Fixed-ratio Behaviour of Lake Sturgeons (*Acipenser fulvescens*): Darkness as a Reinforcer

by

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Abstract

In an experimental tank (ET), three experimentally naïve lake sturgeons (*Acipenser fulvescens*) were operantly conditioned to enter one of four target areas where they received an auditory response-feedback stimulus (RFS) in the form of a click sound and – according to the prevailing FR schedule – 10 seconds of darkness. A multiple-baseline-across-subjects design was used. Visual observation and a video-tracking system (VTS) monitored the number of responses emitted on each of the four target areas. The target areas were in the corners of the ET and had to be entered by the subject to constitute a response. The experiment generally consisted of the following phases: (1) no-feedback baseline (NFB) phase; (2) discriminative stimulus baseline (DSB) phase; (3) response-feedback baseline (RFSB) phase; and (4) fixed-ratio phase (FR n). The data indicated a preference for the target area that produced darkness, which suggests that darkness is a reinforcer for this species. This preference was indicated by a greater number of target area responses for the target area whose entry into it produced darkness, and greater activity in and around that area relative to baseline phases. Furthermore, when the ratio of the FR n phase was increased the subject's rate of responding also increased.

Keywords: operant conditioning, *Acipenser fulvescens*, lake sturgeons, darkness, reinforcement, fixed-ratio (FR)

Operant Conditioning of Lake Sturgeons (*Acipenser fulvescens*): Darkness as a Reinforcer

Associative learning is a vital aspect of human and non-human learning. According to Pear (2016), *associative learning* involves "the pairing or association of two events that occur close together in time" (p. 26). This association of two events is what enables human and non-human animals to learn and readily adapt to their changing environment. Consider the example of associative learning where you are training your dog to sit. By feeding your dog a treat every time he sits following the command "sit" your dog associates treats with the behaviour of sitting. This association increases the likelihood of your dog sitting when you say "sit" in the future.

Associative learning can be divided into two types: (1) respondent conditioning and (2) operant conditioning (Pear, 2016). *Respondent conditioning* involves pairing an unconditioned stimulus with a neutral stimulus resulting in the neutral stimulus eliciting a response it did not previously elicit. "*Operant conditioning* is a type of learning in which behaviour is modified by its consequences" or stimuli that follow it closely in time (Martin & Pear, 2015, p. 29). Operant conditioning differs from respondent conditioning in that operant conditioning involves associating a response with a stimulus instead of associating a stimulus with a stimulus (Pear, 2016). The stimulus associated with a response in operant conditioning is called a *reinforcer*, which is a stimulus whose occurrence following a response increases the future probability of the occurrence of that response. Operant conditioning is an important form of learning because it enables an animal to learn how to interact with its environment in a manner that enhances its chance of survival.

Operant conditioning has been studied in a variety of non-human vertebrate animals. Roper (1973) used operant conditioning to teach female virgin albino mice to press a lever for strips of paper, which the mice then used to build nests. Following conditioning, the researcher

placed the mice on a *fixed-ratio* (*FR*) *reinforcement schedule,* which is a contingency whereby "a reinforcer occurs each time a fixed number of responses of a particular type are emitted" (Martin & Pear, 2015, p. 73). For example, an FR 10 schedule requires 10 responses to occur for each reinforcer that is received. Starting from FR 1 Roper gradually increased the FR schedule until FR 10 was reached and found that, after reaching FR 10, ratio strain occurred. *Ratio strain* is the occurrence of long pauses when a response requirement is too large to maintain consistent responding (Pear, 2016, p. 69).

Park, Okanoya, and Dooling (1985) used operant conditioning to teach budgies (*Melopsittacus undulatus*) and canaries (*Serinus canaria*) to discriminate between conspecific contact calls and those of other species. The first training procedure consisted primarily of autoshaping but in some cases hand-shaping was also used to train the subjects to emit responses. *Autoshaping* is "consistent contact with a stimulus paired with a reinforcer" (Pear, 2016, p. 105). Additionally, the subjects were trained to discriminate between two pure tones, one that was a "GO stimulus" or discriminative stimulus for responding (S^D) and the other a "NOGO stimulus" or discriminative stimulus for not responding (S^Δ). Responding to the GO stimulus yielded 4-seconds of reinforcement (yellow millet) and responding to the NOGO stimulus yielded 10-seconds of a *time out* – i.e., a period in which reinforcement will not occur. The results of the study illustrate birds' ability to be operantly conditioned to discriminate between different stimuli to earn reinforcement.

In addition to mammals and birds, fish have also been shown to learn when operant conditioning principles are used. Salzinger, Freimark, Fairhurst, and Wolkoff (1968) conditioned a goldfish (*Carrasius auratus*) to strike a lever to receive food reinforcement. The study progressed from every response reinforced, called *continuous reinforcement* (*CRF*), to an FR 10

reinforcement schedule. Note that a CRF schedule is equivalent to an FR 1 reinforcement schedule. Another example of operant conditioning with fish was an experiment conducted by Hogan (1967) who conditioned Siamese fighting fish (*Betta splendens*) to swim through a ring suspended in an experimental tank to receive access to a mirror in which the subject could view itself. The use of the fish's mirror image as a reinforcer resulted in a significant increase in responding during reinforcement (Hogan, 1967).

Interestingly, operant conditioning is not restricted to vertebrate animals but has also been observed in a variety of invertebrate animals such as bumblebees, crayfish, lobsters, and cockroaches (Bhimani & Huber, 2016, p. 240). Bhimani and Huber taught crayfish (*Orconectes rusticus*) to respond to a spatial contingency to avoid a mild electric shock. Loukola, Perry, Coscos and Chittka (2017) taught bumblebees (*Bombus*) to move a ball to a specific location and to pull a string to gain access to food reinforcement.

Different schedules of reinforcement yield distinct behaviour patterns across species. For example, FR schedules of reinforcement yield high and steady rates of responding followed by a brief stoppage of responding after reinforcement is received; this brief stoppage in responding is known as a *postreinforcement pause* (*PRP*) (Pear, 2016, p. 65). This high rate of responding with a sudden pause after reinforcement is called a *break-and-run pattern*. PRPs increase in duration as FR size increases. In other words, a PRP for FR 10 will be shorter than a PRP for an FR 25. The correlation between the FR size and PRP has been found to occur in many species (Pear, 2016, p. 65).

Operant conditioning interacts with an organism's behavioural ecology. *Behavioural ecology* is "the study of the evolutionary basis for animal behaviour due to ecological pressures" (*Behavioural ecology*, 2019). Behavioural ecology revolves around Niko Tinbergen's four

questions to address when studying animal behaviour: (1) proximate causes; (2) ontogeny; (3) survival value; and (4) phylogeny (Tinbergen's four questions, 2019). Proximate causes refer to the causal mechanisms of behaviour; mechanisms such as the brain, hormones, and pheromones that influence how an organism behaves. *Ontogeny of behaviour* is the development of an individual's behaviour as a result of individual's genetics and development. The survival value of behaviour refers to the function of the behaviour in relation to the survival of the organism and consequently its offspring. Finally, the phylogeny of an organism provides an evolutionary history of the organism and why certain anatomical and behavioural features are present.

Behavioural ecology plays a role in selecting a reinforcer for operant conditioning as an organism's phylogeny and current ecological environment can influence the ontogeny and probability of a behaviour. As described above, stimuli that act as reinforcers vary – e.g., strips of paper, a mirror, and food. The strength a reinforcer has can vary depending on the organism. For example, a strip of paper would not be reinforcing to a Siamese fighting fish as it serves no evolutionary or survival purpose to the fish, whereas for a female virgin mouse a strip of paper serves as nesting material for reproduction thus has survival value. The behaviour of nesting increases the probability of producing offspring by providing offspring a safe and warm place to develop. By producing successful offspring, genetic material is passed on and over time, as more generations are produced, the behaviour of nesting becomes a part of the species reproductive phylogeny.

An organism's phylogeny is important to consider when conducting operant conditioning experiments as operant conditioning is the primary focus of behavioural evolution (Baum, 2017, p. 322). Based on this view, William Baum developed three laws of behaviour: the law of allocation; the law of induction; and the law of covariance (Baum, 2018). The law of allocation

is mathematically derived from the matching law (Herrnstein, 1961). The law of allocation states: (1) only whole organisms behave; (2) to be alive is to behave; and (3) every action is composed of parts that are themselves activities.

The law of induction states that there exist objects or events called inducers that "…increase time spent in some activities, and, because activities compete for time, decreases time spent in other activities" (Baum, 2018, p. 242). *Inducers* are phylogenetically important events (PIEs). PIEs have been referred to as reinforcers, punishers, aversive stimuli, and unconditioned reinforcers (Baum, 2018, p. 242). A PIE would induce an activity that (a) may be understood by considering an organism's phylogeny, and (b) affects the organism's fitness. An organism's fitness according to Baum (2017) is the combination of contingency and induction resulting in an operant activity having a higher recurrence than other activities. Since time is limited only so many activities can occur in an organism's lifetime, putting all activities in competition with one another. The competition between activities an organism completes suggests that fitness is always relative, because if one activity increases another must decrease (Baum, 2017, p. 322). Furthermore, since PIEs impact fitness of an organism PIEs facilitate natural selection of the activities they induce.

Finally, the law of covariance "… states that (a) when covariance exists between a signal and a PIE, the signal becomes a proxy for the PIE and induces the same activities as the PIE, and (b) when covariance exists between an activity and a PIE, the activity becomes a PIE-induced activity" (Baum, 2018, p. 244). Baum postulated that "a contingency controlling behavior had to include a difference between two conditions: likelihood of the signaled event (PIE) when the signal (S) is present and likelihood of the signaled event (PIE) when the signal (S) is absent" (Baum, 2018, p. 243). In other words, for a strong correlation to occur between the response and

reinforcer, the likelihood of the reinforcer occurring only after the response must be great and the occurrence of the reinforcer without the response must be low to have the PIE induce the response.

I hypothesized that based on lake sturgeon's behavioural ecology darkness would be a PIE for a few reasons. First, lake sturgeons inhabit a low light environment as they are bottom feeders and live at bottom of lakes and rivers where there is little light penetration. This dark immediate environment directly influences the ontogeny of the organism and in turn its behaviour; for example, the reliance of barbels for detection of the environment and food.

Second, juvenile lake sturgeons are dark in color which aids in camouflage from predators while living in the dark environment. Lake sturgeons only become lighter in color when they grow too large to be prayed on by other organisms in their immediate environment. These changes in the lake sturgeon's appearance demonstrate ontogeny which is influenced by both the organism's genetics and developmental environment.

Finally, since lake sturgeons are decedents of sturgeons that evolved around 200 million years ago (Peterson, Vecsci & Jennings, 2006), there has been much opportunity for evolution. The above mentioned ontogenetic, anatomical, and behavioural traits have been selected for again and again through lake sturgeon phylogeny suggesting a preference for dark environments has evolved. All considered, lake sturgeon's behavioural ecology suggests that darkness would be a PIE where darkness (inducer) would induce responding in an operant conditioning experiment.

Operant conditioning experiments with animals often involve an "operandum" such as a lever or key that when depressed triggers a change, such as a change in illumination. There have been operant conditioning experiments conducted with mammals that have found that different

species of rats prefer light to darkness. Hurwitz (1960) examined the effectiveness of light as a reinforcer for hooded rats. He found that the rats who were previously in a dark box pressed the lever significantly more times than did rats that were previously in an illuminated box.

Barry and Symmes (1963) examined the reinforcing effect of light-onset for rats that were on a diurnal cycle. This experiment suggested that the light-onset acted as a reinforcer when it was most novel to the rats. Rats for which pressing the bar led to light-offset showed a gradual increase in lever pressing regardless of time of day. This suggested that a lit box provided competing reinforcers like being able to crouch and engage in visual exploration, which may be less likely in the dark.

Barker, Sanabria, Lasswell, Thrailkill, Pawlak, and Killeen (2010) found the opposite effect; viz., that bright light is an aversive stimulus for rats. One experiment that was conducted provided Wistar rats with two levers to press; both would produce the same amount of food. The researchers found that rats developed a preference for one lever during baseline sessions. During experimental sessions a *variable interval* (*VI*) schedule was implemented on the preferred lever so that in addition to food bright light would also occur. A VI schedule is a schedule in which "a reinforcer is presented following the first instance of a specific response after an interval of time, and the length of the interval changes unpredictably from one reinforcer to the next" (Martin & Pear, 2015, p. 76). This resulted in the rats changing their lever preference to avoid the light. The aversive effect of bright light on albino rats has also been observed on a CRF schedule where depression of a lever produced darkness for 1 minute (Kaplan, Jackson, & Sparer, 1965).

Similar effects have also been observed in birds. According to Podkowa and Surmacki (2017) "light has a significant impact on many aspects of avian biology, physiology and behaviour" (p. 1). One example of the impact of light on avian behaviour is nest site choice.

Podkowa and Surmacki (2017) examined this behaviour in the great tit (*Perus major*) by providing a choice between illuminated and dark nest boxes. The relationship between illumination and nesting behaviours in the great tit, the researchers believe, supports a biologically driven function that light can be perceived by embryonic birds through the shell of its egg where the light aids in the embryonic development and speeds up the process (Podwoka & Surmacki, 2017). This would not be true in all species as some species prefer darkness.

Avoidance of light has been observed in a variety of fish species. Maximino et al. (2007) observed this in five different teleost species: zebrafishes (*Danio rerio*), cardinal-tetras (*Paracheirodon axelrodi*), lambaris (*Astyanax altiparanae*), Nile tilapias (*Oreochromis niloticus*), guppies (*Poecilia reticulata*) and banded knifefishes (*Gymnotus carapo*). All five species preferred a dark background to a light background, and the light-coloured background was aversive to all species except the Nile tilapias (Maximino et al., 2007, p. 364).

One species of fish that has seldom, if ever, been investigated in operant conditioning experiments are lake sturgeons. Lake Sturgeons are large, extant non-teleost, freshwater fish native to North America (Peterson et al., 2007). Lake sturgeons have cartilaginous skeletons as well as other primitive features like a heterocercal tail, heavily armoured skull, a spiral valve intestine, and absence of scales. Other extant non-teleost fish include sharks, bowfin fishes, and gars. There is evidence that fish are capable of learning by operant conditioning (Salzinger et al., 1968 and Hogan, 1967) even though the literature is not as extensive for fish as it is for birds and mammals. Previous research conducted in Dr. Joseph Pear's fish lab has obtained confirming evidence that some fish are capable of operant learning (e.g., Hunter, Pedreira, & Pear, 2018; Hurtado-Parrado, Acevedo-Trianac, & Pear, 2018). Furthermore, research by Cook, Fonti, La Fleur, Martin, Martsynkevych, Summers and Pear (2018) found in one juvenile lake sturgeon

that darkness was an effective reinforcer on both CRF and FR schedules of reinforcement. Their findings support the viability of continuing research for lake sturgeon operant learning and using darkness as a reinforcer.

The present study applied operant conditioning principles using a custom-built automated video-tracking system (VTS) to monitor the subject's spatial location, produce a response-feedback stimulus (RFS) and darkness automatically upon entry into a specified target area, where darkness was a reinforcer. The RFS was an auditory cue to the subjects that established an association between entering the target area and receiving darkness. Meyer et al. (2010) determined that lake sturgeons can hear and appear to have similar best frequencies to teleost species having a best frequency distribution between 50 and 400Hz (p. 1574). [1]

The aim of the present study was to add to the literature regarding operant conditioning principles by demonstrating further that lake sturgeons can learn when placed on an FR schedule of reinforcement. Additionally, the present study expanded on the findings of Cook et al. (2018) by replicating their findings with three new juvenile lake sturgeons as well as improving the control of the experiment. The control of the experiment was improved by adding a discriminative stimulus. A *discriminative stimulus* is "a stimulus in the presence of which a response will be reinforced" (Martin & Pear, 2015, p. 317).

Hypothesis

I hypothesized that when darkness is used as a reinforcer for lake sturgeons the behaviour of entering a target area to produce an RFS paired with darkness on an FR reinforcement schedule would produce an increase from operant level (frequency of responding under baseline conditions) for the reinforced target area. Additionally, I expected decreased activity in the non-reinforced target areas compared to operant level. I developed this hypothesis based on (1) the

[1] See Appendix E for a list of the abbreviations used in this thesis.

previous research that I conducted on lake sturgeon learning (see Cook et al., 2018); (2) Baum's theories regarding behavioural evolution; (3) lake sturgeon behavioural ecology; and (4) the principles of operant conditioning.

Reinforcing a subject's spatial location resembles the use of an operandum with rats and pigeons to produce a reinforcer. This experiment therefore provided a means of relating operant learning in lake sturgeons to operant learning in mammals and birds. For example, I expect that by using an FR schedule of reinforcement I should observe a break-and-run pattern in the cumulative record similar to that observed in mammals and birds exposed to and FR schedule of reinforcement (Ferster & Skinner, 1957).

Method

Subjects

Three experimentally naïve lake sturgeons (referred to as Cheese, Mac, and Big) were obtained from an available research pool where the subjects were maintained in a 45-gallon shared tank by University of Manitoba Biological Sciences Animal Care Personnel at the Fort Garry Campus.[2] The subjects were housed with other lake sturgeons that were used for other research projects conducted in the same lab as the present research. The subjects were selected based on (a) color, (b) size, (c) availability in the research pool, and (d) health. With respect to color, the subjects were dark with light spots. The subjects had to be dark to be reliably tracked by the three-dimensional video-tracking system (VTS) that was used during experimental sessions (described below). The subjects were juvenile (approximately 1 year of age). Each subject was small enough in length (see below) to ensure that their anterior and posterior ends were not in two target areas simultaneously but large enough to track reliably. The sex of the subjects could not be determined because the subjects were too young. (For convenience, the

[2] I thank Dr. Gary Anderson for the use of these fish in this research.

pronouns he and his will be used to refer to the subjects.) See Figure 1 for a picture of a lake sturgeon similar in appearance to the ones used in the present research.

Cheese. Cheese was approximately 70 mm in length from his rostral to caudal end. Cheese was used for 12 sessions (all NFB, described below) before being euthanized. Cheese was euthanized due to lack of appetite resulting in poor health. Length at death was not measured; however, after only 12 sessions his length was assumed to still be approximately 70 mm.

Mac. Mac was approximately 120 mm in length from his rostral to caudal end. Mac was used for 72 sessions and was euthanized due to lack of appetite resulting in poor health. Mac was used for NFB, DSB, RFSB, reverse to DSB, FR 1, FR 2 and FR 3 phases (described below). During FR 3 was when his behaviour appeared to be affected by his health due to uncharacteristic swimming behaviour such as swimming in small circles in the center of the experimental tank (ET) and very slow swimming within the ET. Postmortem was conducted and the results were inconclusive. Mac's length at death was 135 mm.

Big. Big was selected to replace Cheese in the experiment. Because Big was obtained after the experiment had begun an initial measurement of his length was not collected. It was estimated that Big's length was approximately 140 mm at his introduction to the experiment. In appearance, Big was thicker, had fully fanned fins and was a strong swimmer, which suggested he was a healthy subject. Big was used for NFB, DSB, RFSB, FR 1, FR 2, FR 3, and FR 4 (described below). At the end of the experiment Big measured approximately 155 mm in length.

Home tank (HT). The subjects' HT was a 45-gallon flat-pan tank held off the ground by legs. The tank had a corrugated plastic lid that kept the subjects in darkness with the exception of a few holes. One hole in the lid allowed fresh water to continuously pour into the HT. The water

temperature was 16°C (±1°C). Another hole allowed some light to enter the HT. The fish were fed twice a day by University of Manitoba Biological Sciences Animal Care Personnel at the Fort Garry Campus.

Ethics

Ethical approval for the research was obtained from the Fort Garry Campus Animal Care Committee of the University of Manitoba (approval protocol number: F16-025).

Apparatus

Figure 2 shows the experimental apparatus consisted of: (a) an experimental tank (ET), (b) four work lights, (c) two speakers, (d) metal scaffolding, (e) a white platform, (f) two cameras, and (g) video camera. These items are detailed below. Figure 3 shows an overhead view of the ET with four target areas (TA, TB, TC, and TD) placed as virtual cylinders by a custom-made VTS software to register target contacts. These target areas were marked with white paint underneath the ET for manual recording purposes. Each target cylinder had a radius of 100 mm. In addition, two speakers provided a response-feedback stimulus (RFS) in the form of a click ("metal bat hitting a ball") sound that occurred upon every response on the reinforced target area. The whole apparatus sat on a platform adjacent to a scaffold that housed two video cameras (described below) and connections to all the computer components including the VTS and associated program called "Fishcamp" (described below).

(a) Experimental tank (ET). All sessions were conducted in an ET measuring 195 mm high × 405 mm long × 405 mm wide filled with dechlorinated water to a depth between 100 and 110 mm. The water temperature of the ET was adjusted to be the same temperature as the subject's HT, within ±0.5°C, by adding dechlorinated water as needed prior to each session. Cold water was obtained from a departmental walk-in fridge; heated water was obtained from a lab-

based electric kettle. Heated water was only needed if too much cold water had been added. All HT and ET temperature readings were recorded. Since the same ET was used for other fish experiments, water in the ET was removed after each session and the tank dried with a paper towel. This was done to minimize contact with pheromones from other subjects and to prevent any spread of infection or disease. The bottom of the ET was made of clear glass, the top was open, and the sides consisted of frosted glass. The thickness of the glass measured 6 mm. The purpose of the frosted glass was to prevent the visual environment external to the ET from influencing the subject's behaviour. The tank sat on a white platform for the purpose of using brightness contrast to track the subject.

(b) Lights. Four 250W halogen work lights manufactured by Globe Electric Company Inc. were mounted to the steel frame of the experimental apparatus. Each work light was angled to shine on the opposite top edge of the experimental tank to provide 360° coverage of light in the ET.

(c) Speakers. Two Logitech speakers were positioned on the white platform the ET sat on and faced the front of the ET. The two speakers were angled towards TA and TD (see Figures 2 and 3). The speakers were used to present the RFS during response-feedback stimulus baseline (RFSB) and FR sessions upon entry into the reinforced target area (the RFSB phase is described below). The speakers operated in conjunction with Fishcamp and the VTS. The speakers produced the RFS when the subjects responded to their reinforced target area (determined after NFB) during RFSB and FR sessions.

(f) Cameras. The cameras used by the VTS were two Panasonic WV-BL 200s manufactured by Matsushita Communications Industrial Co., Ltd. Both cameras were mounted to the white steel frame directly above the ET (see Figure 2). The cameras were 304.80 mm apart

and approximately 1397 mm from the lens to the bottom of the ET. The cameras were angled towards each other at a combined angle of 14° and were connected to a SHARP 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 provided a real-time video view that allowed for the observation of the subjects responding while the session was in progress; it also allowed alternation between the views of the two cameras.

(g) Video camera. A Panasonic HDC SD40 video camera was used to visually record each session. This camera was attached to a tripod and pointed in a downward angle so that the lens captured each session from overhead. The tripod sat on the platform the ET was on. The tripod and camera were located outside the ET between the wall of TA and TD (see Figure 2). The video camera did not interfere with the VTS (tripod was covered with white shower curtain) and was not visible to the Panasonic cameras used in conjunction with Fishcamp and VTS.

Fishcamp & the video tracking system (VTS). The VTS defined the four virtual cylinders in the four corners of the ET (see Figure 3). The VTS also recorded the 3-D position of the fish 10 times per second during sessions. The VTS was a custom-made system consisting of the two Panasonic WV-BL 200s cameras mentioned above, a circuit board connected to an IBM XT computer, a SHARP television monitor, and a Dell Intel (Intel Core 2 Quad) computer with Windows XP, and a LG monitor. The computers also contained two pieces of software for collecting and analyzing the data received by the IBM XT computer from VTS. The two pieces of software used to analyze the data will be V2001 and Fishcamp. V2001 and Fishcamp are custom-made programs designed for Dr. Pear's lab.

Fishcamp recorded: (a) the occurrence of contacts with the four computer defined target locations (i.e. TA-TD) as shown in Figure 3; (b) the occurrence of the RFS; (c) the occurrence of

tracking errors (i.e., momentary loss of tracking by the VTS); (d) the coordinates of the location of the tracked object 10 times per second; (e) the turning off of the work lights (reinforcement); and (f) the length of time the subject was in a designated target area. A data file was created by Fishcamp documenting the above-mentioned information, which was used for data analysis. The target response locations were situated in each of the four corners of the ET (see Figure 3). In order for a response to be registered by Fishcamp, the subject had to enter the virtual cylinder. The subject then had to leave the virtual cylinder and re-enter it for Fishcamp to register another response. However, if the subject remained in the reinforced corner after the RFS had expired, its first movement was registered as a contact by Fishcamp.

Procedure

Sessions. Experimental sessions were conducted 4-5 days a week. Sessions were 30 minutes long. Time of day of each experimental session was recorded. Each session began by the researcher preparing the equipment for use. This entailed (1) turning on the computers, (2) measuring the HT water temperature and making the ET in equilibrium with the HT (±0.5˚C of HT temperature), (3) loading computer programs to prepare the appropriate parameters of the session, (4) preparing the visual observation data sheet for recording, (5) turning on the video camera for recording the session, and (6) transporting the subject from their HT in a plastic container filled with water and placing him in the ET. During sessions, the Dell Intel computer that contained the Fishcamp program was set up by selecting Fishcamp and opening the data file for the appropriate subject. The session parameters were preprogrammed for each subject and not required to be inputted each session. When the subject entered a target area Fishcamp recorded a response for that target. A response was defined as any portion of the subject's body crossing over the boundary of the target area. Please see Appendix A for full definition of response

requirements. Interobserver agreement (IOA) was used to ensure reliability between observers. To record responses, the researcher and an observer (who provide IOA measurements) relied on a live video feed during sessions from the television monitor in the room adjacent to the ET. Alternatively, if a second observer could not physically be present during a session then IOA of a video recording was randomly selected at a later time to meet IOA standards (described below). Individuals who participated as an IOA were other members of the lab who had previous experience to conduct IOA within the experimental parameters; their participation was voluntary.

