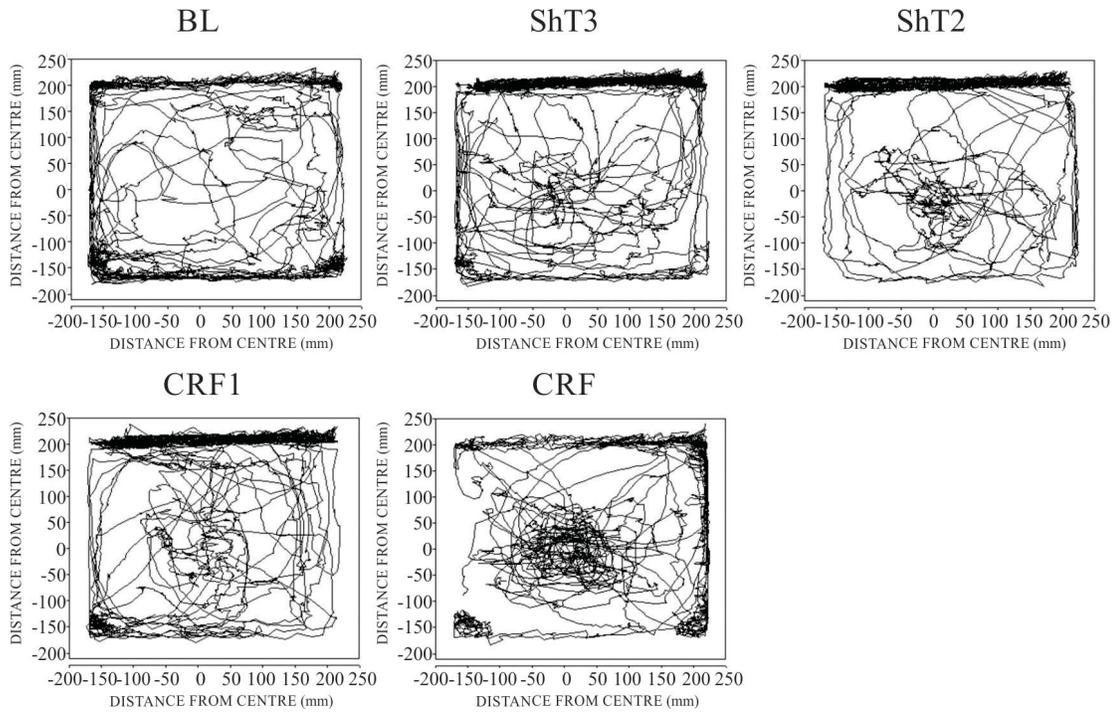


Figure 4A. XY plots of the last session of baseline (BL), the last session in each shaping step (ShT3, ShT2), the first session of CRF (CRF1), and the last session of CRF (CRF) for F04.

Appendix B

CRF

Figure 1B shows the cumulative response plot of the last CRF session for each fish. F01 and F03 experienced CRF without the coin or light present (CRFNN) whereas F02 and F04 experienced CRF with the coin and light present (CRFCL). A typical constant rate of responding was not observed during CRF for any of the subjects in the present study. Long pauses between responses were observed for all fish (see regions labelled as "a" for examples) and for 2 fish (F01 and F04), satiation towards the end of the session was observed.