After the completion of a session, Fishcamp automatically saved the data and the program was closed. Observational notes were kept for each session and if any technical challenges arose the session was terminated, and the subject returned to its HT. During all experimental phases, subject retrieval and clean up protocols were followed as stated in Cook (2018). A complete copy of *Dr. Joseph Pear's Basic Animal Research Lab Manual* will be made available upon request. Please see the Appendix B for fully detailed procedures used for experimental sessions.

Measures. Each session's data was automatically recorded by Fishcamp. At the end of the session the data was saved as a DAT file to the Dell computer. The data in the DAT file for each session was then used for data analysis such as making graphs and *swim maps* – plots of a fish's 2-dimensional swimming pattern from an overhead point of view (described below). Data was also manually recorded via visual observation on data collection sheets that included: the session number, the date, the subject's ID, the experimental condition, the HT temperature, the ET temperature, the experimenter's initials, and the individual who completed the IOA initials if an IOA was completed on that session (a copy of a data collection sheet can be found in Appendix C). Data collection sheets also included a schematic that resembled the ET from a top-

down perspective where “responses” were recorded next to the appropriate target area. A mark was made for each response in a target area based on specific guidelines that can be found in Appendix A. After the session was completed, the responses were totaled for each target area and then transferred to an excel document for analysis. The data collection sheets also included space for written observations regarding the subject’s behaviour before, during, and after the session, swim patterns, and environmental factors, which may have contributed to a subject’s unexpected behaviour. These data were kept in an organized binder for reference when analyzing the data and writing the results and discussion sections.

At least 30% of all experimental sessions received an IOA for each phase with 80% or more agreement between observers. IOAs with 80% or more agreement between observers were required to prevent bias by the researcher that may have influenced the reported observed and quantitative data. In other words, the IOA was used to increase the reliability and accuracy of the observed and quantitative data. If the percent of IOA was below 30%, additional IOA of video-recorded sessions was done at random to maintain a minimum of 30% IOA. A Pearson correlation (*r*) was obtained using Microsoft Excel to ensure that the visually observed data and the Fishcamp data were comparable as well as to ensure the comparability of the IOA between visual observations.

Experimental Design

This experiment was classified as a multiple-baseline-across-subjects design. In this experiment, the intervention was an FR schedule of reinforcement where darkness was the prospective reinforcer for two of three lake sturgeons. The experiment consisted of the following phases: (1) no-feedback baseline (NFB) phase; (2) discriminative stimulus baseline (DSB); (3) a

response-feedback stimulus baseline (RFSB) phase; and (4) fixed-ratio phase (FR n), where each FR was a sub-phase of the intervention.

NFB. The purpose of the NFB phase was to determine the subjects' normal behaviour while in a 30-minute session in the ET – i.e., its behaviour in the ET when there are no programmed consequences for its behaviour. This baseline phase allowed the experimental subjects to become accustomed to the ET. It also allowed observers to draw clear conclusions about any observed changes in behaviour as the baseline acted as a record for the subjects' behaviour without exposure to experimentally manipulated stimuli. During baseline sessions the subjects could swim freely throughout the ET without manipulating any stimuli. All three subjects completed this phase.

Twelve experimental sessions were conducted with Cheese before he was euthanized due to reasons related to his health (see Table 1a). The 12 experimental sessions that were conducted were all NFB sessions. Cheese's results were included for the purpose of control; Mac was used simultaneously with Cheese. Mac began its RFSB phase while Cheese was still in NFB (both session 10) providing multiple baseline control and increasing the internal validity of the research.

DSB. To distinguish the target that was selected to become the reinforced target for each subject a prospective discriminative stimulus (S^D) was introduced (see definition of discriminative stimulus on p. 11). The reinforced target area was determined after the completion of the NFB phase and was the target area that was visited the least frequently. The S^D that was selected was a Canadian one-dollar metal coin (loonie) because the VTS could not track the metallic surface. The purpose of this phase was to act as a control measure by demonstrating that the subject could distinguish the target with the S^D from the other three identical targets. The S^D

was demonstrated to be effective by the disruption to the subject's swim pattern when the S^D was introduced. Furthermore, due to the S^D not being reinforced the subjects habituated to the S^D and demonstrated no preference or reinforcing function. Subjects Mac and Big completed this phase.

RFSB. During the RFSB phase the RFS was introduced to each subject's reinforced target area in addition to the S^D. Subjects Mac and Big completed this phase. The purpose of this phase was to act as a control measure by demonstrating that each subject did not prefer the RFS. Note that following the RFSB phase Mac went through a second DSB phase to remove preference for the RFS before progressing to the FR phase.

FR. The purpose of the FR phase was to determine whether darkness can be used as a reinforcer to operantly condition the subjects to enter their designated target area a predetermined number of times before being reinforced with darkness. This number depended on the FR sub-phase that the subject was at and only increased after stable behaviour was observed according to the stability criteria.

The stability criterion for moving from sub phase to the next was that stable behaviour was observed after a minimum of 3 sessions. Stable behaviour of a subject was observed in the form of consistent target area responses or relative frequency. This consistency was defined as all values falling within a range of 10%. For example, to determine if behaviour was stable, I ordered each target areas frequency ratio values from smallest to largest and subtract the smallest value from the biggest value to determine the range. If the range is 10% or less, I was able to confidently state that the behaviour was stable and progress to the next phase or sub phase. To reiterate, if the frequency ratio values for TA for sessions 1, 2 and 3 were 10%, 15% and 12% respectively, the range is 5% (largest value subtract the smallest value) meeting the stability

criteria to move to the next phase or sub phase.

Data analysis

Swim maps and scatter plots[3]. Two-dimensional contour maps of each subject's location within a given session or "swim maps" were generated using the program R from the data in the DAT files produced by Fishcamp and VTS. R utilized the XY coordinates provided in the DAT file that specified the subject's location every tenth of a second within the ET (The syntax that was used to produce the contour maps can be viewed in Appendix D). Essentially what the syntax in R did to the DAT file was divide the x-y plane of the ET into a grid of cells (or bins) of a certain size. The number of XY data points falling within each bin was summed, which yielded the amount of time spent in each bin, since each data point was one tenth of a second of time 100 data points equals 10 seconds of activity.

The lines on a swim map are referred to as isolines (line of equal elevation) -- all points within the isoline represent the same amount of time. A steep change in time spent in an area is represented by closely spaced isolines on the map and a gradual change is shown by widely spaced isolines. It can be determined how much time a subject spent in specific area by looking at the labels of the isolines to see if they are increasing or decreasing. The more time spent in one area the higher the number of the isoline. The less time spent in one area the lower the number of the isoline. For example, a isoline with the number 10 would indicate less time was spent at that location than an isoline with the number 60. Swim maps allowed changes in the subjects' location to be observed and compared from session to session and from phase to phase.

Swim maps are not as intuitive as the scatter plots, but the swim map gives more detailed information about the amount of time spent in various areas of the ET during a given session. Therefore, in addition to the swim maps, the corresponding scatterplots were included for

[3] I thank Wayne Chan for his expertise and guidance in producing the swim maps.

reference. Every dot on the scatterplot was the subject's location every tenth of a second (except when tracking errors occurred, which was less than 5% of the time) and demonstrated the actual location of the subject during the entire session. The scatterplots were difficult to read due to the duration of the session producing a very large number of data points thus, the swim maps are simplified, clearer views of the scatterplots.

Graphs. Line graphs of the number of target area responses and their relative frequency for each subject was constructed based on visually observed data. The graphs were produced using Microsoft Excel. Additionally, cumulative records of the subjects' rate of responding was constructed using Fishcamp data to illustrate the expected break-and-run pattern associated with FR behaviour. Cumulative records were constructed using a custom-made program called Cartesian Graphing created by Barrie Todd for Joseph J. Pear.

Statistics. Pearson correlations (*r*) were calculated for each target area across phases using target area responses from visual observation, IOA and Fishcamp data. The purpose of these correlations was to demonstrate the reliability of Fishcamp and the VTS as well as the reliability of visual observation and IOA. The correlations were calculated in Microsoft Excel.

In addition to Pearson correlations (*r*) the accuracy of Fishcamp and the VTS were examined by calculating the percentage of lit tracking errors across all phases. A lit tracking error occurred when the VTS lost tracking of the subject while the lights were on during a session. The higher the percentage the worse the accuracy Fishcamp and the VTS had at tracking the subjects. The goal was to have a maximum lit tracking error percentage of 5%. Accuracy was important for ensuring accurate swim maps were produced using Fishcamp data.

Results

Interobserver Agreement (IOA)

Cheese. 58% of sessions received observation by a second observer. The overall IOA was 97% where the agreement for each target area was 96%, 96%, 97%, and 96% for targets TA, TB, TC, and TD respectively (see Table 2).

Mac. 39% of sessions received observation by a second observer. The overall IOA was 97% where the agreement for each target area was 96%, 97%, 95%, and 97% for targets TA, TB, TC, and TD respectively (see Table 4).

Big. 50% of sessions received observation by a second observer. The overall IOA was 96% where the agreement for each target area was 94%, 96%, 96%, and 95% for targets TA, TB, TC, and TD respectively (see Table 6).

Pearson's Correlations (*r*)

Cheese. Initially when the experiment was started there was a miscalibration of the VTS and Fishcamp that caused poor tracking at the beginning of the NFB sessions. This produced error in recording responses automatically; thus, only 75% of sessions from Fishcamp were used to produce Pearson's correlations when comparing human observation to Fishcamp data. The correlations between the two human observers were all highly significant ($p < .05$). The correlations ranged from $r = 0.853$ to 0.974 for TA, TB, TC and TD (see Table 3). These results suggested a strong correlation between the observers who completed the IOA as well as high reliability.

When comparing the primary observer's number of responses recorded to the number of responses recorded by Fishcamp the correlations ranged from $r = 0.188$ to 0.760 for TA, TB, TC, and TD (see Table 3) where only TC and TD correlations were significant ($p < .05$). These results suggested weak to moderate correlations between the human observation and Fishcamp.

Mac. Due to the same technical error with Fishcamp that occurred with Cheese during NFB only 78% of Mac's NFB sessions were included in the Pearson's correlations. All of DSB and RFSB sessions were included; 67% of DSB2 were included due to a tracking error that occurred because of the loonie; and 100% of FR 1, FR 2, and FR 3 sessions were included.

The correlations between the two human observers' correlations ranged from $r = 0.992$ to 0.996 for TA, TB, TC and TD (see Table 5). These results suggest a nearly perfect correlation between the observers who completed the IOA as well as high reliability.

When we compared the primary observer's number of responses recorded to the number of responses recorded by Fishcamp the correlations ranged from $r = 0.606$ to 0.819 for TA, TB, TC, and TD (see Table 5). These results suggest strong correlations between the human and computer observed responses as well as high reliability.

Big. There were no technical errors with Fishcamp and the VTS during Big's experimental sessions which allowed for 100% of the Fishcamp data to be used for comparison with human observation data to produce a Pearson's correlations.

The correlations between the two visual observers ranged from $r = 0.953$ to 0.988 for TA, TB, TC, and TD (see Table 7). These results suggested a very strong correlation between the human observers who completed the IOA as well as very high reliability.

Comparing the primary observer's number of responses recorded to the number of responses recorded by Fishcamp yielded correlations that were all large and highly significant ($p < .001$). The correlations ranged from $r = 0.862$ to 0.938 for TA, TB, TC and TD (see Table 7). These results suggest very strong correlations between the visual observation and computer observed responses as well as high levels of reliability. However, the assumption violations of these statistical tests should be noted.

Cheese

During NFB Cheese demonstrated typical NFB behaviour that consisted of swimming the interior perimeter of the ET in a clockwise or counterclockwise manner. Observational notes state that Cheese swam the interior perimeter of the ET in a clockwise pattern during NFB sessions. This typical pattern resulted in Cheese responding approximately equally to each of the four designated target areas. Cheese's consistency in responding was observed through: (1) swim maps and scatterplots (see Figure 4); (2) responses to each target area (see Figure 5); and (3) the relative frequency of responses to each target area (see Figure 6).

The swim maps from NFB sessions visually showed that Cheese mostly swam in close proximity to the perimeter of the ET. Because of this behaviour - moving along the perimeter, there was minimal activity by Cheese in the central area of the ET (see Figure 4). This behaviour became stronger as more sessions were conducted as indicated by the decrease in deviation from the perimeter of the ET (see Figure 4) from session 10 to 12. The first 9 sessions of Cheese's NFB phase were not suitable to produce swim maps because of a miscalibration of Fishcamp and VTS. However, IOA was high within this phase therefore the data was determined to be reliable and accurate.

Typical NFB behaviour is further illustrated in Figures 5 and 6. Figure 5 shows that the number of responses for each target area was relatively constant. This effect is mirrored in Figure 6 where each target area frequency hovered around 25% relative frequency of responding. The consistency at which Cheese responded to each target area suggested that there was no preference for any of the four designated target areas. Figures 5 and 6 also demonstrate that Cheese met the stability criteria. Additionally, Cheese provided control for Mac's progression to DSB as Mac's first DSB session was session 10 while Cheese's session 10 was an NFB session.

After session 12 was complete I was notified by animal care that Cheese was no longer eating and would not likely survive. The decision to terminate Cheese was made.

Mac

During NFB sessions Mac developed a perimeter swim pattern like what was observed during Cheese's NFB sessions (see Figure 4). Observational notes state that Mac swam the perimeter in a clockwise manner as the sessions progressed. There was also notes that Mac displayed emotional behaviour (Pear, 2016, p. 38) initially when introduced to the ET. Emotional behaviour is behaviour that an animal displays when aggravated or frustrated. Mac displayed behaviours best described as rubbing the interior walls of the ET, rapid swimming, and flapping that caused water disturbance. Due to miscalibration of Fishcamp which caused tracking errors over the NFB phase there are no swim maps from Mac's data to illustrate Mac's behaviour. However, IOA was collected and confirmed that the data was highly reliable and accurate. Mac responded approximately equally to each of the four designated target areas which was expected. Mac's consistency in responding was observed in: (1) responses to each target area (see Figure 7); and (2) the relative frequency of responses to each target area (See Figure 8).

As can be seen in Figure 7, the number of responses Mac made on each target area was relatively constant and, as time progressed, the number of responses Mac made for each target area became increasingly stable. This trend was mirrored in Figure 8 where each target area's relative frequency hovered around 25% over the entire NFB phase. However, the relative frequencies of Mac's responding on each target area were closest to 25% beginning at session 6. The consistency at which Mac responded on each target area indicated that there was no preference for any of the four designated target areas. Figures 7 and 8 also demonstrate that Mac met the stability criteria, which provided control for Mac to progress to DSB.

During DSB TB was selected to be the reinforced target area because based on the data in Figure 7 and 8 TB was the target area least frequently responded too. Initially when the S^D (loonie) was introduced, I observed predator inspection (Pear 2016, p. 318) by Mac. Predator inspection is approaching a potential predator apparently to determine if the potential predator is indeed a predator. Predator inspection resulted in a distinct approach and avoidance pattern where Mac swam up to the stimulus and swam away as well as avoided the unknown stimulus. In Figure 9, it is not clearly seen whether predator inspection occurred; however, Mac's activity was widespread throughout the ET with no distinct pattern which was not indicative of typical NFB behaviour. In conjunction with this, visual observation revealed a variety of behaviours characteristic of predator inspection, such as swimming directly toward the loonie and at the last second changing direction to avoid it or circling it. As the DSB phase progressed, as can be seen in the bottom of Figure 9, Mac resumed swimming in the same pattern as during NFB which suggested habituation or adaption to the loonie. Additionally, it can be seen in Figures 10 and 11 that Mac's number of responses and relative frequency of responding on TB did not change from NFB as determined by visual observation. By the end of the DSB phase TB was still the least frequently responded to target area.

RFSB introduced the RFS that was elicited automatically when Mac responded to TB; the loonie was still present in TB. It was expected that if the RFS had no reinforcing value that the swim maps and graphs should resemble those from DSB. For Mac this was not the case. It can be seen in Figures 12, 13 and 14 that Mac preferred TB when the RFS was introduced.

The swim map of session 15 (see Figure 12) shows that compared to session 14 of the DSB phase there was a decrease in Mac's activity along the walls between TA and TD as well as TC and TD. There was also an increase in activity along the wall of TB and TC with increased

contours in TB. As the RFSB phase progressed to session 28 the swim map showed that almost no activity was occurring in the region of the tank between TA and TD but almost exclusively between TB and TC with the highest concentration seen as a black circle in TB.

Observational notes stated that initially, Mac showed an avoidance for TB which quickly changed to a preference which was observed stopping over the loonie for hundreds of seconds. Additionally, there were pauses that lasted over 100-s that occurred in the other three target areas. These observations were further confirmed in Figures 13 and 14. In Figures 13 and 14 it can be clearly seen that Mac responded the most frequently to TB and TC as the RFSB phase progressed. Particularly in Figure 14 where approximately 35% of responding occurred in TB by the end of the phase. Much higher than what was expected if the RFS had no effect.

Due to the unanticipated results from the RFSB, a second DSB (DSB2) phase was added to the experimental design for Mac. The purpose of the DSB 2 was to extinguish Mac's responding to TB. For this phase the RFS was removed but the loonie remained in TB. Over the DSB2 phase Mac's number of responses to TB did decrease to lower than the previous number of responses from the first DSB phase. The changes in Mac's responding were observed in Figures 15, 16, and 17.

The swim map from session 29 shows the first session where the RFS was removed (see Figure 15). Mac's activity was not as concentrated in TB as it was during session 28 and Mac's behaviour was more widely dispersed with a higher concentration of activity in TC. It was observed that Mac would swim between TB and TC and stop in TC. Initially, Mac demonstrated emotional behaviour when the RFS did not occur after entry in TB suggesting Mac was aware of the consequence of responding. By session 43 Mac's swim map appeared to resemble the swim map of from the first DSB phase.

The DSB2 phase lasted 15 sessions (29 to 43, see Figures 16 and 17). The preference for TB and TC appeared to be extinguished by session 33 (see Figure 16) since all four target areas were responded to equally on that session. As expected, each target area was responded to 25% each for session 33 (see Figure 17). But in session 34 there was a steep increase to roughly 35% relative frequency of responding for TB. The elevated relative frequency of responses for TB continued until session 39 where responding to TB finally appeared to extinguish.

After stability was attained for DSB2 Mac progressed to FR 1. During FR 1 every response to TB was reinforced with 10-s of darkness that co-occurred with the RFS; the loonie was still present in TB. In the swim maps for FR 1, like previous phases the first FR 1 session produced a broad swim map with little concentration of activity, there were localizations of activity surrounding TB though (see Figure 18). As time progressed and we examine the last FR 1 session we can see that activity within the session localized around the interior perimeter of the ET with more activity closest to TB.

FR 1 lasted 14 sessions (sessions 44 to 58, see Figures 19 and 20). When examining the number of responses for each target area (Figure 19) it was observed that generally TB had the highest number of responses within a FR 1 session. There was some variability in the number of TB responses across sessions. The number of responses for TB recorded by human observer appeared to range between 60 to 80 responses in a session whereas TA, TC, and TD highest response across sessions is 60 responses in a session. This suggested that there was some reinforcing value when the RFS and darkness were introduced. These observations were mirrored in Figure 20 where the relative frequency of responses generally hovered around 25% for TA, TC, and TD but was much greater for TB.

The cumulative records of Mac's responses for FR 1 (Figures 21 and 22) demonstrated that over the FR 1 phase there was an increase in the rate of responding as the slope of responding increased from session 44 to session 58. It can be seen in Figure 21 that the curve of responding over the session appears to have a slight negative acceleration between responses and time. What that means is that initially the rate of responding occurred quickly and with very little pauses between responses however as time progressed the length of pauses increased following responses, which suggests that the novelty of the new stimulus wore off and that Mac began to settle into a more maintainable rate of responding.

Responding during the last FR 1 session was linear, Mac demonstrated a very consistent responding to TB over the entire session with the exception of a few pauses. This linear pattern is further notable by examining the consistency between the instances of reinforcement for Mac.

When stability was reached during FR 1 the experiment progressed to FR 2 which required Mac to enter TB twice before receiving darkness. The loonie was still present in TB and the RFS occurred with each response. The trends in responding for each target area varied more systematically and the number of responses for each target area did not fluctuate as much compared to FR 1. During FR 2 it was obvious that TB was the most frequently responded to target (see Figure 23). During the first FR 2 session, session 59, the shift in activity can be seen by the increase in activity between TB and TC and decrease between TA and TB. As well as the amount of activity in the center region increased slightly (from 10 contour to 20). This increase in activity in the center region is consistent with previous phase switches as the change in consequences of responding previously increased activity in the center region. By the last session of the FR 2 phase activity in TB increased and activity around the interior perimeter increased.

In Figure 24 and 25 it is obvious that TB was the most responded to target area across sessions of the FR 2 phase. Though at times TC was close in the relative frequency of responses TB was almost always the highest percentage (Figure 23). These figures provide explicit evidence that Mac preferred TB over the other three target areas which if there had been no preference should have been responded to equally. This suggests that darkness had reinforcing value to Mac.

The cumulative records of Mac's responses for FR 2 (Figures 26 and 27) demonstrate that over the FR 2 phase there was an increase in the rate of responding as the slope of responding increased from session 49 to session 67. It can be seen in Figure 26 that the change from FR 1 to FR 2 stunted responding which was expected as Mac was now required to respond more to receive the same number of reinforcers as earned previously. For the first 300-s of session 59 the rate of responding was linear and there were almost no pauses between responses. The next 600-s yielded very little responding with lengthy pauses in between responses. The last 900-s demonstrated a negative acceleration in the rate of responding. My interpretation of Mac's responding during session 59 is that the first half of the session illustrates Mac's contact with the contingency that darkness no longer occurred after every response, resulting in the lack of responding for 300-900-s.

Responding during the last FR 2 session (session 67) demonstrates two trends. For the first 700-s a very consistent and linear rate of responding occurred, and reinforcements were earned roughly every 20-30-s. After 700-s the rate of responding decreased approximately every 50-s. The two trends considered together resulted in a negative acceleration in responding. Perhaps this decrease in responding over the session was due to fatigue or decline in health. Further research would be required.

Four FR 3 sessions were run with Mac; however, the data was excluded from analysis because of the lack of responding and unusual behaviour that was observed. The lack of responding and unusual behaviour were brought to the attention of animal care who determined that Mac was no longer healthy. Due to Mac's poor health the FR 3 sessions that were conducted were believed to be a poor representation of Mac's performance as the sessions were conducted within the week before Mac was terminated.

Big

Big's NFB phase consisted of seven sessions. During NFB sessions Big swam in close proximity to the interior perimeter of the ET (see Figure 28) – as was typical of the other fish – and did so in a clockwise manner as was found by visual observation. Additionally, visual observation notes state that Big displayed some emotional behaviour when initially introduced to the ET. These visual observations I believe are supported by Big's NFB swim maps. During session 1 it was very clear that Big swam the interior perimeter of the ET spending most of the time between target areas TB and TC as well as TC and TD. Emotional behaviour may be the cause for such dense areas of activities as well as the small amount of perimeter activity that extended slightly into the center region of the ET. It can be seen in the swim map of session 7 that Big's activity was more evenly dispersed around the interior perimeter of the ET as well as the contour closest to the center region was more circular and less jagged, suggesting a smoother less disturbed swim pattern.

Examination of the number of responses Big made to each target area (Figure 29) shows that the progression from session 1 to 7 reduced the range in the number of responses each target area had. In other words, by session 7 Big was responding to each target area roughly the same number of times. This observation was reflected in Figure 30 of the relative frequency of

responses to each target area where, by session 3 Big was already reaching the stability criteria which only became more stable by session 7. With the stability criteria reached by session 7 Big was progressed to the DSB phase. Since during NFB TA was the least responded to target area it was selected as the target area that would eventually be reinforced.

The DSB phase consisted of 12 sessions (8-19). During the DSB phase the loonie was introduced into TA. Initially when the loonie was introduced it had little effect on Big (Figure 31, session 8) it simply seemed to ignore it. By session 10, according to visual observation notes Big appeared to be more interested in the loonie. But by session 19 Big's swim map resembled an NFB session.

When examining the number of responses to each target area across DSB sessions (Figure 32) it was more obvious that Big did notice the loonie was introduced. When comparing Figure 29 and 32 it can be seen that the addition of the coin was followed by increased variation in the number of responses to each target area. In Figure 29 the trend for the number of responses to TA was flat and shows almost no variability. In Figure 32 though there is an initial decrease in the number of responses to TA (session 9) followed by an increase (sessions 10-13) followed by another decrease (session 14 and 15) and increase (sessions 16 and 17) after which Big's responses on TA appeared to stabilize. By session 17 the number of responses to TA appeared to be similar to the number of responses that were observed in the last three NFB sessions demonstrating stability in Big's behaviour.

The disturbances in Big's responses to each target area were further shown in Figure 33. The disturbances that were illustrated in the relative frequency suggest that Big was affected by the loonie as the relative frequencies should have been much closer to 25% as they were during NFB. Such deviations in TA and TC relative response frequencies showed that the loonie

influenced how much or how little Big responded to each target area. Since TA was consistently the lowest and lower than the NFB phase it supports the notion that Big was affected the loonie. The last 4 sessions of DSB met the stability criteria and warranted progression to the RFSB phase.

The RFSB phase consisted of seven sessions. During the RFSB the RFS was added to TA in addition to the loonie. The RFS was intended to be an auditory cue that signaled to Big that a response had been made. Introduction of the RFS during session 20 resulted in only a slight decrease in activity around TA but quick glance at the swim map there appeared to be no change in the swim pattern. (see Figure 34). This lack of change suggested that Big was ambivalent towards the RFS. By session 26 the amount of activity in TA increased again to levels that occurred during session 19 of the DSB phase.

Figure 35 illustrated the number of responses Big made to each target area across the RFSB phase. It can be seen that initially Big's behaviour continued to be stable; however, by session 22 interest in TA steeply increased to the highest number of TA responses Big had made to that point. Then by session 24 responding on TA dropped back down to only 50 responses. After this the number of responses stabilized. These fluctuations suggested that the RFS had an impact on Big's behaviour as the number of responses made to TA during session 22 had not been seen previously. The visual observation notes for session 22 state that there were some technical difficulties with the delivery of the RFS initially. The technical difficulties appeared to result in Big displaying emotional behaviour and increased activity in TA. The increases and decreases in the relative frequency of responding was not as prominent during RFSB phase as it was during DSB phase. All sessions except session 22 were relatively stable across the RFSB

phase. This suggests that all though the RFS had an impact on Big's behaviour the response to the RFS was not as altering as the S^D was.

The FR 1 phase for Big was 17 sessions. During FR 1 the reinforcer, darkness, was introduced to TA in addition to the S^D and RFS. Initially Big did not respond very much, indicating that darkness may have initially been aversive to this subject. This can be seen in Figure 38 where the number of responses to TA decreased to the lowest number of responses within a session up to session 31. However, after session 31 the number of responses Big made to TA began to increase and become the most responded to corner for almost all the remaining sessions of the FR 1 phase. These observations were mirrored in Figure 39 which by session 35 nearly 50% of the responses made by Big were to TA.

The swim map of Big's session 27 was not entirely clear (Figure 37). The perimeter swim pattern was still evident and there was less activity surrounding TA compared to session 26 of the RFSB. The swim map of session 35 was a different story. There was a high concentration of activity surrounding TA and the center region of the ET. By session 43, the variability of the Big's swim map from session 35 appeared more refined and entry into TA appears to come from the direction of TB.

The cumulative records of FR 1 sessions 27, 35, and 43 were constructed to illustrate the rate of responding and reinforcement that occurred and the change that occurred over the phase (Figures 40, 41 and 42). When darkness was introduced as a reinforcer during session 27 Big's responding was linear and constant. The rate of responding was initially gradual but increased in frequency at approximately 550-s. By session 35 the rate of responding had increased and was steady and constant. The rate of reinforcement had also increased such that Big was receiving reinforcement approximately every 15-s. Unexpectedly during session 43 Big showed two

different patterns of responding. For the first 900-s there were two periods of steady linear responding separated by two periods of little responding. The latter 900-s demonstrated linear constant responding that looked similar to session 35.

The FR 2 phase for Big lasted 8 sessions. Big was reinforced every two responses it emitted on TA. Overall, there was an increase in the number of responses for each target area which was expected because of the increased contingency for the reinforcer and the clockwise swim pattern that Big developed during FR 1 (see Figure 44). Interestingly, there was a decrease in the number of responses for TA for the first three sessions followed by an increase where TA became the most responded to target area. These observations are reflected in Figure 45 whereby the end of the FR 2 phase TA is being responded to over 30% of the total number of responses.

The swim map of session 44 of the FR 2 phase (top of Figure 43) shows that Big's behaviour became more refined relative to session 43 of the FR 1 phase. In session 44 swim map there was less activity in the center region of the ET and more in the interior perimeter of the ET. By session 51, the last FR 2 session, the contours increased in the area surrounding TA and the high concentrations between TB and TC and TC and TD has decreased. This suggested a greater allocation of activity being spent on responding to TA.

The cumulative records for both sessions 44 and 51 of the FR 2 phase for Big (Figures 46 and 47) are very similar with the rate of responding during session 51 being a little more consistent. In both sessions rate of responding started slowly and increased forming a positively accelerated trend. Consequently, the rate of reinforcement stabilized later within each session. During session 44 the rate of reinforcement appeared to have become steady around 1000-s where reinforcement is being earned approximately every 30-s. During session 51 reinforcement

appears to become steady around 600-s occurring every 30-s approximately and again increases around 1200-s and appears to be occurring every 20-s approximately.

FR 3 sub-phase lasted 8 sessions. Across all target areas there was an increase in the number of responses compared to the FR 2 sub-phase (Figure 49). A similar trend as in FR 2 in the number of responses was observed. Initially, the number of responses to TA decreased slightly followed by an increase in the number of responses by session 55. However, during FR 3 TA was the most responded to corner across sessions. By the end of the phase TA was generally responded to about 100 times per session. This is reflected in the relative frequency of responses as the relative amount of responses to TA was about 30% across the entire phase (Figure 50). The spacing between each target area when looking at Figure 50 demonstrated the observation that Big continued to swim in a clockwise pattern in the ET during the FR 3 phase.

Figure 48 illustrated Big's activity in the ET across the FR 3 sub-phase. The first session, session 52, it was clear that Big was swimming the perimeter of the ET. The increase in the FR caused a change in Big's activity as there was much more contours all over the ET compared to session 51 of the FR 2 sub-phase. There was increased activity surrounding TA as expected with the increase in the FR but there was also an increase in activity between TB and TC as well as TC and TD. By the last session, session 59, Big's behaviour settles again and Big was swimming only the interior perimeter of the ET again.

Figure 51 illustrates Big's response rate and reinforcement rate for TA during session 52. When the new FR was introduced Big was initially slow to respond however by 800-s Big resumed frequent and steady responding to TA as denoted by the steady stepwise function of the responses and the linear pattern. After 800-s the reinforcement rate also became steady and it appeared that Big was receiving reinforcement approximately every 30-s. In Figure 52 Big

responded steadily across the entire session as denoted by the linear and stepwise pattern of the responses. The trend for reinforcement appears to be the same where Big received reinforcement approximately every 30-s.

FR 4 also lasted 8 sessions. There was an increase in Big's overall responding to TA which was expected because one period of reinforcement required four responses in TA. TA was consistently responded to the most across the FR 4 phase and showed similar trends in TA as the previous FR phases (Figure 54). The relative frequencies of this phase for TA did appear to decrease slightly to just under 30% (Figure 55). This slight decrease may be due to the increase in the clockwise swim pattern (see Figure 53) where there is a greater number of contours over the entire ET but most greatly around the interior perimeter as illustrated by dark black areas on the contour maps of session 60. By session 67 Big's behaviour normalized back to no activity in the central region of the ET and the swimming was just around the interior perimeter.

Figure 56 showed Big's rate of responses for session 60 (the first FR 4 session) and it was clear that Big's rate of responding was constant because the trend was linear with very few plateaus in responding. Big's rate of reinforcement did increase to approximately every 50-s which was expected due to the increase in the FR schedule. By session 67 (Figure 57) Big's rate of responding on TA increased as the slope of the linear pattern became steeper. Notably there was one long plateau in responding at 900-s. Possibly a break due to fatigue, but that is a subjective statement. When examining the rate of reinforcement, it appears that Big was receiving darkness approximately every 40-s, which was an increase compared to session 60.

Discussion

IOA

The overall IOA across the 3 subjects was over 95%. In addition, IOA had minimal variability because the differences in the number of responses recorded for each target area by two different observers differed only by a few responses, if any, for a given session. The results of the IOA provide confidence that the number of responses recorded by human observation was very reliable and accurate.

Pearson's correlations (*r*)

I examined the correlations between the number of responses recorded by the primary and secondary observer as well as the primary observer and Fishcamp for each target area for each subject. The Pearson's correlations were calculated to determine the reliability of the data collected.

The correlations between human and Fishcamp recorded responses for Cheese were weak to moderate. In comparison, the correlations between the two human observers was much stronger and less variable compared to Fishcamp. The same analysis was conducted on Mac and Big's data. For both Mac and Big all the correlations were significant however, when comparing human observers all the correlations were very strong and less variable compared to human versus Fishcamp recorded responses. The correlations between human recorded responses and Fishcamp recorded responses were more variable and only moderate to strong; although still good results. Regardless, these results reduced my confidence in Fishcamp to reliably count responses, so I visually inspected the Fishcamp recorded response data. Upon visual inspection of the Fishcamp recorded response data there appeared to be an issue in that the Fishcamp recorded response values were inflated and did not represent the subject's true number of responses, despite the lit tracking error rate being very low (less than 5%).

Since the correlations of between human observers for all subjects was very strong and the IOA across all subjects was over 95%, I felt that using visual observation data to produce excel graphs from the recorded response was the best option. The human recorded responses showed to be more reliable and accurate compared to Fishcamp recorded responses. However, the data from Fishcamp was still reliable as shown by the Pearson's correlations but the accuracy in recording responses was not as good as human observation.

Since the lit tracking error rate was low, tracking was still accurate which provided accurate data from Fishcamp to produce swim maps and scatterplots. I speculate that the reason Fishcamp could track the subject accurately but not record responses accurately was likely because of the age of the technology in the VTS (see limitations). Or perhaps the definition of a response was too narrow. Finally, Fishcamp data was still used to produce cumulative records despite the above concerns because Fishcamp had an exact record of the time of each response and reinforcer occurred which was necessary to produce the cumulative record.

NFB

During the NFB phase I observed consistent responding (each target area hovered around 25% each, +/- 5%) to each target area with each subject. The consistency in responding was observed in three forms: (1) swim maps and scatterplots, (2) graphical representation of the number of responses, and (3) the relative frequency of responses for each target area.

The swim maps from each baseline session indicated that each subject's activity mostly occurred close to the interior perimeter of the ET. Because of this behaviour – moving around the perimeter – there was minimal activity in the central area of the ET. The swim maps of NFB phases demonstrated that the subjects developed a stable swim pattern around the interior perimeter of the ET and that this pattern occurred in a clockwise direction for all three subjects.

In the graphs of the number of responses for each target area during NFB for each subject there was more variability in the number of responses to each target area observed between each subject. However, when comparing the relative frequencies of responses for each target area the three subjects responding looked similar, especially for later sessions. This observed consistency in three forms suggested that none of the subjects preferred any of the four target areas.

Discriminative stimulus (S^D) baseline (DSB) phase

This portion of the experiment was participated in by two subjects, Big and Mac. Because the subject's eyes were peripheral on the top of their head and the S^D (loonie) was below their bodies, I was not sure if the subjects would show a change in behaviour that would indicate awareness of the new stimuli.

Initially, I observed a change in each subject's behaviour that was most easily noted by the change in the first DSB session swim map compared to the last NFB swim map. Additionally, both subjects showed a disruption in their behaviour initially by displaying predator inspection of the loonie. Both subjects were observed swimming towards the loonie and swimming away in avoidance. The predator inspection behaviour demonstrated by the subjects may be able to explain the fluctuations in the number of responses and relative frequency of responses across the DSB phases. For example, the increases and decreases in responding for Big may illustrate predator inspection when examined across sessions not so much within sessions as observed with Mac. Where decreases in responding would be a session where TA was avoided and increases in responding would be sessions where Big was interested and approached TA.

The initial change in the swim pattern and observation of predator inspection demonstrate both subject's awareness that the loonie was a new stimulus. This suggests that the loonie was a discriminative stimulus at least initially distinguishing TB from the other target areas.

Eventually, both subjects habituated or adapted to the loonie's presence, suggesting that it had no reinforcing or preferred qualities to the subjects. In Baum's terminology, the loonie was not a PIE.

Additionally, Mac received a second DSB (DSB2) phase to extinguish his preference for TB following the RFSB phase. The DSB2 phase yielded preliminary evidence of extinction for the species. Initially Mac showed expected trends in behaviour for extinction, a decrease in responding to TB was observed following the removal of the RFS. Then an extinction burst was observed followed by a final reduction in the behaviour. During DSB2 there was an increase during the first DSB2 session (session 29) in the amount of activity in TA and TD compared to the last session of the RFSB phase (session 28). I speculate that due to Mac's previous back and forth swim pattern between TB and TC the increase in activity seen in session 29 swim map on TC may be due to pausing in TC after entering TB as well as emotional behaviour. The sudden steep increase after the responding to TB decreased may have been evidence of Mac experiencing an *extinction burst* or a related experience (Pear, 2016, p.38). Extinction bursts are "increases in responding above the level that occurred during reinforcement of the response just prior to extinction" (Pear, 2016, p. 38). Although this result is interesting, further research on extinction behaviour in lake sturgeons is required. The observation of a possible extinction burst was not as clearly represented in Figure 16 as in Figure 17 as the number of responses are close together.

Response feedback stimulus baseline (RFSB) phase

Mac and Big participated in the RFSB phase. Since the RFS was not intended to be reinforcing, I expected minimal change in the subjects' behaviour as demonstrated by little difference between DSB phase swim maps and RFSB swim maps.

Big, demonstrated expected results. Big's data showed that initially the addition of the RFS to the selected reinforced target area (TA) there was a disruption to its behaviour however, as expected Big returned to behaviour resembling NFB phase and later DSB sessions. The data indicate that the RFS did not affect the frequency at which the subject responded to each target area. I believe that this observation demonstrated that Big was aware of the consequence of responding to TA, that the RFS would sound, and when the RFS did not occur Big's "expectations" were "violated". This is reminiscent of the fact that an infant will stare at a stimulus longer if their expectations about the stimulus are violated.

This was not the case for Mac. Mac showed some unexpected behaviour towards the RFS. I did not expect for Mac to demonstrate a clear preference for the RFS. This was indicated by increased responding to TB and TC where TB was the selected target area that would eventually be reinforced. And a decrease in responding to TA and TD. The reason for the preference for the RFS was unclear. Perhaps the RFS resembled a sound that was reinforcing in its natural habitat or it resembled a sound that was reinforcing from its current habitat. Further research is certainly required to determine this behaviour was observed. Perhaps it was exclusive to this subject or a subset of this species. Since this finding was not the primary purpose of the present research a second DSB phase was added to the experimental design for Mac to extinguish the preference for the RFS. Ultimately, it was not clear why Mac preferred the RFS but certainly more research is required. Perhaps the frequency of the RFS resembled a frequency that was similar to something reinforcing in nature.

FR n phase

Two subjects participated in the FR n phase. Big completed FR 1, 2, 3, and 4 whereas Mac completed FR 1 and 2. Since I expected darkness to be a PIE for the subjects the subjects

should have visited the reinforced target area more frequently to receive darkness. And as the FR increased the subjects should have responded more frequently to continue earning the same amount of reinforcement which should have consequently decreased the relative frequencies of the non-reinforced target areas. This was not the case for either subject.

For Big responding appeared to be very consistent and flat with the reinforced target area (TA) being visited the most frequently; followed by TB, TC and TD. There was not a great deal of increases or decreases in responding. The consistency of relative frequencies of this phase may be the result of Big's clockwise swim pattern and the increase in FR. By requiring more responses to receive reinforcement Big would have completed laps around the interior perimeter of the ET which would consequently increase the number of responses for each target area which may have had an impact on the relative frequency of each target area bringing the relative frequencies closer to 25% thus decreasing TA relative frequency. The only time the clockwise pattern was disrupted was when a technical error occurred causing the lights to not shut off after the required number of responses (session 66). This violation of Big's expectations produced emotional behaviour that altered his clockwise behaviour. Big started focusing his responding to TA by turning around to swim back into TA after making a response instead of swimming a clockwise lap of the ET.

Additionally, by the FR 2 phase Big had grown making responding slightly more challenging in that Big's whole body did not fit into the target areas fully. Visual observations noted that Big had to swim into TA along the TA TB interior wall and bend its tail into the target area for Fishcamp to count a response. When a response was not detected by Fishcamp – i.e. the RFS did not sound when expected – Big would display emotional behaviour. Big also appeared to have found a more efficient way to earn reinforcement where he would flick his tail to count

multiple responses and earn reinforcement more quickly than entering multiple times. It was also observed that Big would swim into TA with its rostral end into the corner and wiggle vigorously to trigger the RFS multiple times until darkness occurred. This behaviour of Big's occurred during FR 3 and FR 4 sessions as well.

For Mac the increase in responding to the reinforced target area (TB) may have not emerged because only an FR 2 was reached before he was terminated. Perhaps if a greater FR schedule was reached the decreased responding to the non-reinforced target areas may have become more noticeable since a greater number of responses would be required to earn reinforcement.

Alternatively, the cumulative records of Big and Mac's behaviour during FR n did match my expectations. I expected each subject's rate of responding to show the characteristic stepwise/ break-and-run pattern. What I observed was as the FR was increased the rate of responding increased. A drop in the rate of responding often happened when there was an increase in FR followed by negative acceleration to increase the rate of responding relative to the increased FR. In other words, when the FR ratio was increased the subjects would speed up their responding to maintain reinforcement.

Conclusion

In this experiment there were many observations made about lake sturgeons learning:

(1) Lake sturgeons are quick to respond to changes in their environment and can quickly distinguish a potential threat.

This was observed during DSB and RFSB phases where the subjects demonstrated predator inspection when new stimuli were added to their environment. Additionally, the

subjects' behaviour changed rapidly when expectations about darkness were violated (i.e. the lights didn't shut off).

(2) Lake sturgeons change their rate of responding when more responses are required to earn reinforcement.

This was observed during the FR n sub-phases in the cumulative records where we observed negative acceleration and positive deceleration in addition to steady rates of responding. These alternative functions suggest compensation to maintain reinforcement delivery.

(3) Lake sturgeons detect patterns in their environment rapidly.

(4) Darkness is certainly a PIE (reinforcer) for lake sturgeons.

The ability for a behaviour to adapt is to have phenotypic plasticity in response to a changing environment. This could be thought of synonymously with behavioural plasticity as sensitivity to correlations between the organism and the environment which could loosely be thought of as learning. Learning takes time and multiple interactions with the environment; these interactions create correlations between behaviour and the environment in ways that promote an organism's survival.

The occurrence of darkness by entering the target area created a strong correlation between the behaviour of responding and the darkness that followed. The subjects developed expectations that responding to the reinforced target area would result in the RFS and darkness. There were instances of technical error that caused this expectation to be violated. It was observed that when the expectation was violated the subjects would display increased activity to the reinforced corner as if checking to make sure responses were being made and emotional behaviour following the reinforcer failing to be emitted. Or the subjects would respond and

quickly turn around and respond again. Leaving me with no doubt that they were aware of the correlation between responding and the lights shutting off. In other words, they learned.

The results and observations made during the experiment leave no doubt that lake sturgeons can learn when the principles of operant conditioning are applied as has been seen in a variety of organisms including mammals, birds, fish, as well as invertebrate species such as insects and crayfish.

Limitations

There were a few limitations with the presented research. There were equipment failures, equipment function, subject mortality, and time was a restriction. Regarding equipment failures, there were challenges with the experimental apparatus and computer tracking. Initially, the calibration of Fishcamp and VTS was off and tracking of the subject was poor resulting in some data being unusable. This turned out to be a simple adjustment to the ET and adjusting the scale of the ET in the Fishcamp program.

Further challenges such as the RFS not coming on automatically and the lights not turning off when they were supposed to were more challenging. When the RFS did not sound accordingly, often a few responses would be made before the problem was resolved, usually, requiring me to unplug the speakers and plug them back in. This failure in function occurred several times over the course of the experiment but was resolved within a few minutes. The lights were most challenging as a relay switch responsible for turning the lights on and off failed. This equipment failure only occurred once.

Although these failures occurred, observational notes were recorded, and cross examined for effect as well as the instances provided insight into the subjects behaviour when expectations were violated. Furthermore, the equipment is dated which resulted in some difficulties recording

the number of responses accurately. The VTS did track the subject's location accurately as there were less than 5% tracking errors within each session; however, the cameras operated by tracking top down and left to right. This resulted in errors in the number of responses recorded depending on the size of the subject. The larger the subject, the larger the risk of inflating the number of responses recorded. For example, if the subject had entered TA (rostral portion was inside the corner) and the tail was sticking up towards TB along the interior wall of the ET the tracking system would consequently encounter the caudal end or the subjects tail first possibly missing the response. Alternatively, if the subject had its rostral end in TB and its caudal end pointing towards TC with its body along the interior wall of the ET the cameras would contact the headfirst and it may count multiple responses when only one occurred. Although this problem occurred and was out of our control it did yield positive results. The accuracy of the tracking the subject's location was still excellent providing us with swim maps. It also provided for interesting observations regarding the subject's phenotypic plasticity; in other words, the subjects were observed to be very sensitive to the position of their body in and around the reinforced target area in relation to producing darkness. It was observed in Big and Mac that as they grew, and it became difficult to swim into the target area that they could curve their bodies and flick their tails multiple times to register multiple responses. Essentially, they learned to work smarter not harder to elicit the darkness. A very useful adaptation.

Nothing could be done to control against the mortality of the subjects. Procedures were followed, and their health was monitored by animal care rigorously. As we have been told by animal care, hundreds of eggs hatch and some animals lack the fitness to survive especially from the juvenile age. In the future when we select subjects, we will ensure that the subjects are healthy in appearance by examining their mid-section where their dorsal and lateral fins were

wide, wider than their tail which suggests that they are well fed as well and how the subjects swim and the condition of their overall appearance.

Finally, time was a restraint in that I could not continue to run the subjects due to personal fatigue and exhaustion as well as an extended period away from the lab resulted in the decision to terminate the experiment.

Future directions

In the future researchers may want to examine other reinforcers that could be used to induce lake sturgeon behaviour as well as environmental problems that may be positively impacted by understanding that darkness is a reinforcer. The next plan is to examine if we can increase the rate of responding to the reinforced target area perhaps with a VR schedule of reinforcement.

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Tables

Table 1. Experimental designs for each subject.

a) Cheese

Baseline	
No Feedback Baseline (NFB) Sessions 1-12	Subject terminated due to poor health

b) Mac

Baseline				Experimental Manipulation		
No Feedback Baseline (NFB) Sessions 1-9	Discriminative Stimulus Baseline (DSB) Sessions 10-14	Response feedback stimulus baseline (RFSB) Sessions 15-28	Second Discriminative Stimulus Baseline (DSB2) Sessions 29-43	Fixed-ratio reinforcement schedule (FR1) Sessions 44-58	FR 2 Sessions 59-67	Mac terminated due to poor health

**Sessions 68 to 72 (May 1 to May 7) were excluded from analysis as behaviour was unusual which was likely related to Mac's decline in health.*

c) Big

Baseline			Experimental Manipulation	
No Feedback Baseline (NFB) Sessions 1-7	Discriminative Stimulus Baseline (DSB) Sessions 8-19	Response feedback stimulus baseline (RFSB) Sessions 20-26	Fixed-ratio reinforcement schedule (FR1) Sessions 27-43	FR 2, FR 3, FR 4 Sessions 44-51, 52-59, 60-67 respectively

Table 2. Summary of interobserver agreement (IOA) for Cheese.

Phase	IOA %	TA	TB	TC	TD	Total
NFB	58%	96%	96%	97%	96%	97%

Table 3. Pearson's correlations (*r*) of observation method for each target area for Cheese.

	TA	TB	TC	TD
Human vs Human *N* = 7	0.964**	0.968**	0.974**	0.853*
Human vs Fishcamp *N* = 10	0.592	0.188	0.733*	0.760*
* $p < .05$ ** $p < .01$				

Table 4. Summary of interobserver agreement (IOA) for Mac.

Phase	IOA %	TA	TB	TC	TD	Total
NFB	44%	98%	98%	98%	98%	99%
DSB	40%	95%	89%	91%	98%	94%
FRSB	50%	96%	98%	97%	96%	98%
Second DSB	33%	95%	98%	91%	98%	97%
FR1	33%	94%	96%	95%	93%	97%
FR2	33%	97%	100%	96%	96%	98%
All phases	39%	96%	97%	95%	97%	97%

Table 5. Pearson's correlations (*r*) of observation method for each target area for Mac.

	TA	TB	TC	TD
Human vs Human *N* = 26	0.994	0.992	0.992	0.996
Human vs Fishcamp *N* = 65	0.651	0.606	0.646	0.819
All values significant at $p < .001$				

Table 6. Summary of interobserver agreement (IOA) for Big.

Phase	IOA %	TA	TB	TC	TD	Total
NFB	71%	94%	91%	94%	93%	94%
DSB	50%	87%	96%	94%	94%	95%
RFSB	57%	98%	96%	96%	97%	97%
FR 1	35%	94%	95%	97%	97%	98%
FR 2	50%	94%	96%	94%	94%	96%
FR 3	50%	95%	98%	97%	92%	97%
FR 4	37%	98%	98%	97%	95%	98%
Average of all phases	50%	94%	96%	96%	95%	96%

Table 7. Pearson's correlations (*r*) of observation method for each target area for Big.

	TA	TB	TC	TD
Human vs Human *N* = 32	0.988	0.953	0.978	0.985
Human vs Fishcamp *N* = 67	0.862	0.932	0.938	0.893
All values significant at $p < .001$				

Figures

Figure 1. Image of juvenile lake sturgeon.