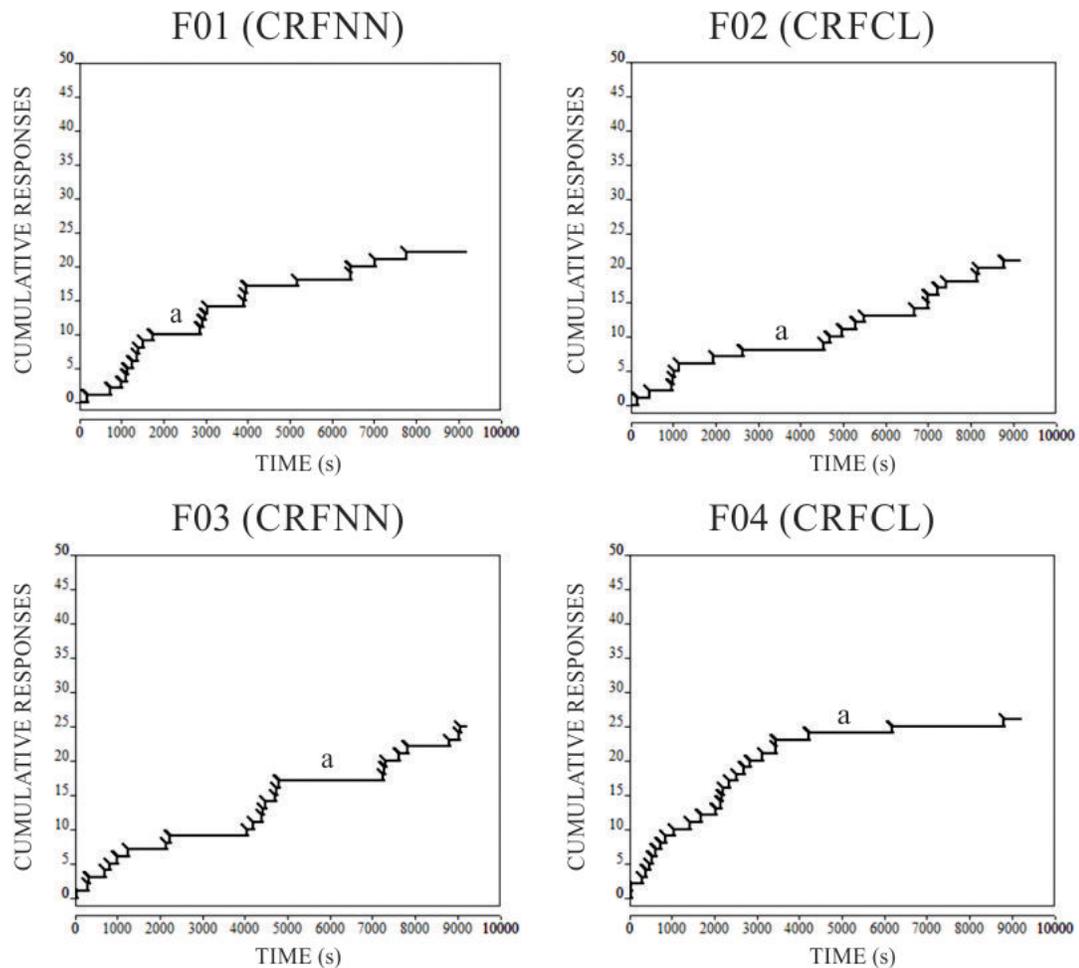


Figure 1B. Cumulative responses of F01, F02, F03, and F04 in the last sessions of CRF.

Appendix C

Graphical Presentation of the Mean Responses During Stability under Each Condition