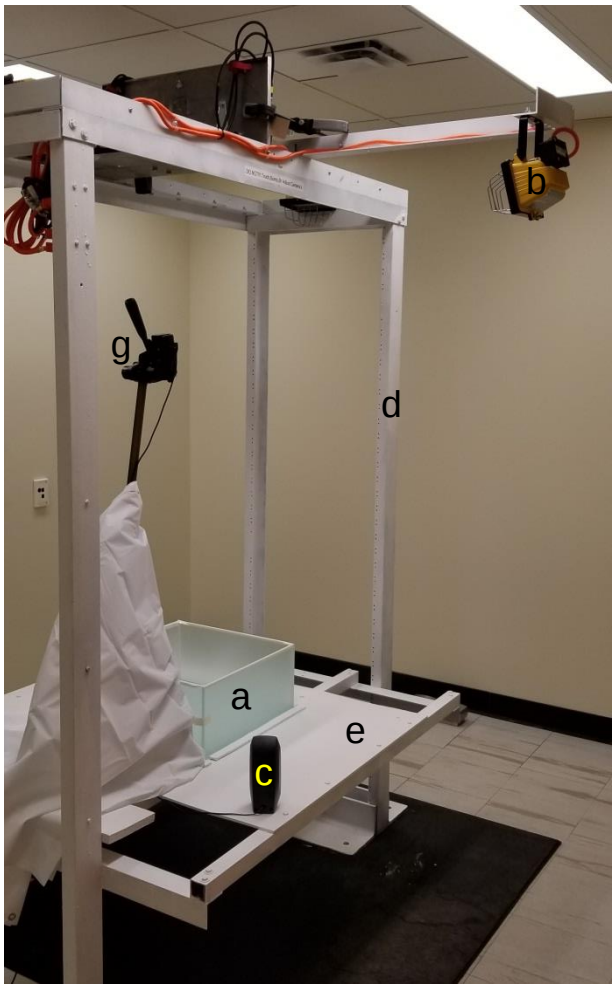
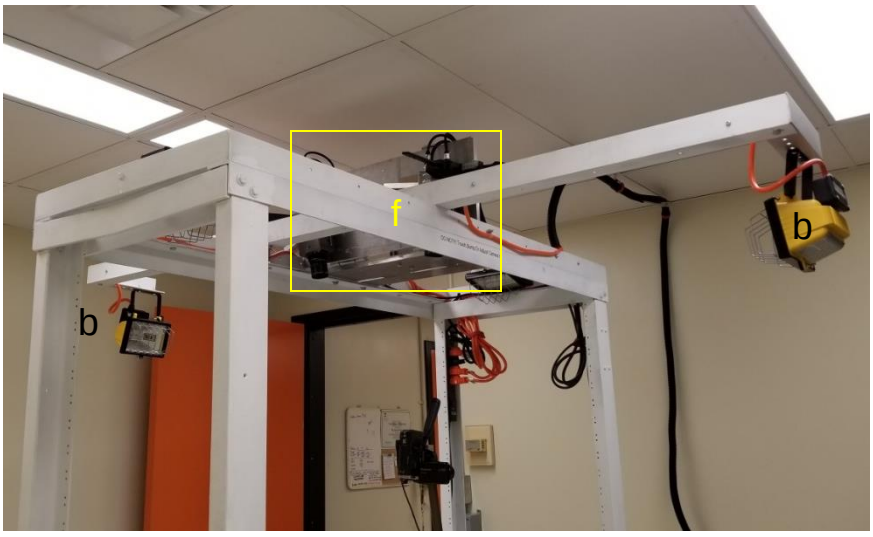


Figure 2. Images of experimental apparatus. Several aspects of the apparatus can be observed including (a) experimental tank (ET), (b) work lights, (c) speakers, (d) metal scaffolding, (e) white platform, (f) cameras, and (g) video camera. Photos by Brittany Cook, June 3, 2019.



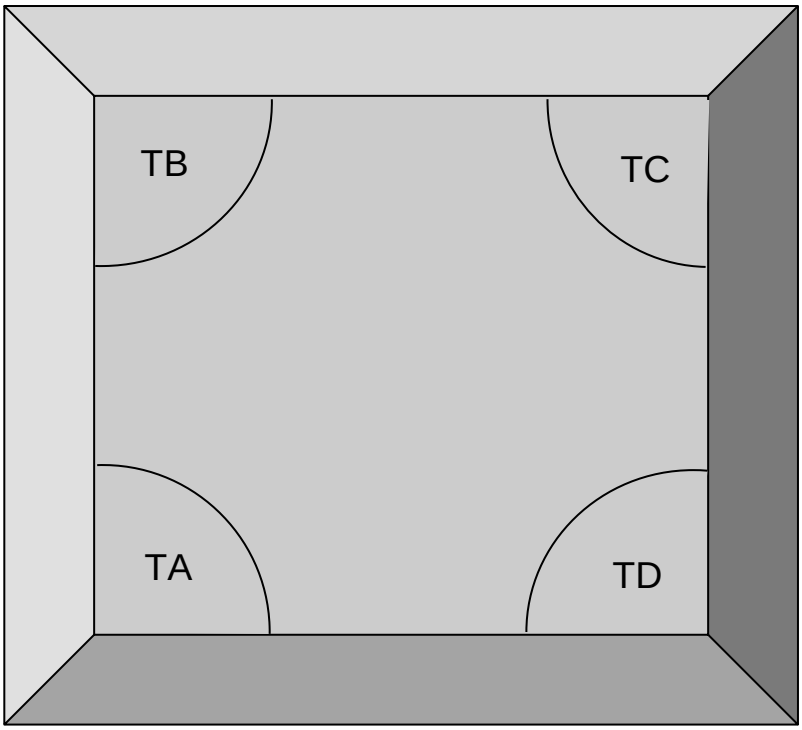


Figure 3. Schematic drawing of birds-eye view of ET. Indicated are the four reinforcer target locations (TA, TB, TC, and TD) which were 100 mm in radius from the corners of the ET and marked with white paint (not drawn to scale).

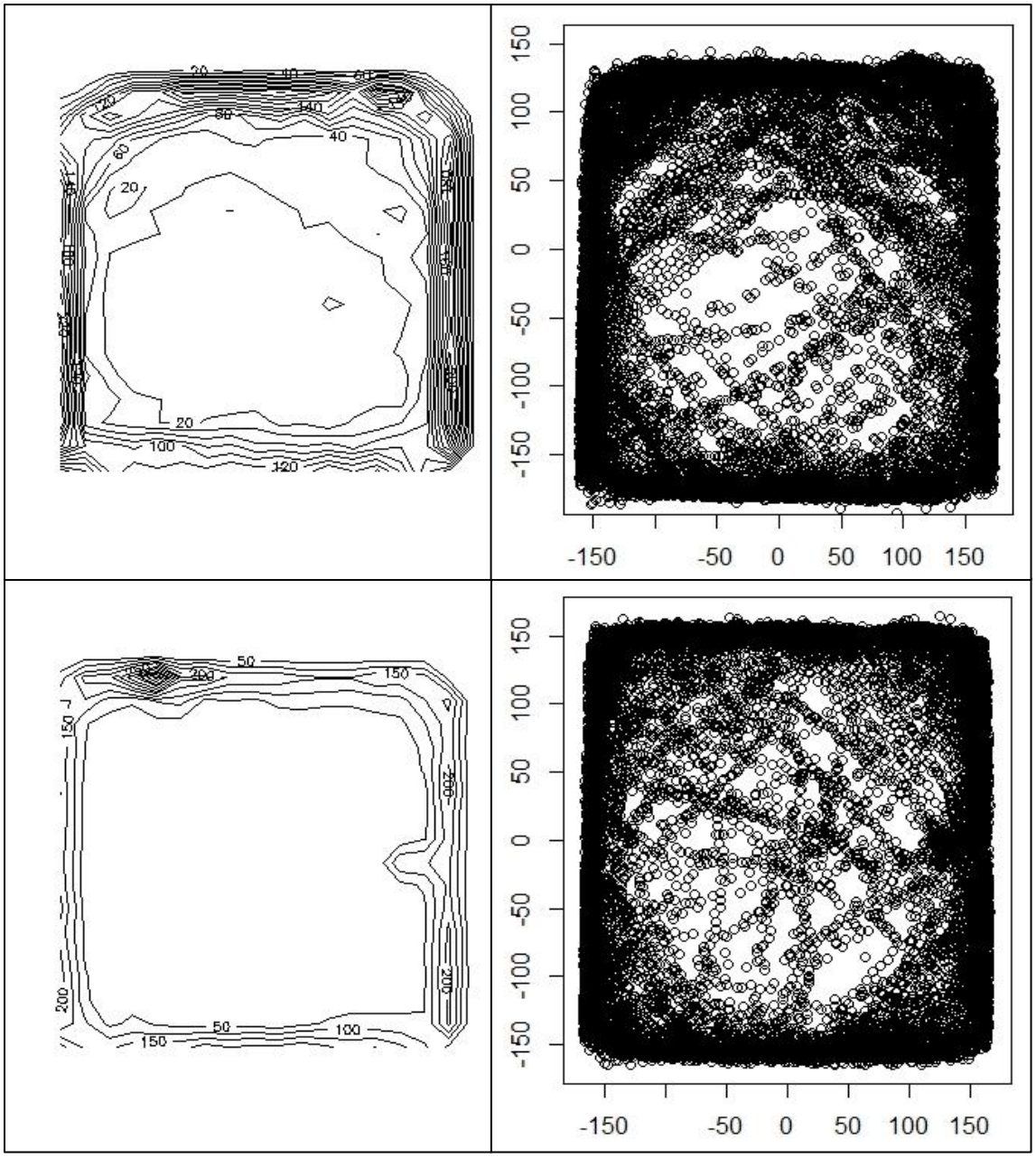


Figure 4. Swim maps (left) and scatter plots (right) of Cheese's location within sessions of the NFB phase. Top: NFB session 10. Bottom: NFB session 12. Note the high concentration of activity around the perimeter of the ET. A similar swim pattern occurred during session 12 but activity hardly deviated from the perimeter of the ET.

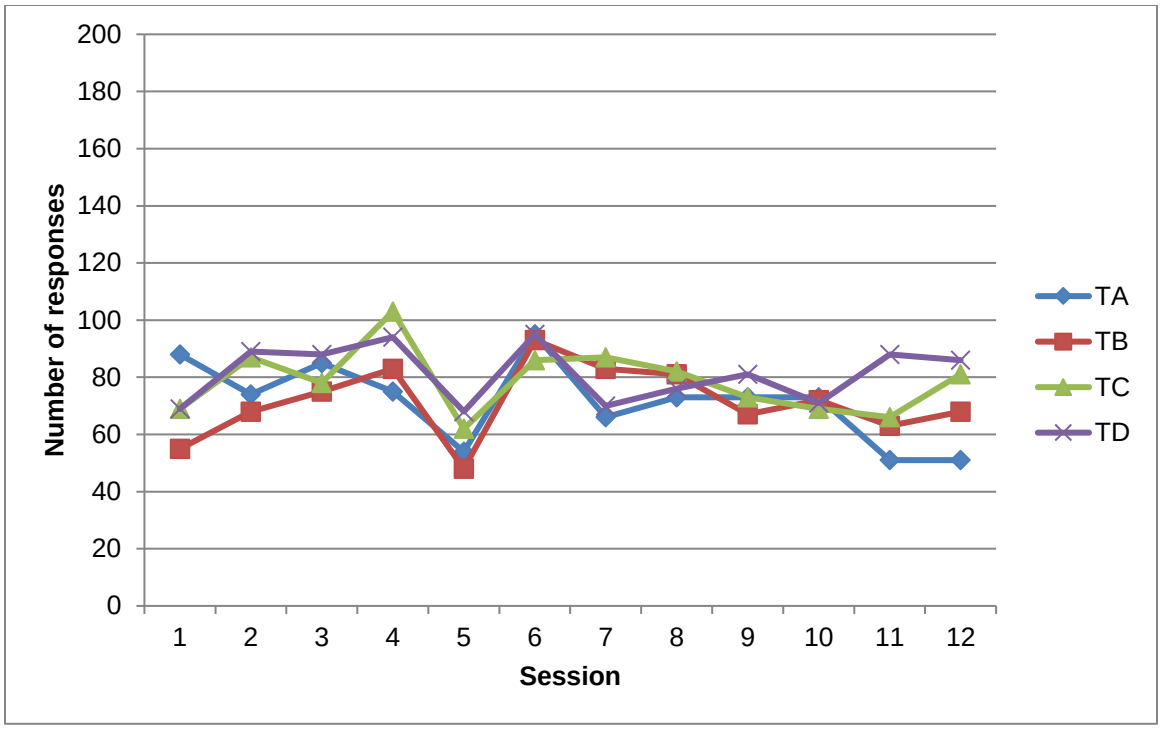


Figure 5. Number of responses for each target area during the NFB phase for Cheese.

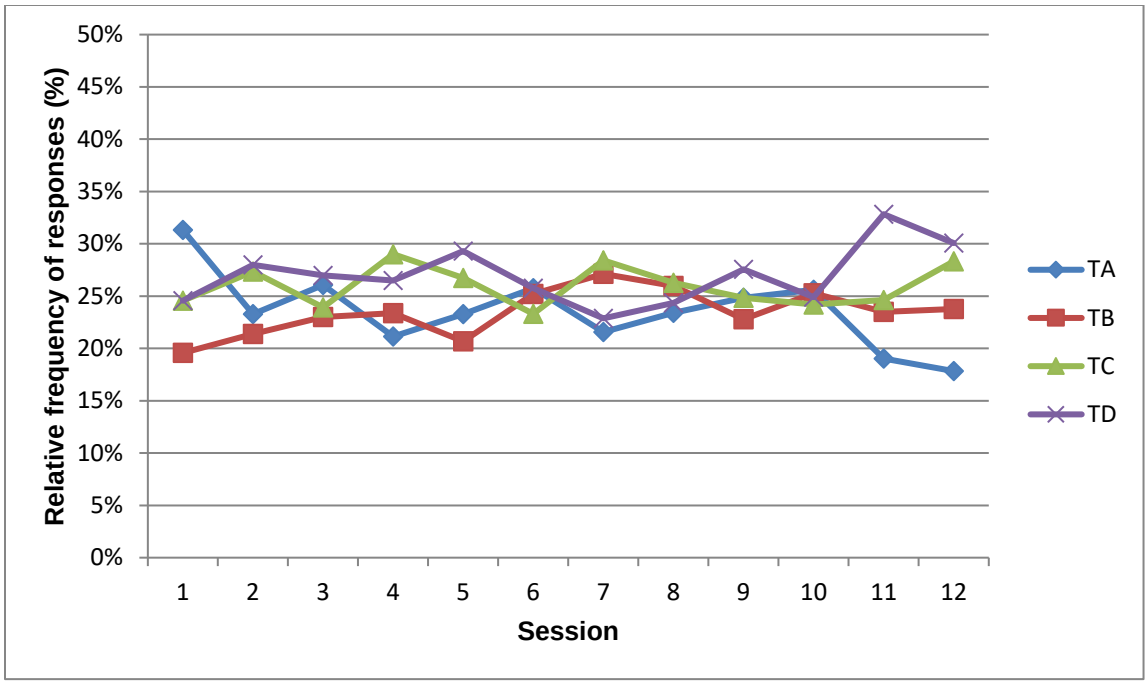


Figure 6. Relative frequency of responses for each target area during the NFB phase for Cheese.

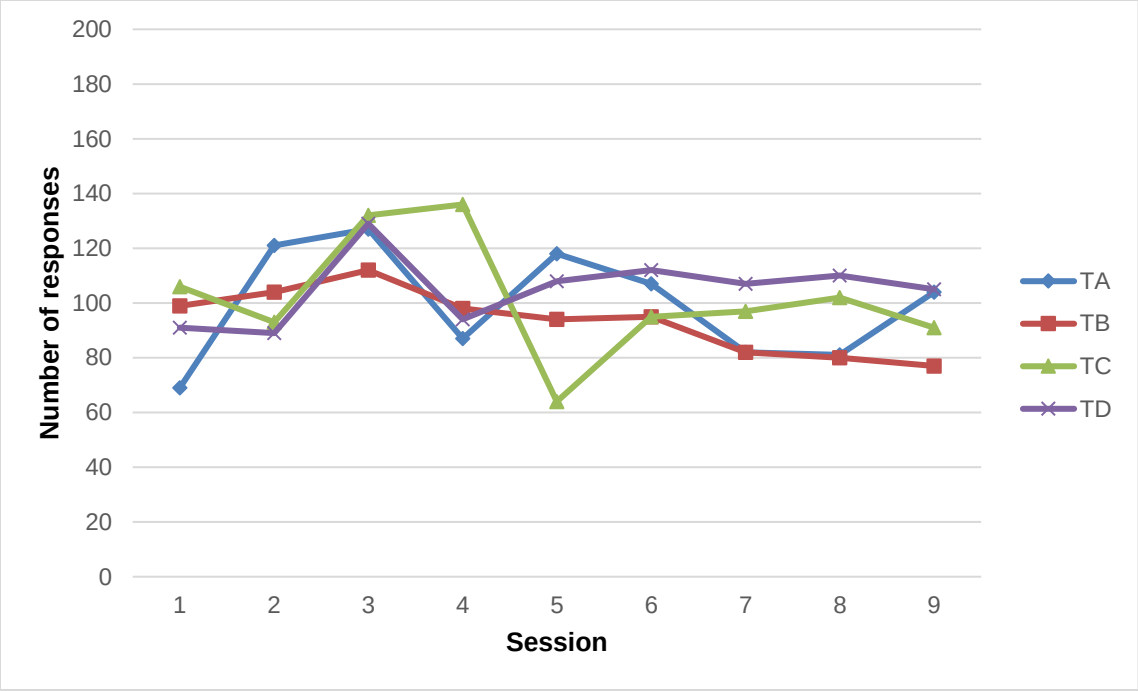


Figure 7. Number of responses for each target area during the NFB phase for Mac.

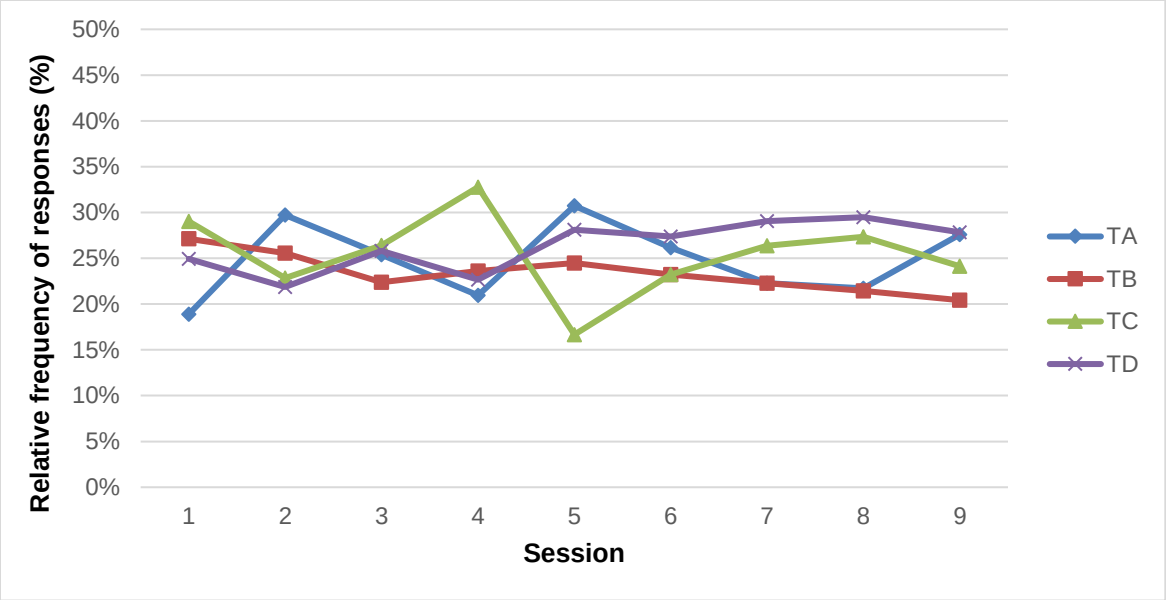


Figure 8. Relative frequency of responses for each target area during the NFB phase for Mac.

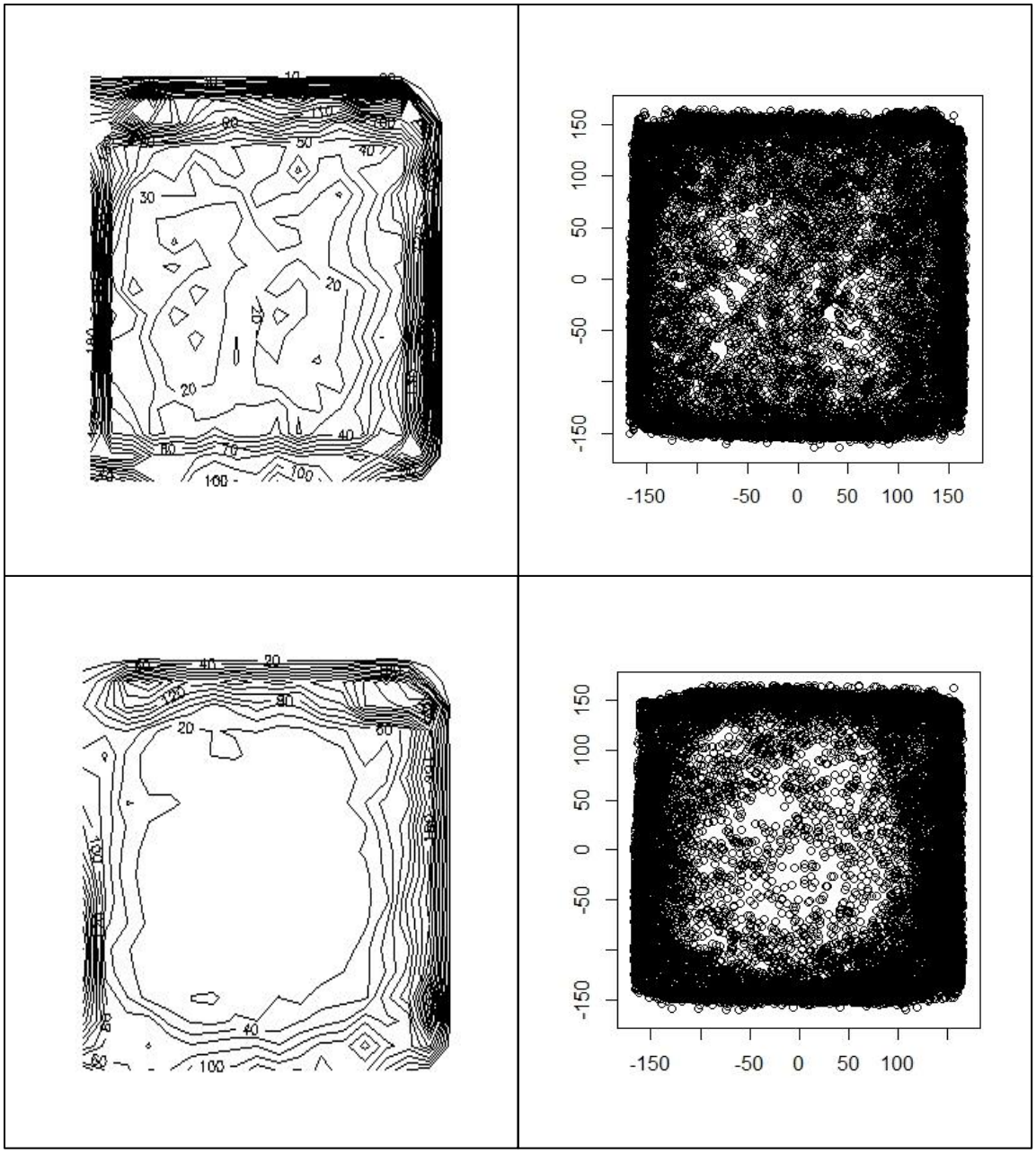


Figure 9. Swim maps (left) and scatter plots (right) of Mac's location within sessions of DSB phase. Top: DSB session 10. Bottom: DSB session 14. The loonie was placed in TB. Note the high concentration of activity throughout the entire ET when the S^D was introduced during session 10. However, by session 14 Mac's swim map more closely resembles a typical NFB session (see Figures 4 or 28 for examples of NFB swim maps). Due to tracking errors with Fishcamp swim maps could not be produced for sessions prior to session 10 for Mac.

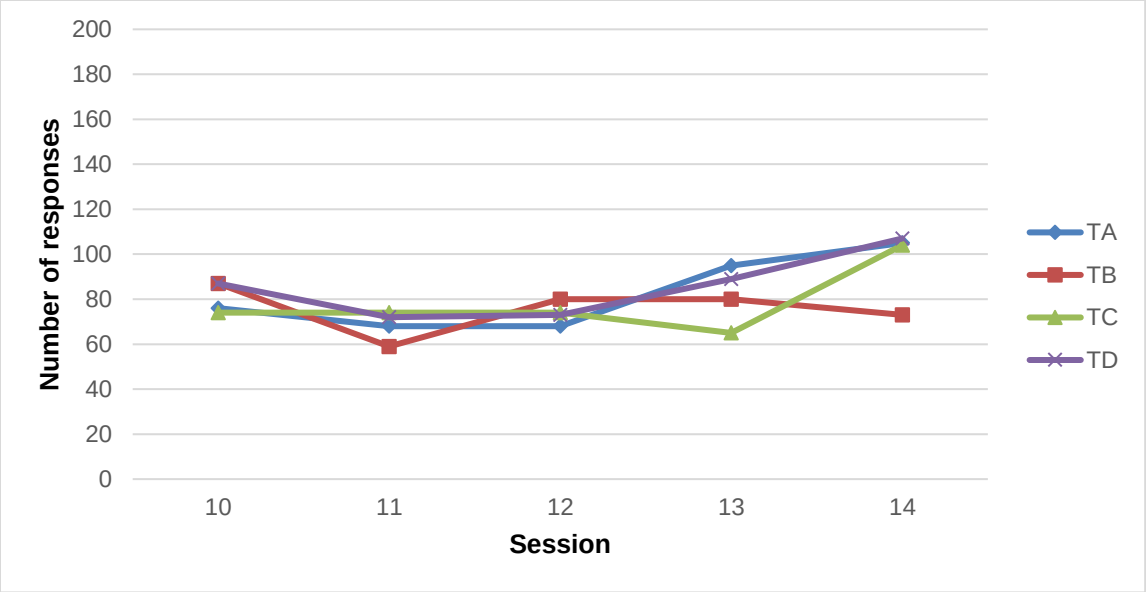


Figure 10. Number of responses for each target area during the DSB phase for Mac. S^D located in TB.

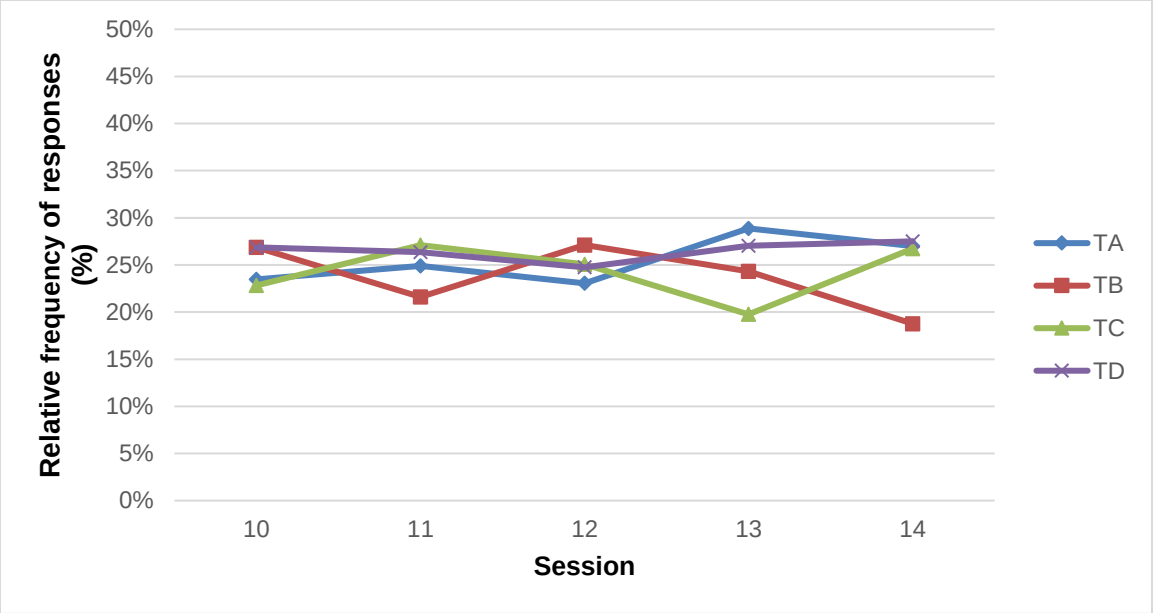


Figure 11. Relative frequency of responses for each target area during the DSB phase for Mac. S^D located in TB.

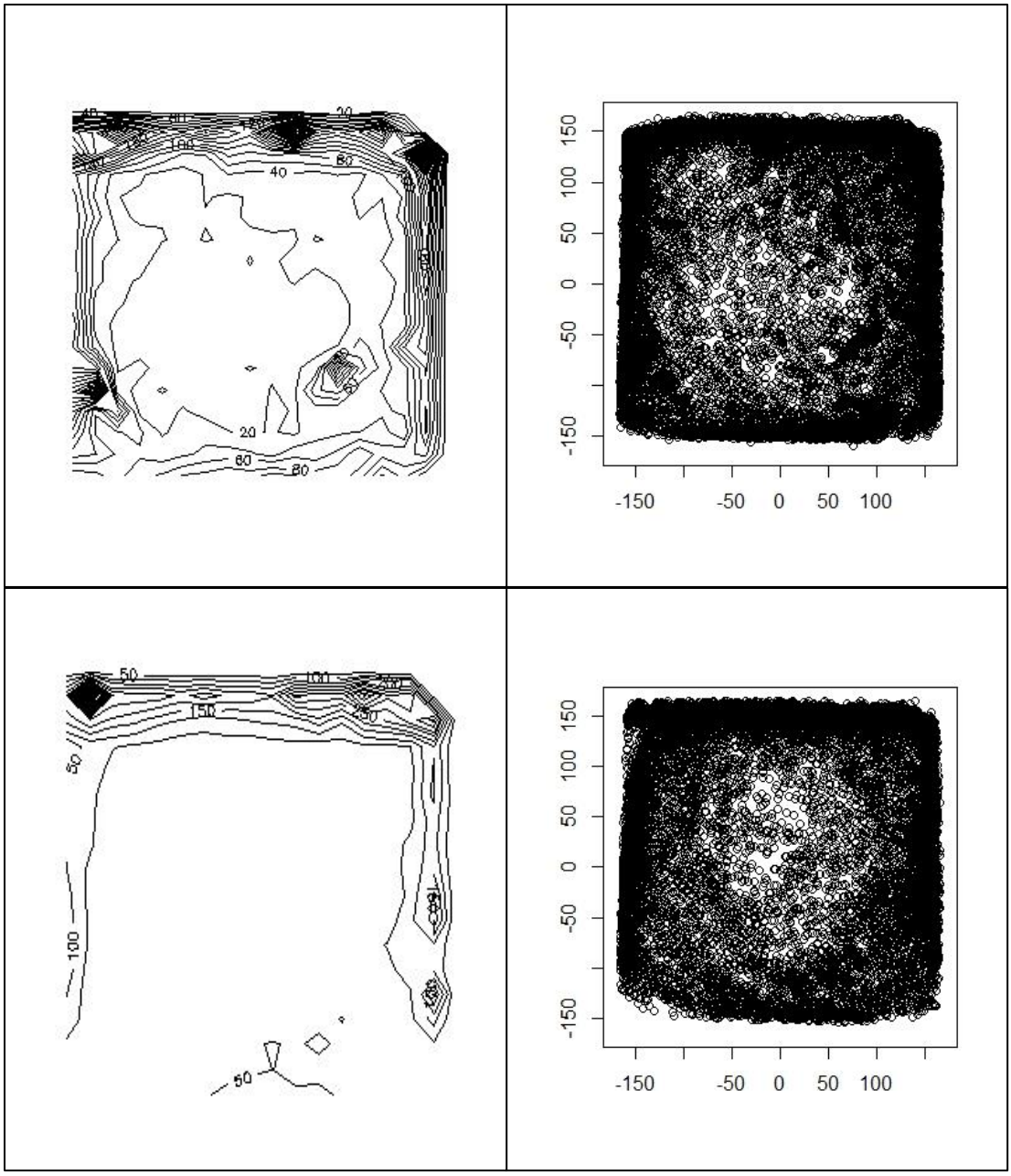


Figure 12. Swim maps (left) and scatter plots (right) of Mac's location within sessions of RFSB phase. Top: RFSB session 15. Bottom: RFSB session 28. The S^D was still in TB and the RFS occurred upon each response on TB. Note the high concentration of activity throughout the entire ET when the RFS was introduced during session 15. The swim map of session 15 illustrates Mac's interest in the region around TB. By session 28 Mac's swim map shows a decreased concentration of activity in TA and the region of the ET between TA and TD.

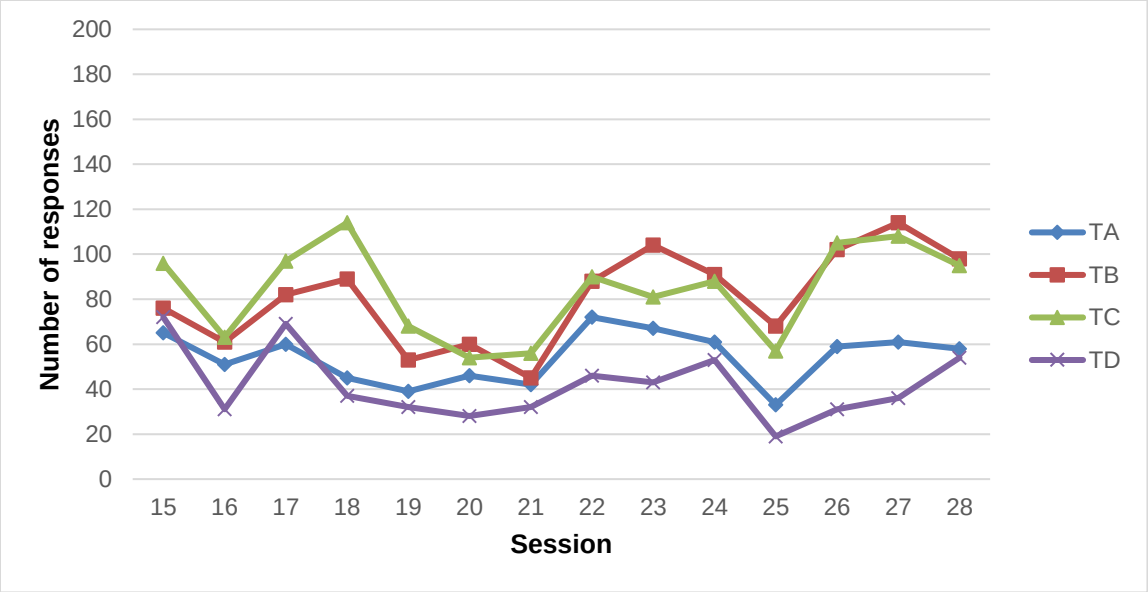


Figure 13. Number of responses for each target area during the RFSB phase for Mac. S^D located in TB and RFS occurred with each response to TB. Note the increased distribution of responding in TB and TC. Compare with Figures 7 and 10.

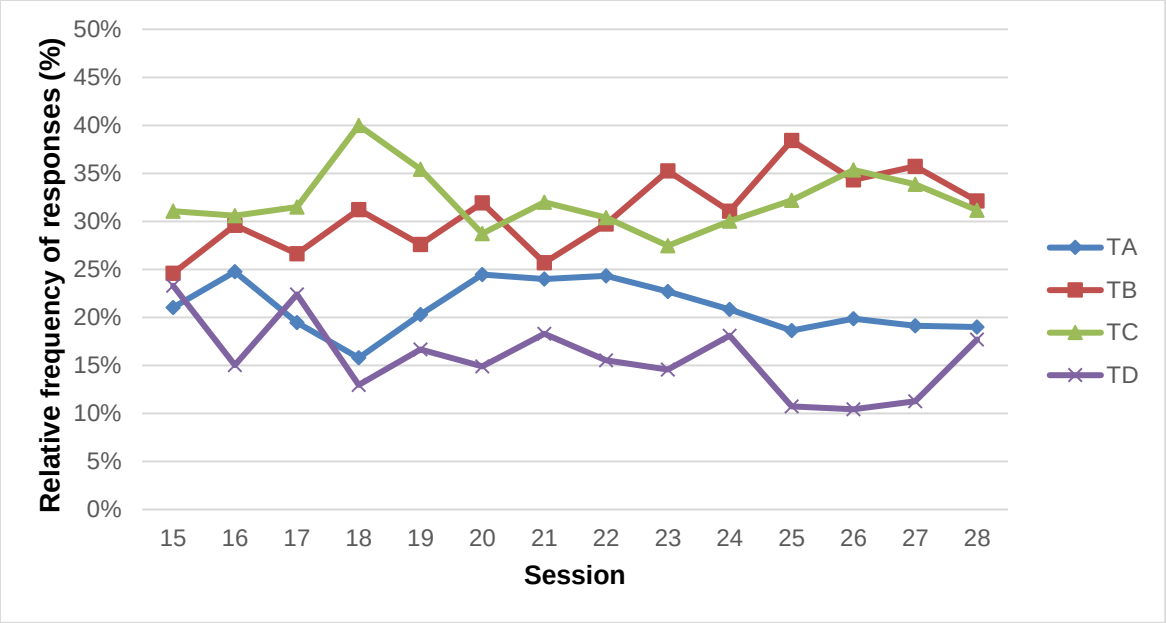


Figure 14. Relative frequency of responses for each target area during the RFSB phase for Mac. S^D located in TB and RFS occurred with each response to TB. Note the increased distribution of relative responding in TB and TC. Compare with Figures 8 and 11.

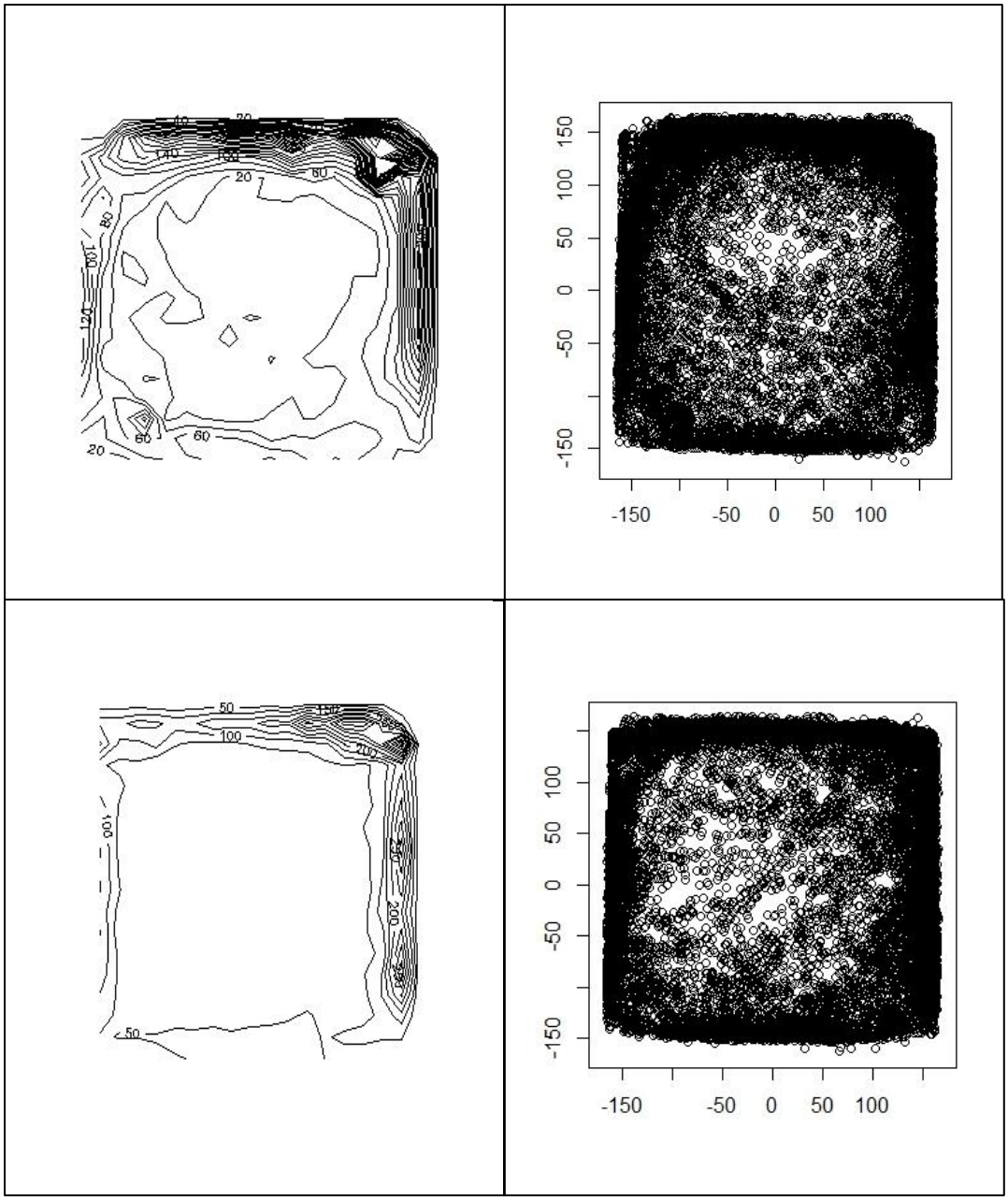


Figure 15. Swim maps (left) and scatter plots (right) of Mac's location within sessions of the return to DSB (DSB2) phase. Top: DSB2 session 29. Bottom: DSB2 session 43. S^D located in TB with no RFS occurring. During the RFSB Mac demonstrated preference for TB when the RFS was added. To extinguish the effect of the RFS it was removed and only the loonie was in TB for this phase. It was observed that by session 43 Mac's swim map had returned to the behaviour of the previous DSB phase (see Figure 9).

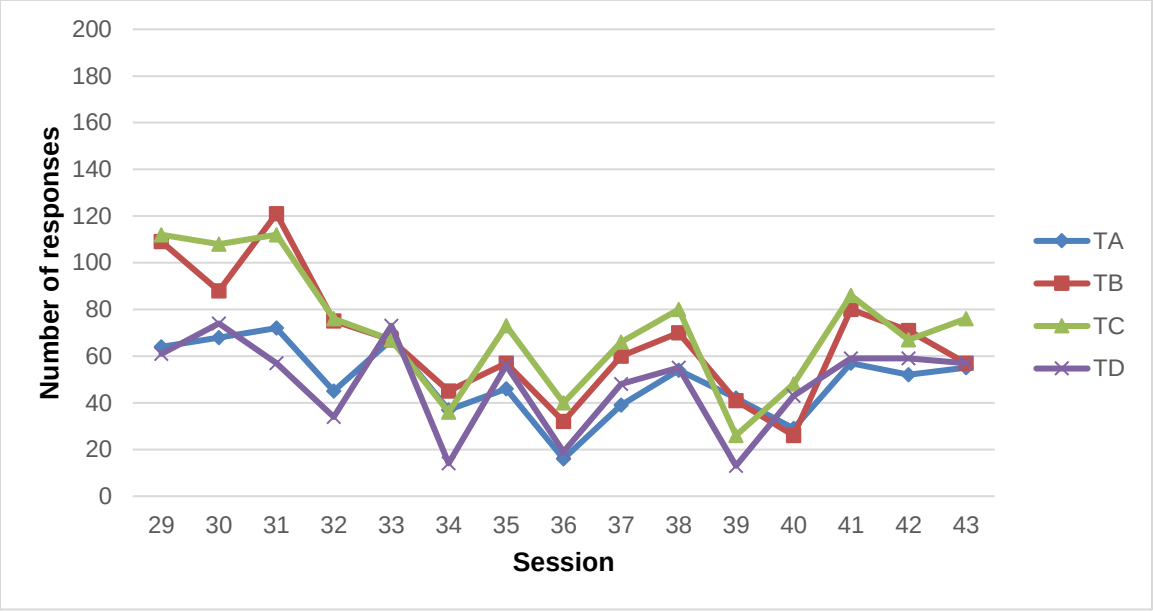


Figure 16. Number of responses for each target area during the DSB2 phase for Mac. S^D located in TB with no RFS occurring. Note that in terms of frequency of responding Mac had returned to the behaviour of the previous DSB phase (see Figure 10).

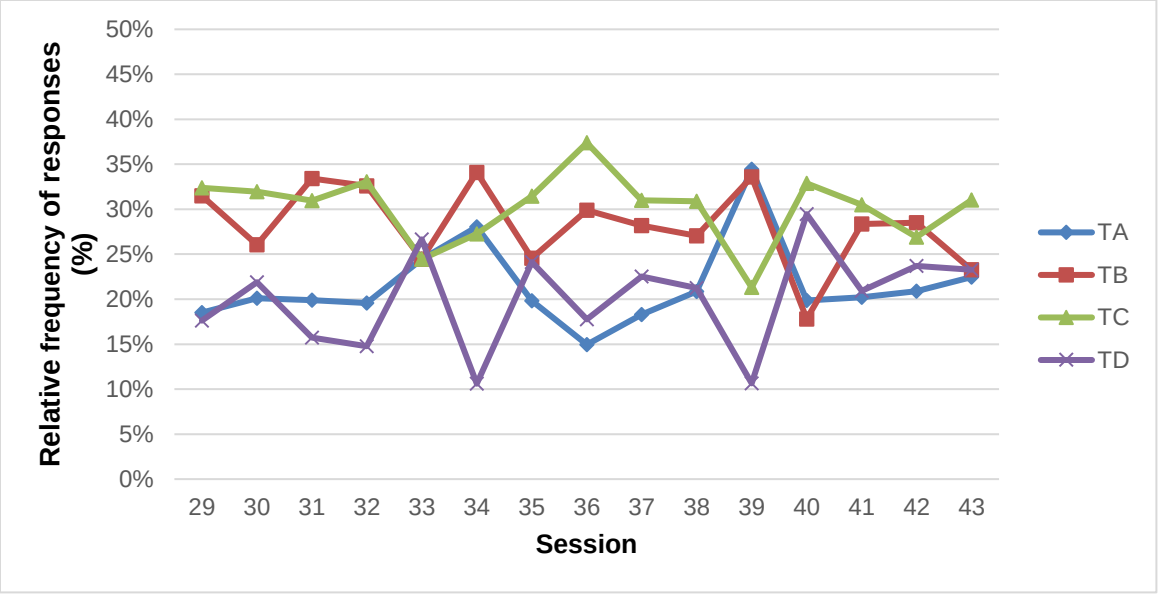


Figure 17. Relative frequency of responses for each target area during the DSB2 phase for Mac. S^D located in TB with no RFS occurring. Note that in terms of relative frequency of responding Mac had returned to the behaviour of the previous DSB phase (see Figure 11).

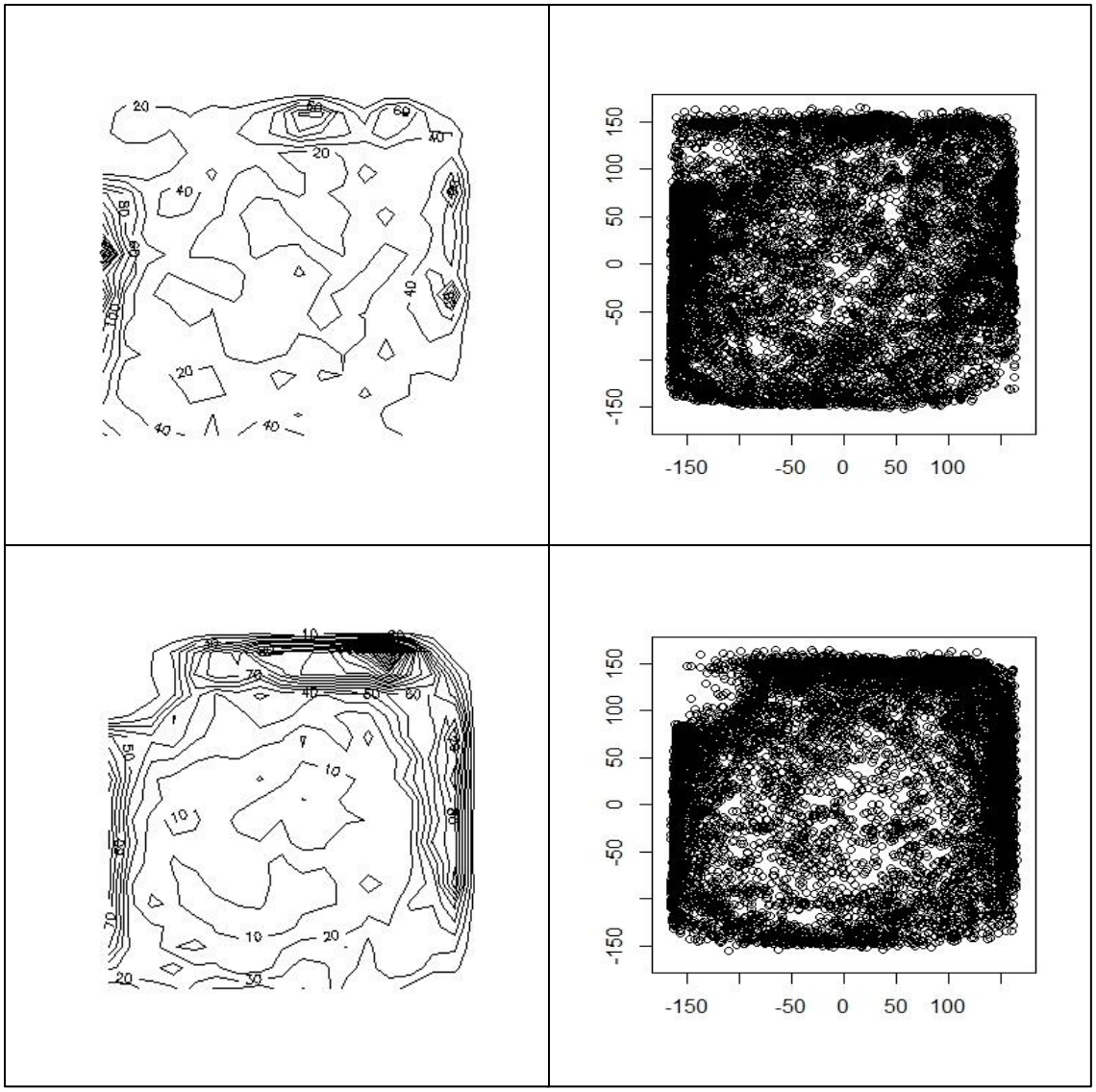


Figure 18. Swim maps (left) and scatter plots (right) of Mac's location within sessions of FR 1 phase. Top: FR 1 session 44. Bottom: FR 1 session 58. With the initial introduction of darkness to TB (in addition to S^D and RFS) during session 44 it can be seen that Mac swam throughout the entire ET, but the highest concentrations of activity were seen in the area surrounding TB. During session 58 Mac's activity became more refined and concentrated around TB with less activity in the center and the region between TA and TD. Note that the lights would turn off upon entry into TB and without the lights on tracking could not occur. Therefore, TB appears to have no concentration of activity, but TB actually had a high amount of activity.