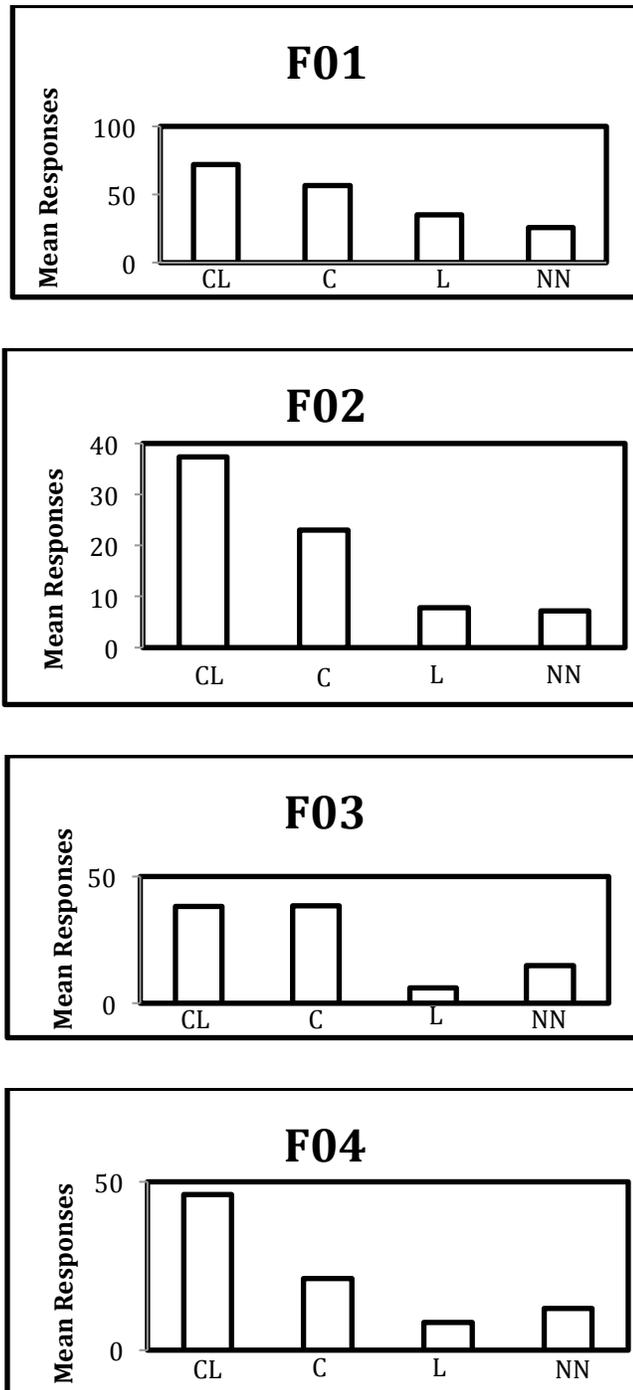


Figure 1C. Mean number of responses in each condition for each subject computed from Table 3. Note that the data for each subject in each condition listed in Table 3 have been averaged.

Appendix D

Avoidance of the Coin

Figure 1D shows the XY plot of the first session of CL under FR6 for F01. Swimming occurred around the target response location (centre of the tank), but a blank space (few data points) is observed in the centre of the tank, suggesting an approach/avoidance behaviour towards the coin of F01 in this session.

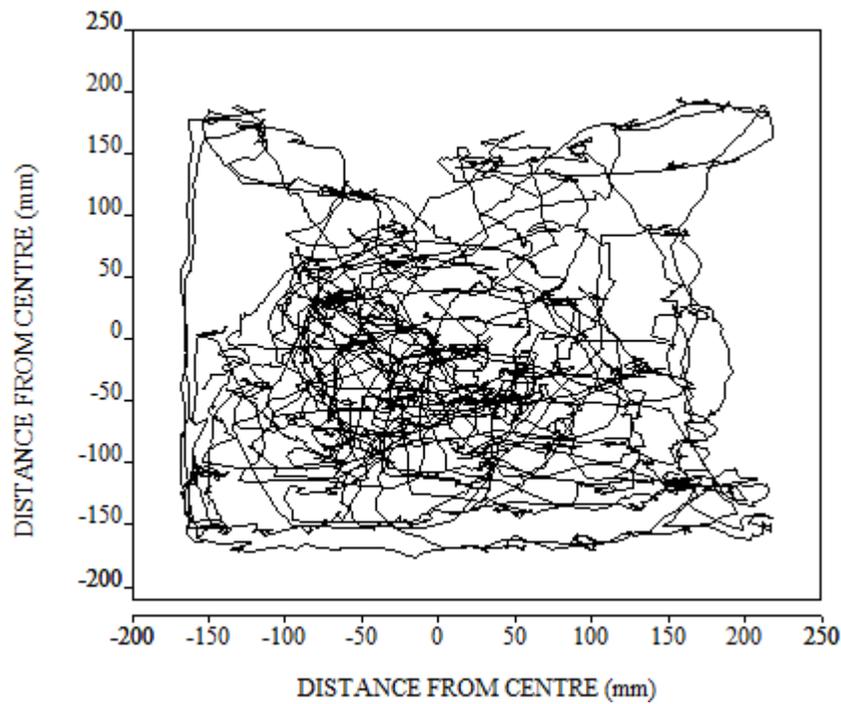


Figure 1C. XY plot of F01's swimming in the first session of the CL condition under FR6.