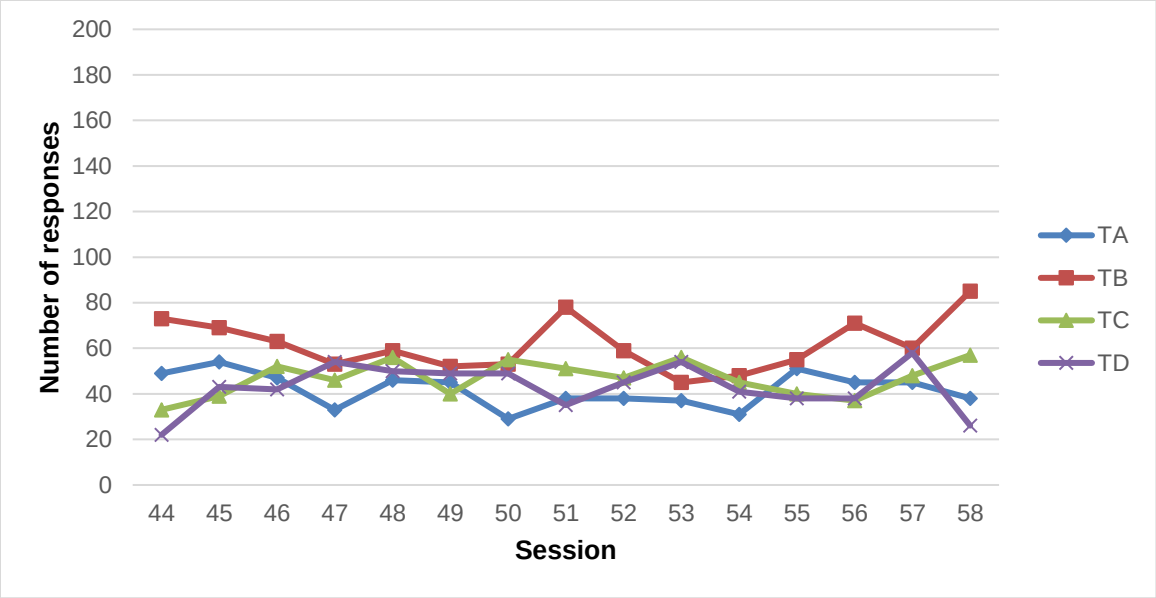


Figure 19. Number of responses for each target area during FR 1 for Mac. S^D still present in TB but RFS and darkness occurred when a response was made.

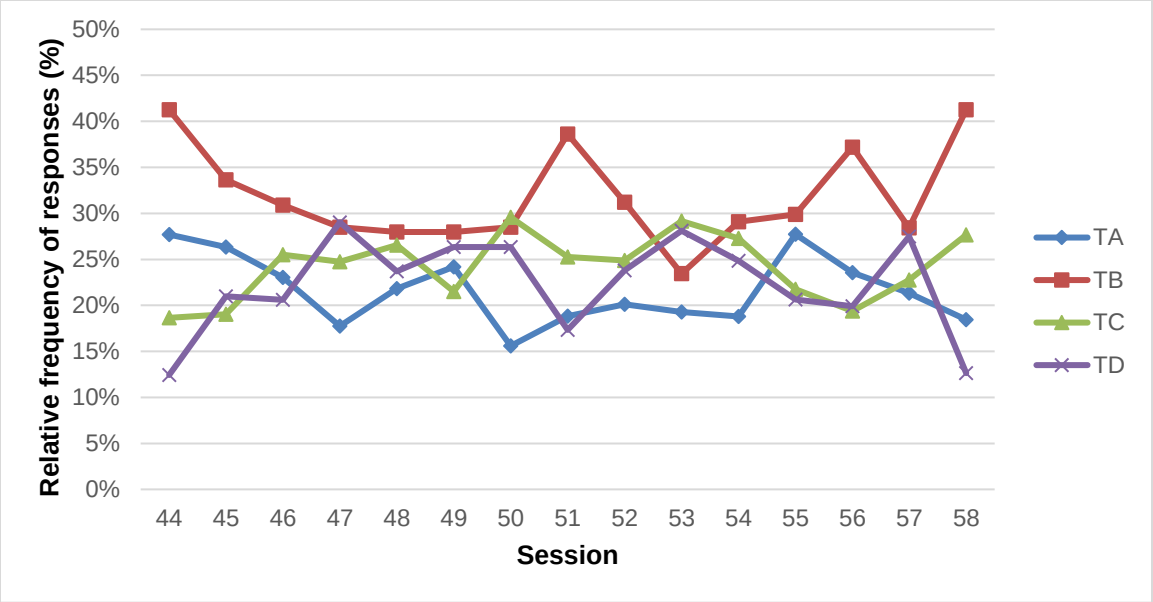


Figure 20. Relative frequency of responses for each target area during FR 1 for Mac. S^D still present in TB but RFS and darkness occurred when a response was made.

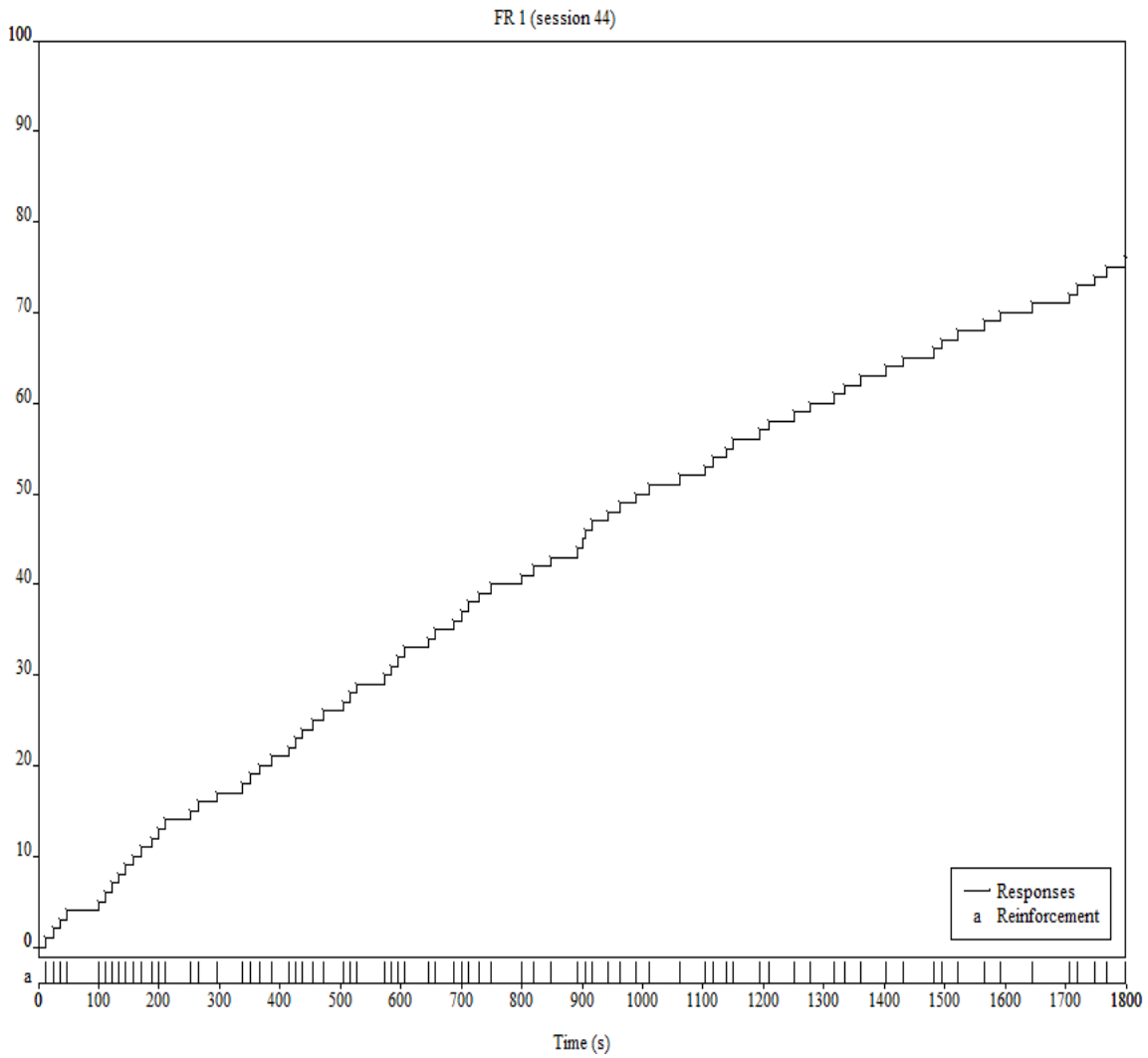


Figure 21. Cumulative record of Mac's responses for FR 1 session 44 (first FR 1 session). Note the concave nature of the graph (negative acceleration), suggesting a satiation effect. Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

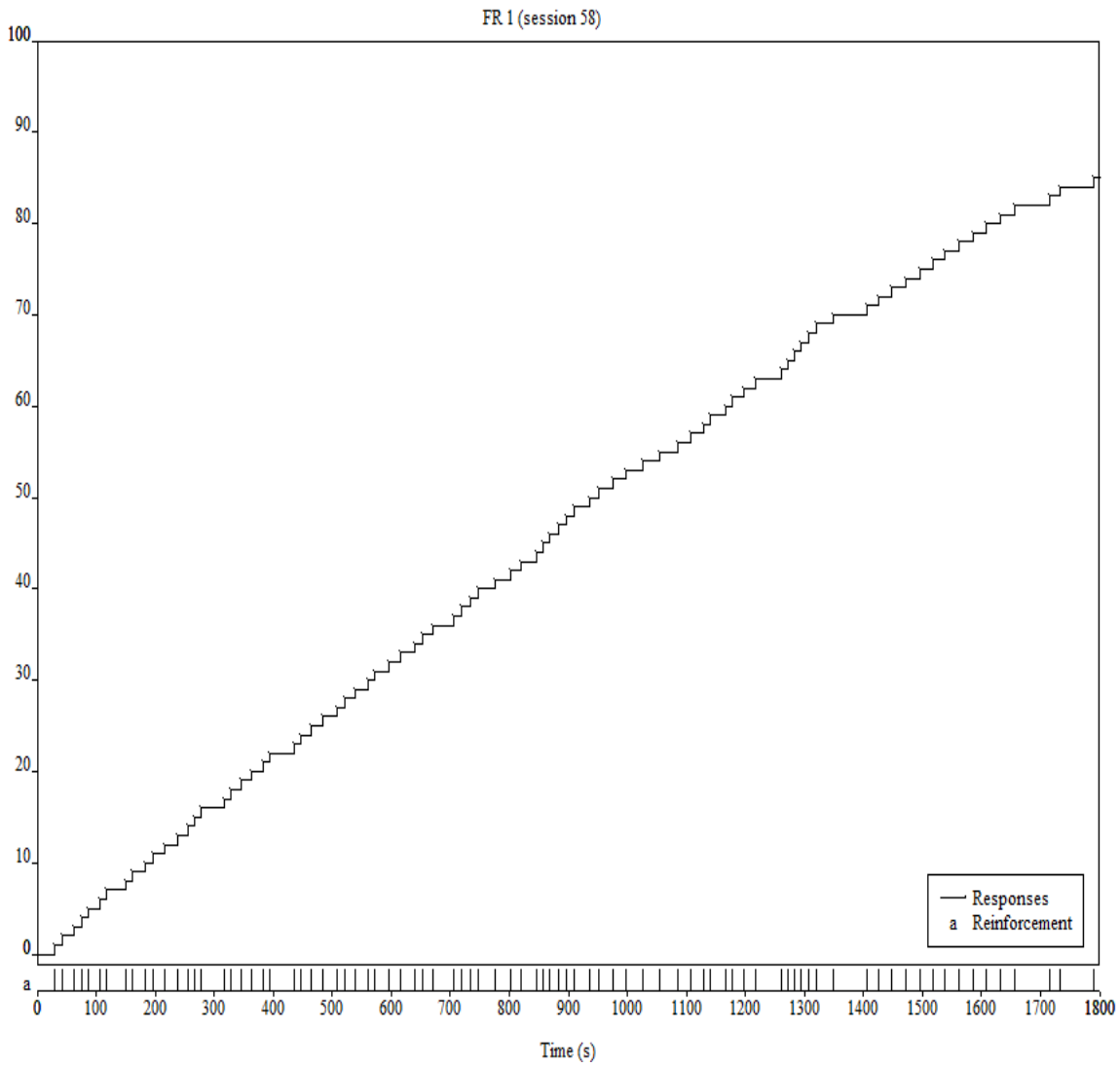


Figure 22. Cumulative record of Mac's responses for FR 1 session 58 (last FR 1 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

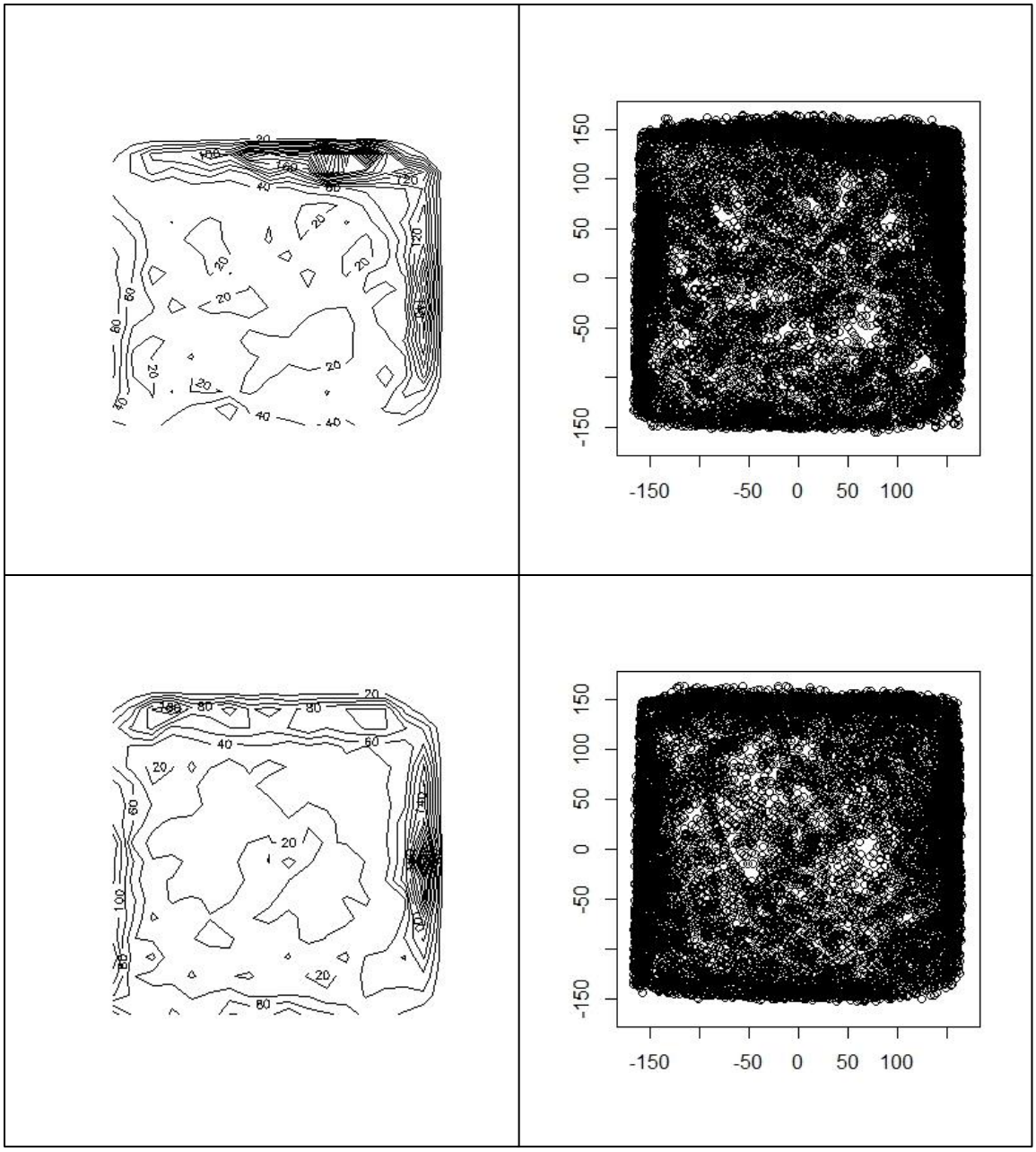


Figure 23. Swim maps (left) and scatter plots (right) of Mac's location within sessions of FR 2 phase. Top: FR 2 session 59. Bottom: FR 2 session 67. S^D still present in TB and the RFS occurred with each response, but darkness occurred when two responses were made. During FR 2 sessions Mac's swim maps became further refined compared to swim maps from FR 1. In the FR 2 swim maps it can be seen that activity in the center of the ET progressively shifts to be closer to TB from session 59 to 67. As well as the concentration of activity in TB is greater during session 67.

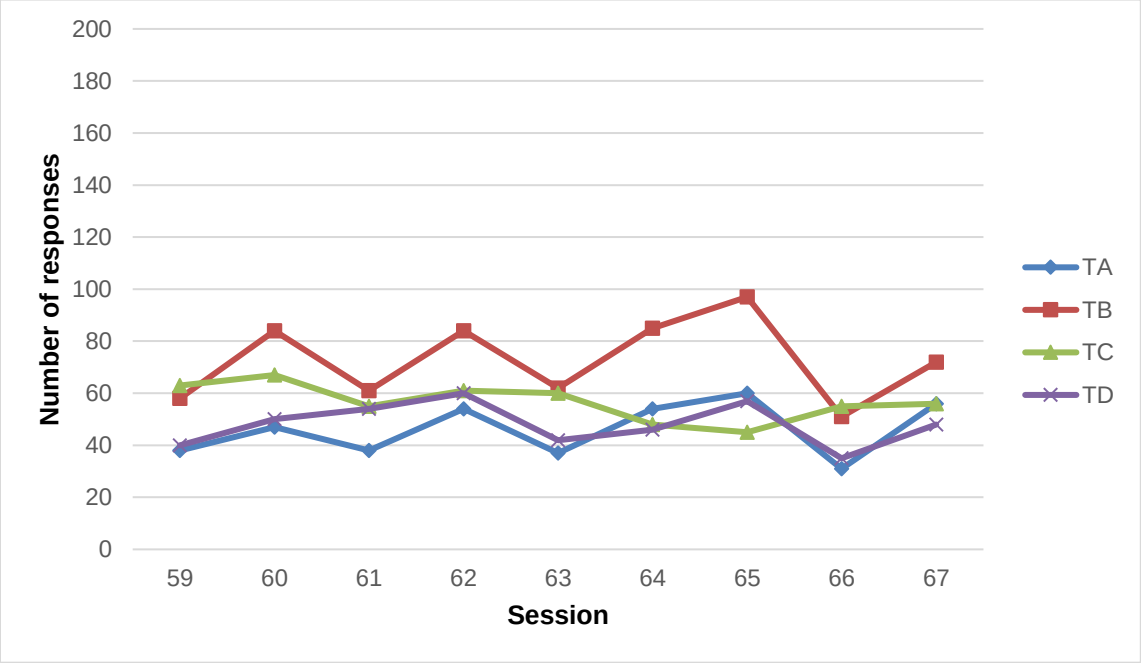


Figure 24. Number of responses for each target area during FR 2 for Mac. S^D still present in TB and the RFS occurred with each response, but darkness occurred when two responses were made.

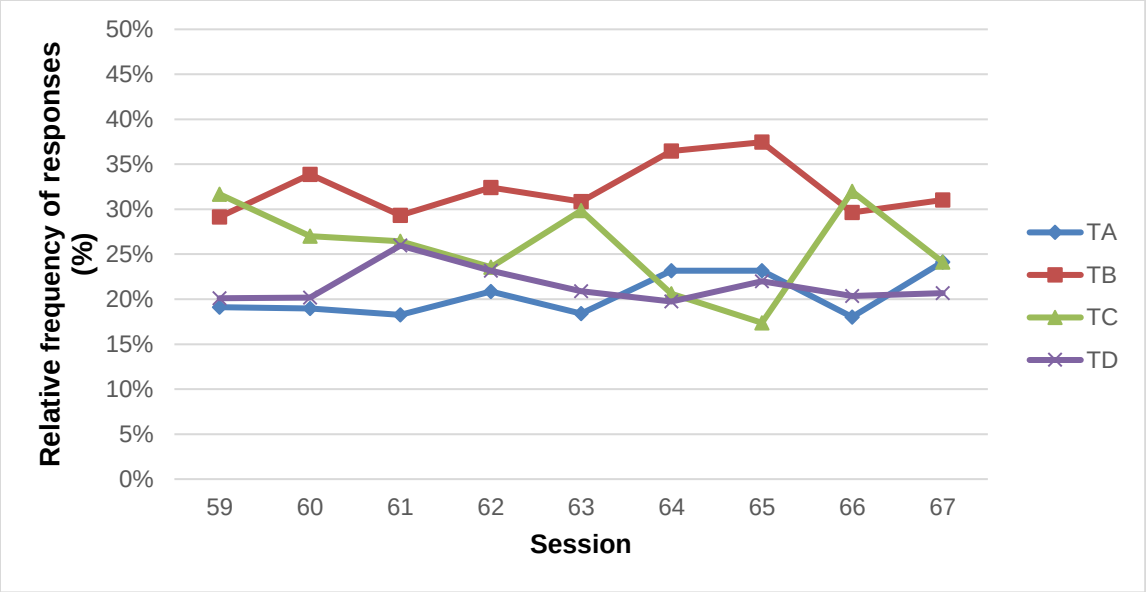


Figure 25. Relative frequency of responses for each target area during FR 2 for Mac. S^D still present in TB and the RFS occurred with each response, but darkness occurred when two responses were made.

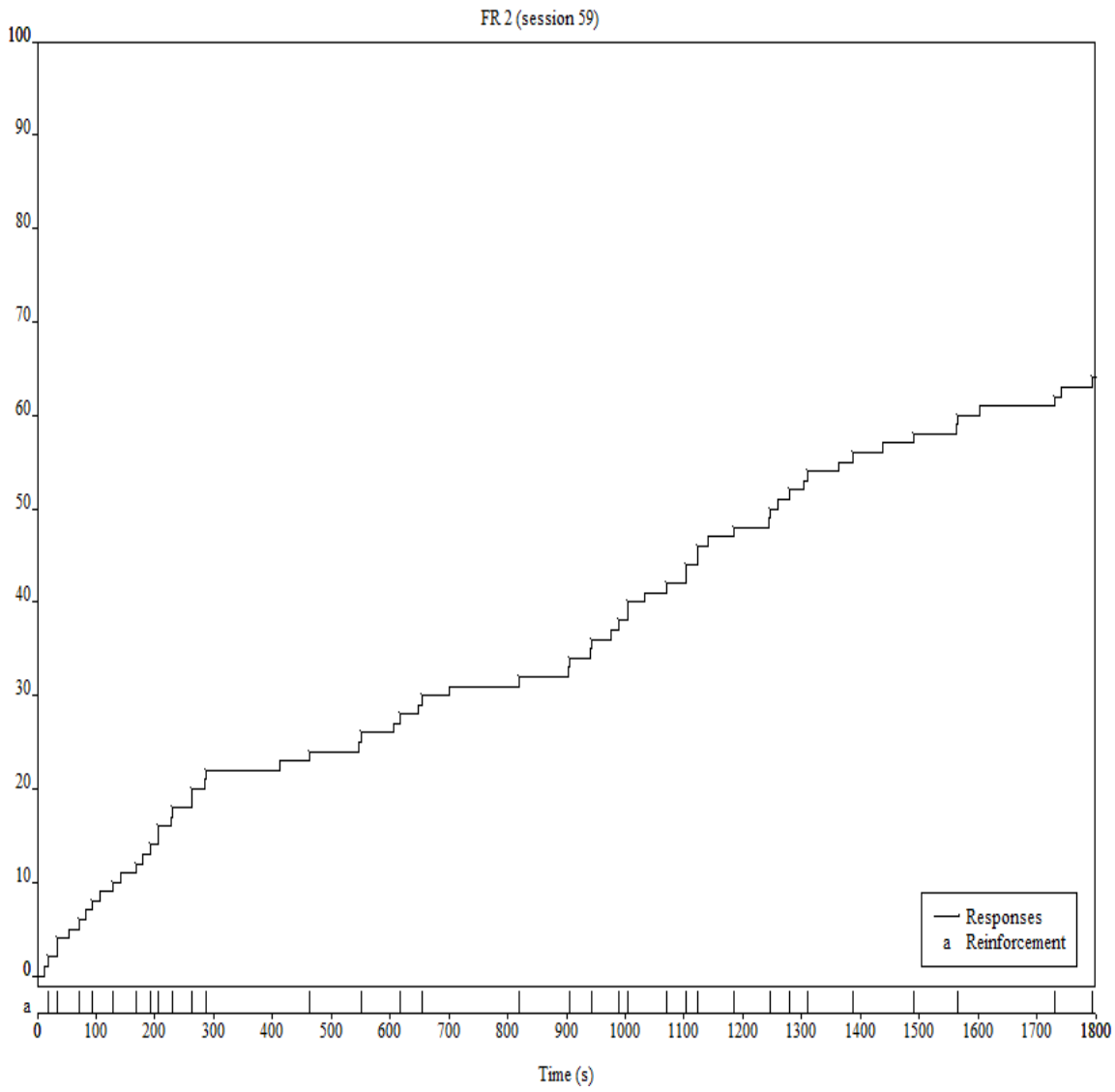


Figure 26. Cumulative record of Mac's responses for FR 2 session 59 (first FR 2 session). Note the variability in the graph, suggesting that the change from FR 1 to FR2 initially had a disruptive effect on responding (compare with Figure 22). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

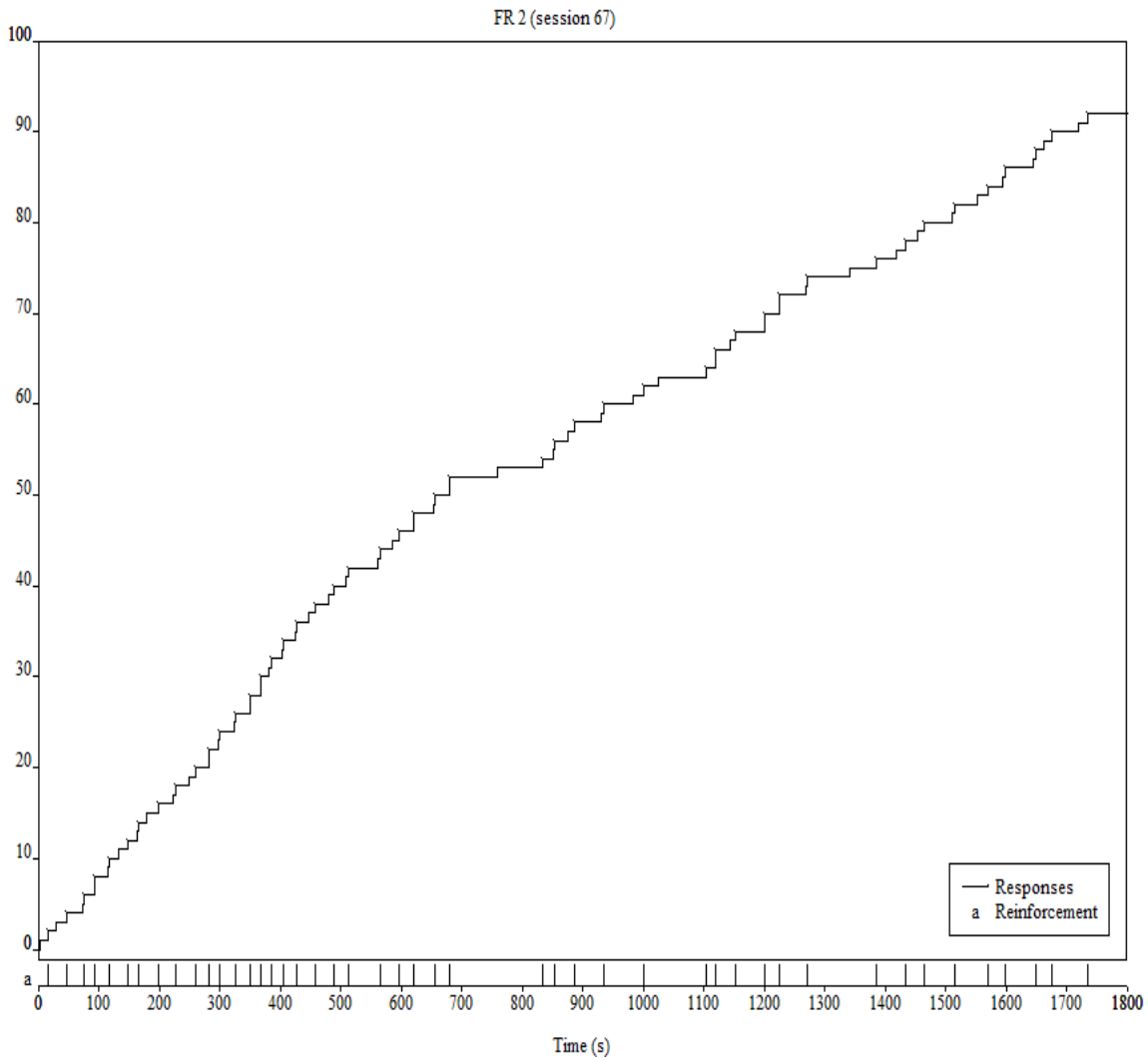


Figure 27. Cumulative record of Mac's responses for FR 2 session 67 (last FR 2 session). Note the steady responding of the graph suggest recovery by the fish from the disruptive effect of introducing FR 2 (compare with Figure 26). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

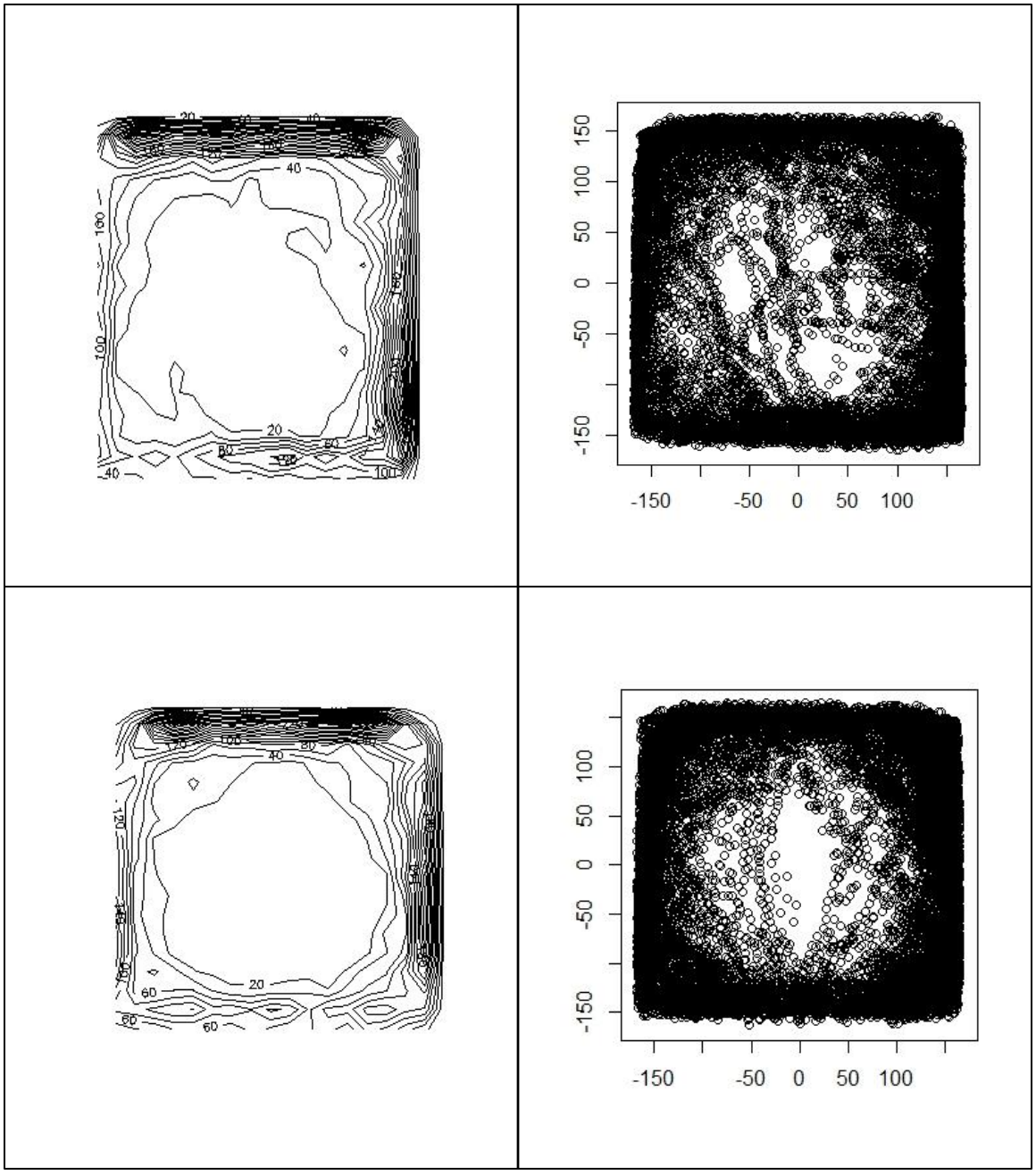


Figure 28. Swim maps (left) and scatter plots (right) of Big's location within sessions of NFB phase. Top: NFB session 1. Bottom: NFB session 7. It can be seen that from session 1 to 7 that Big decreases the amount of activity within the center area of the ET and that by session 7 the majority of activity is within close proximity to the interior perimeter of the ET.

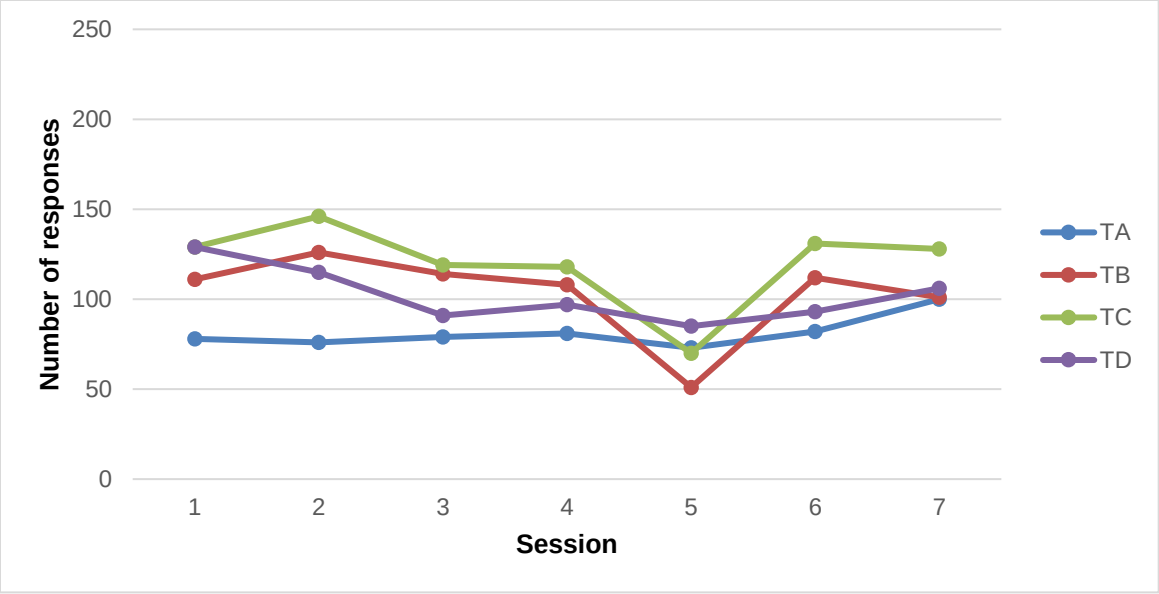


Figure 29. Number of responses for each target area for the NFB phase for Big.

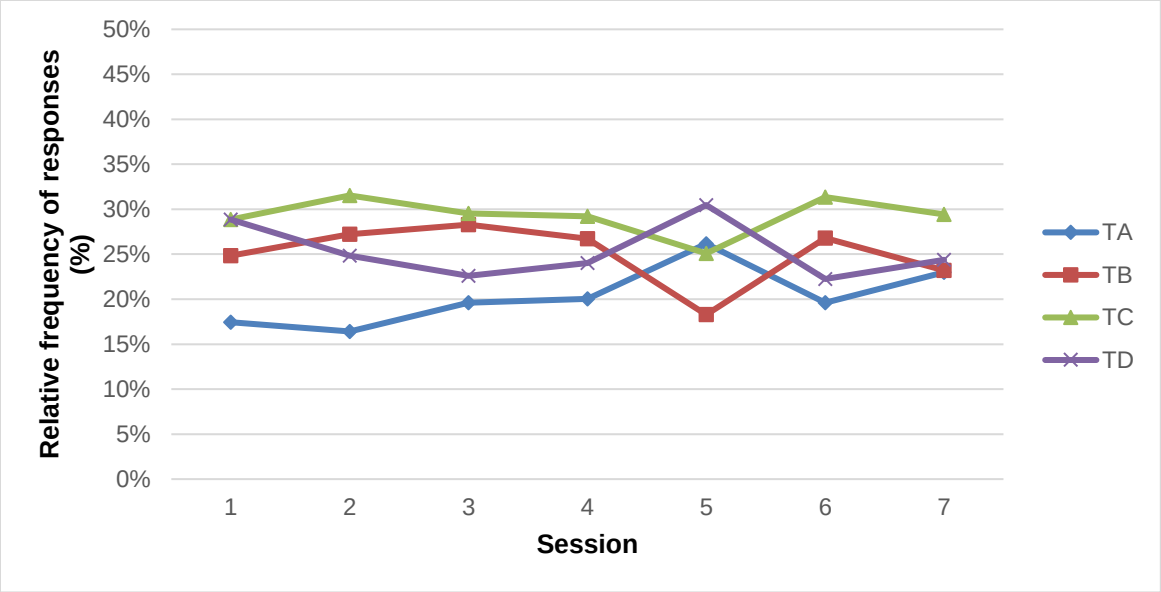


Figure 30. Relative frequency of responses for each target area during the NFB phase for Big.

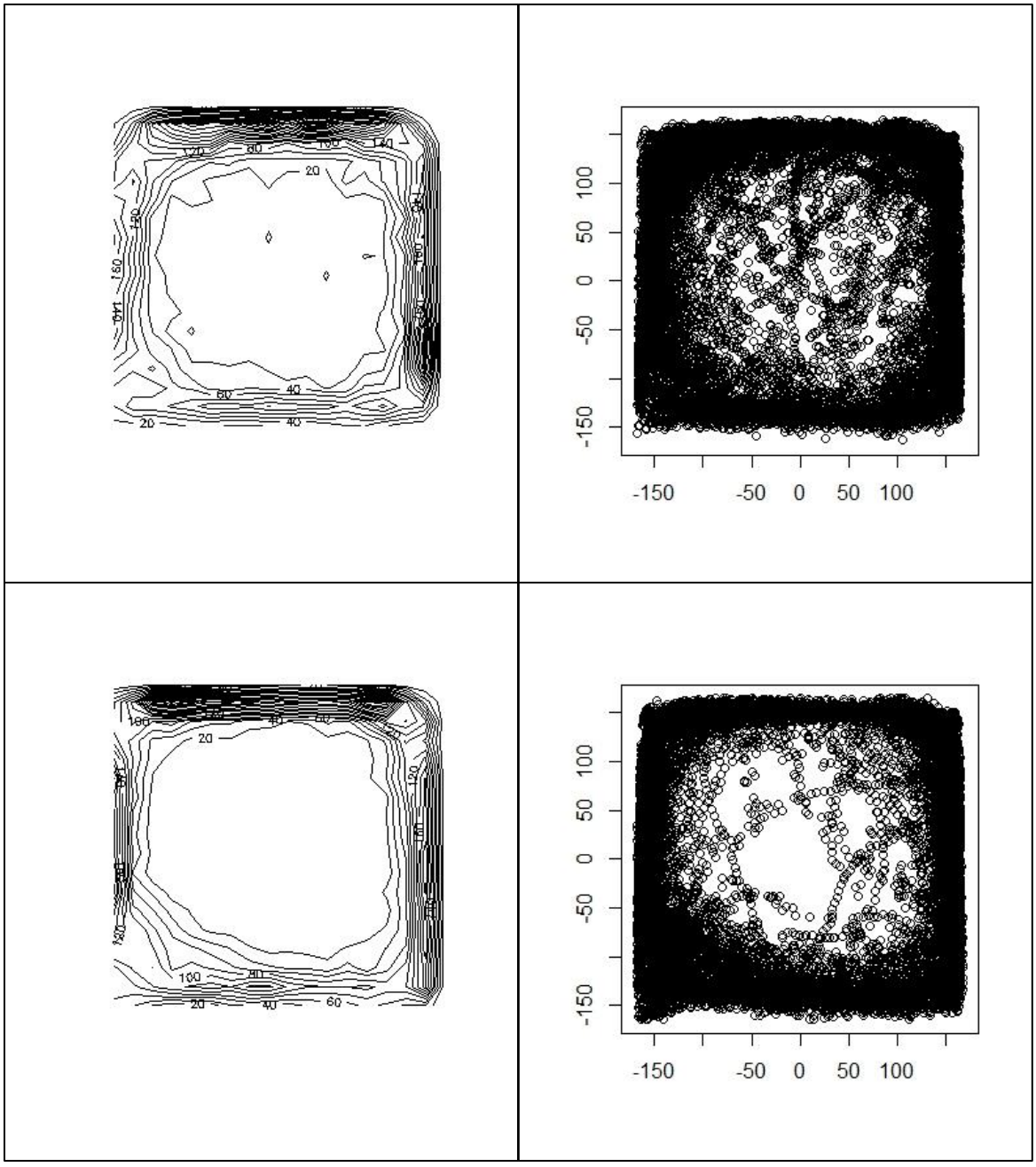


Figure 31. Swim maps (left) and scatter plots (right) of Big's location within sessions of DSB phase. Top: DSB session 8. Bottom: DSB session 19. It should be noted for session 8 that the introduction of the S^D to TA increased Big's activity in the center region of the ET and decreased activity in TA. However, by session 19 Big's activity pattern again resembles that of session 7 from the NFB phase.

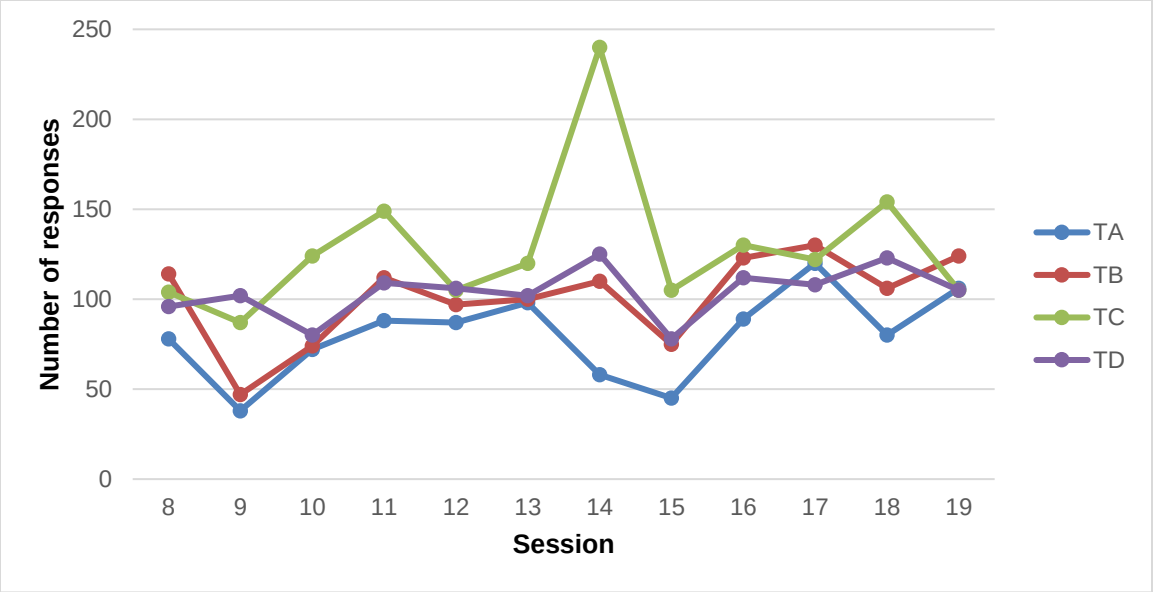


Figure 32. Number of responses for each target area for the DSB phase for Big. S^D present in TA.

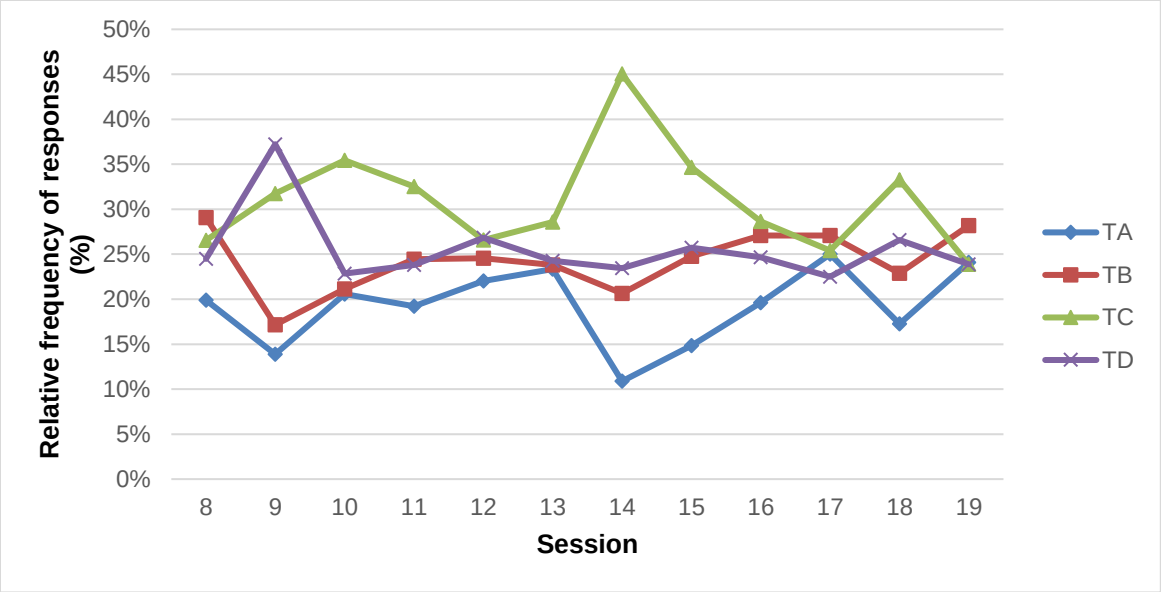


Figure 33. Relative frequency of responses for each target area during the DSB phase for Big. S^D present in TA.

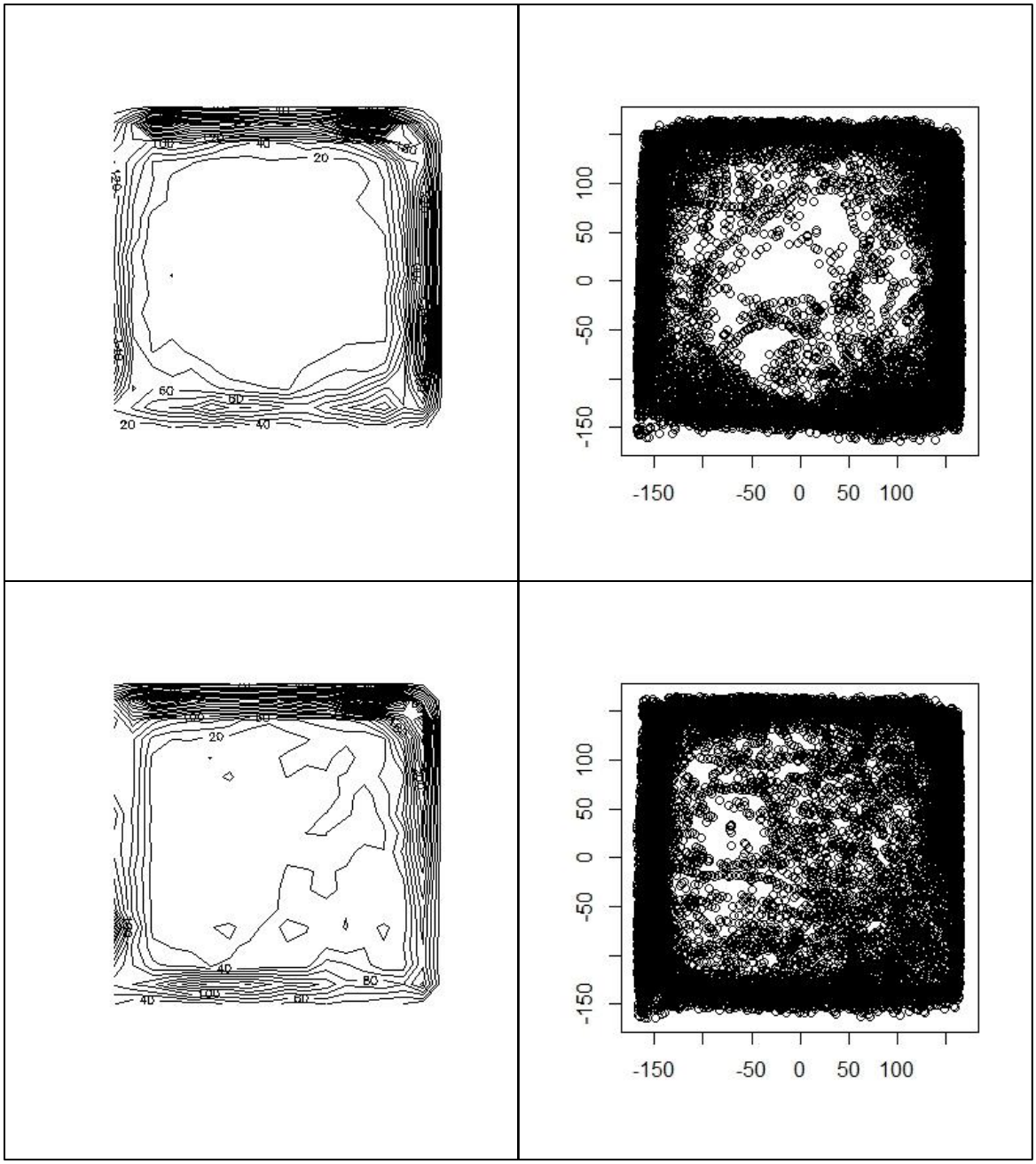


Figure 34. Swim maps (left) and scatter plots (right) of Big's location within sessions of RFSB phase. Top: DSB session 20. Bottom: DSB session 26. S^D present in TA and RFS occurred with each response to TA. In the swim map of session 20 it can be seen that the addition of the RFS had little impact on Big's activity in TA except decreasing it slightly. By Session 26 the swim map appears to show little change in activity with the activity in TA increasing to levels that were observed in session 19 swim map.

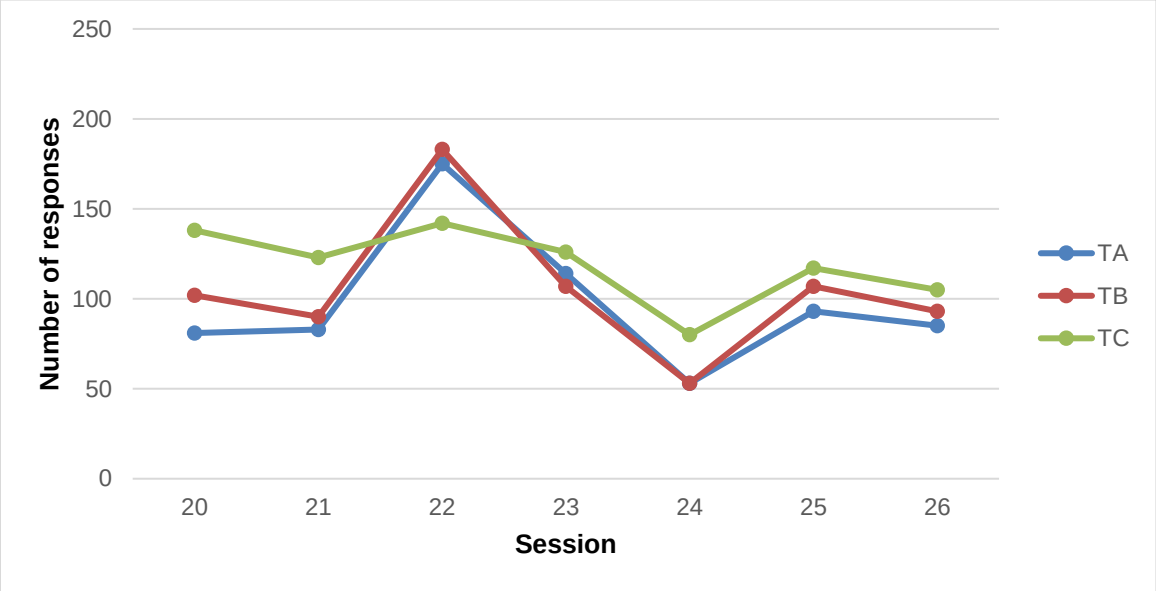


Figure 35. Number of responses for each target area for the RFSB phase for Big. S^D present in TA and RFS occurred with each response to TA.

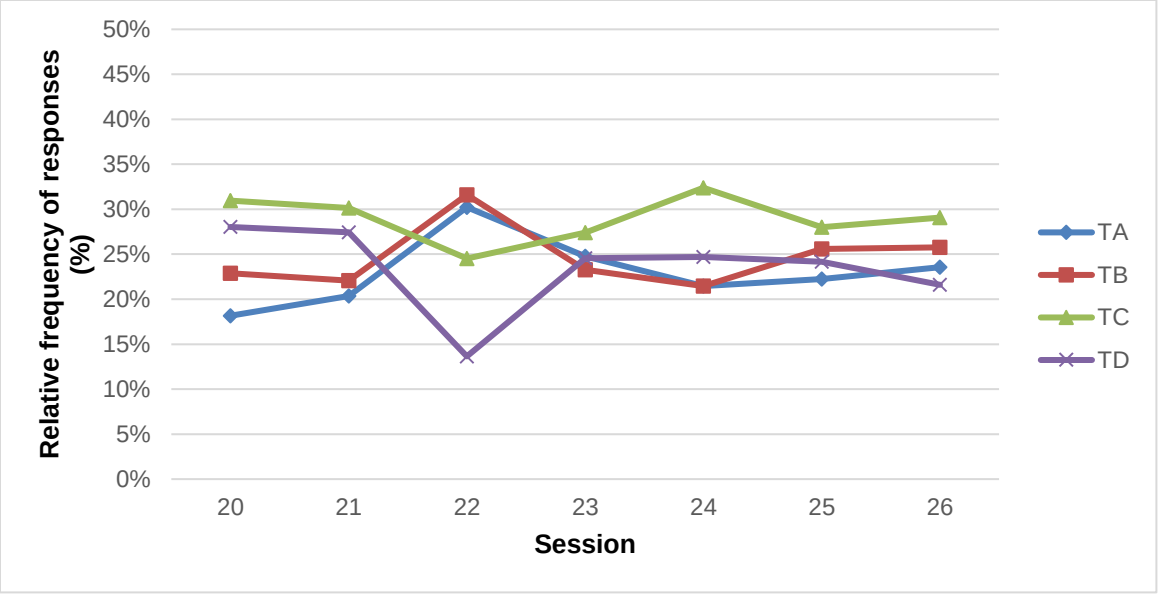


Figure 36. Relative frequency of responses for each target area during the RFSB phase for Big. S^D present in TA and RFS occurred with each response to TA.

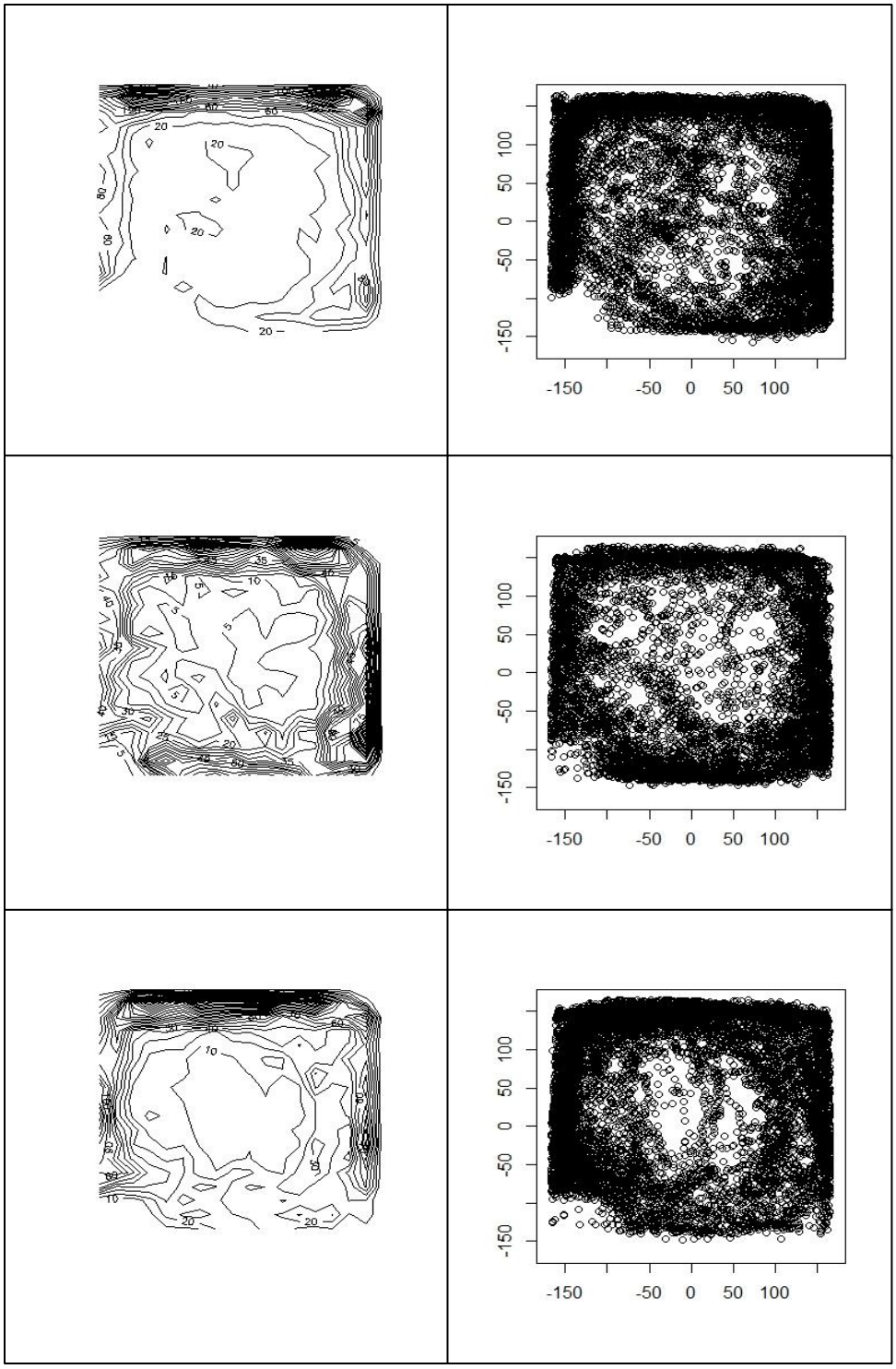


Figure 37. Swim maps (left) and scatter plots (right) of Big's location within sessions of FR 1 phase. Top: FR 1 session 27. Middle: FR 1 session 35. Bottom FR 1 session 43. S^D present in TA where darkness and RFS occurred with each response to TA. It was observed that by session 35 Big's activity around TA had increased compared to session 27. And that by session 43 activity was even greater than session 35 as well as more concentrated.

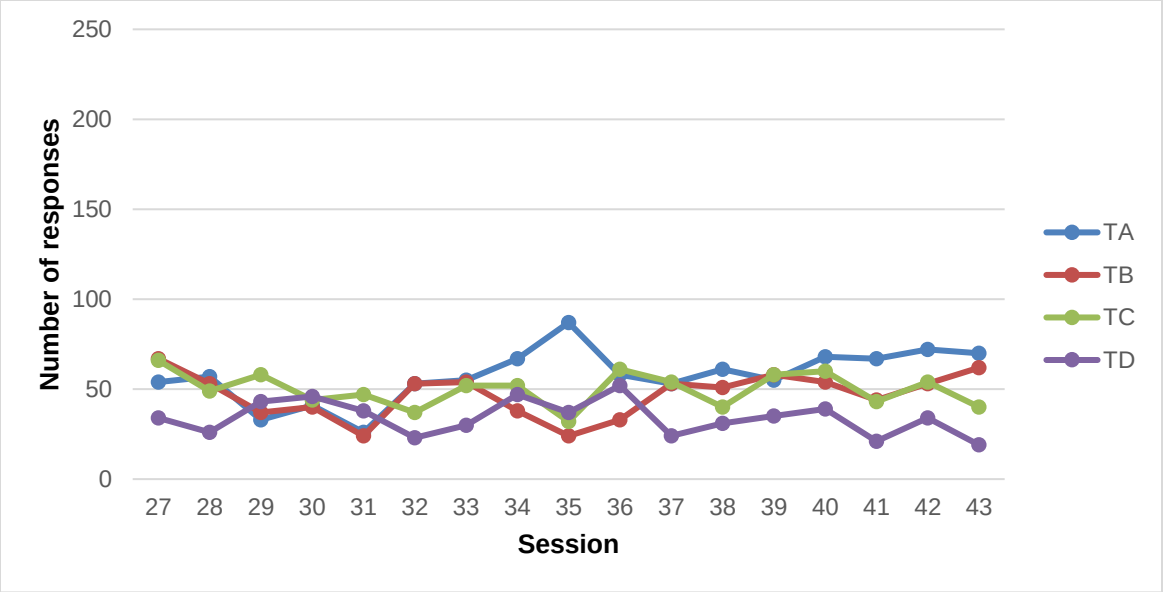


Figure 38. Number of responses for each target area for FR 1 for Big. S^D present in TA where darkness and RFS occurred with each response to TA.

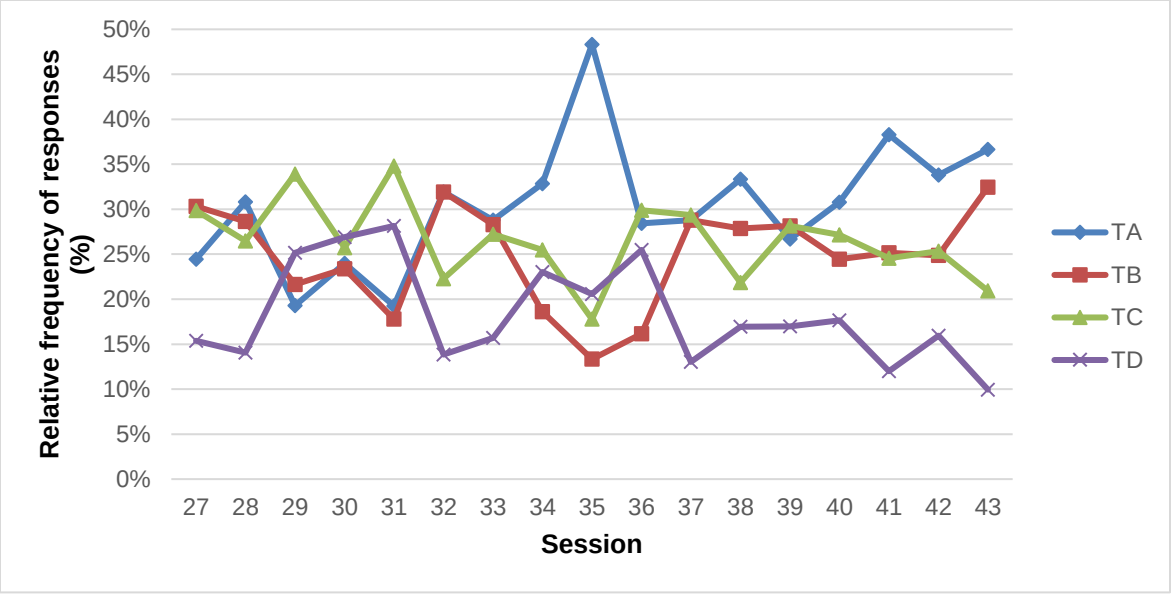


Figure 39. Relative frequency of responses for each target area during FR 1 for Big. S^D present in TA where darkness and RFS occurred with each response to TA.

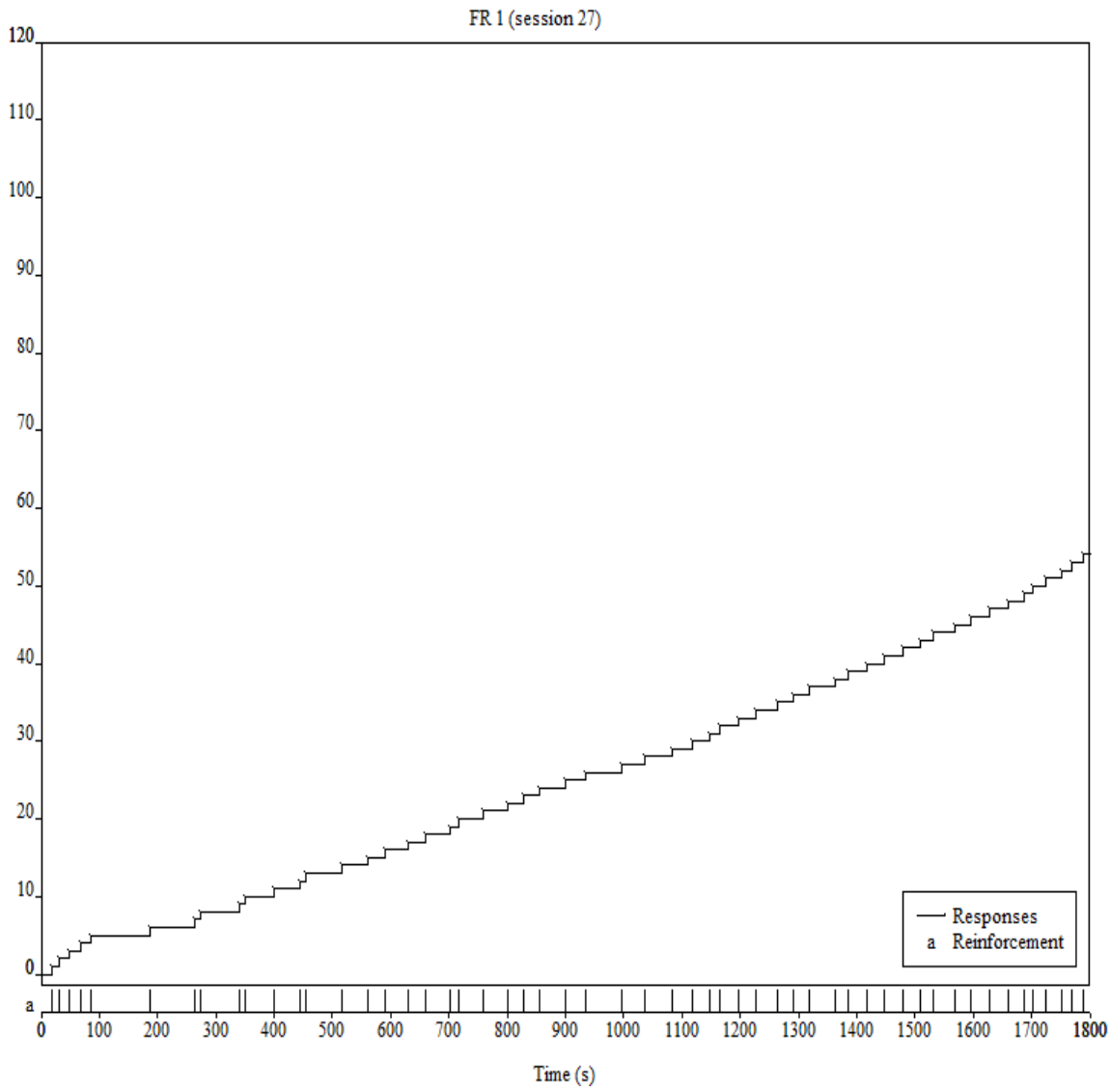


Figure 40. Cumulative record of Big's responses for FR 1 session 27 (first FR 1 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

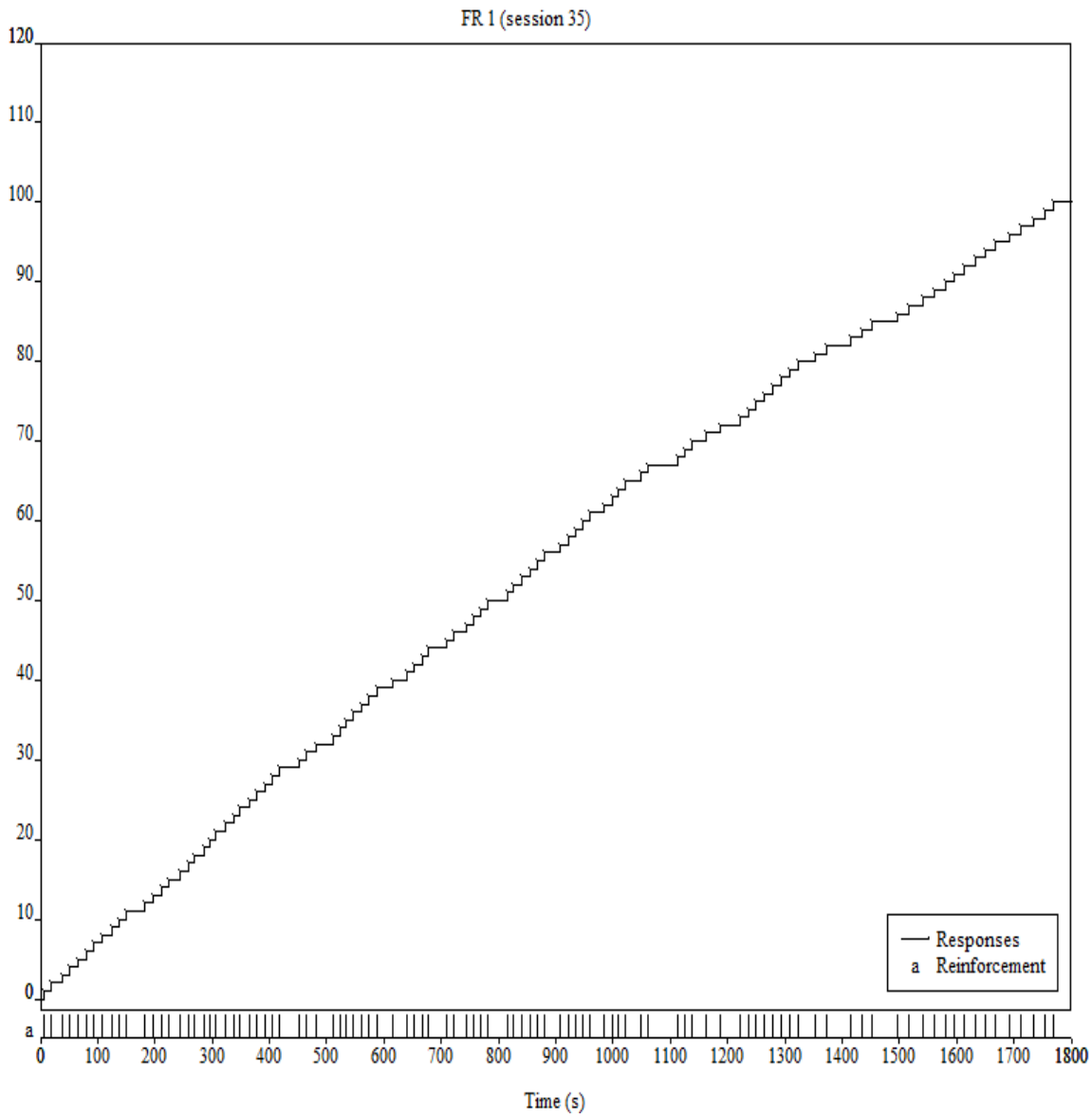


Figure 41. Cumulative record of Big's responses for FR 1 session 35 (8th FR 1 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

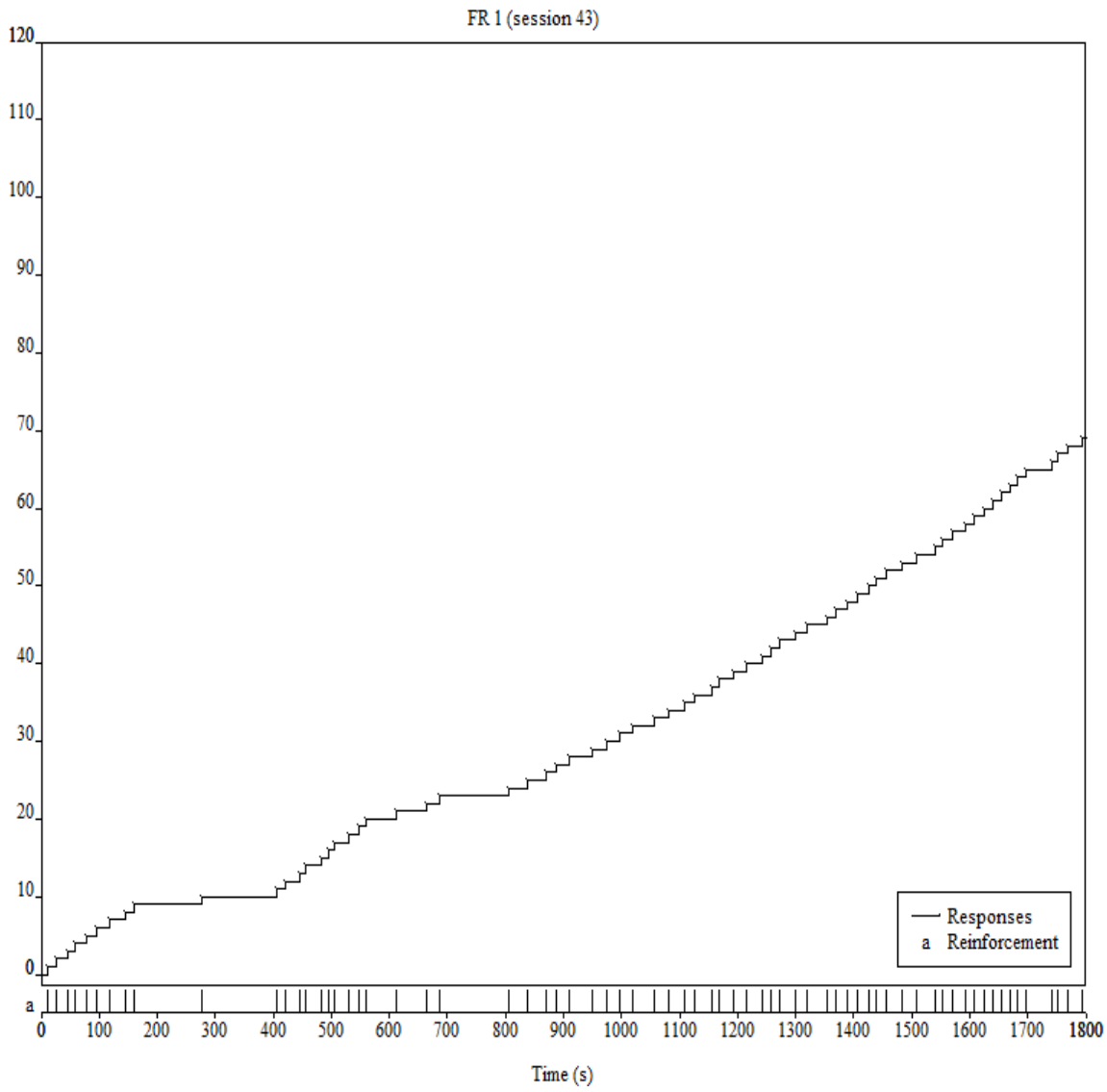


Figure 42. Cumulative record of Big's responses for FR 1 session 43 (last FR 1 session). Note that responding became fairly linear about halfway through the session. Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

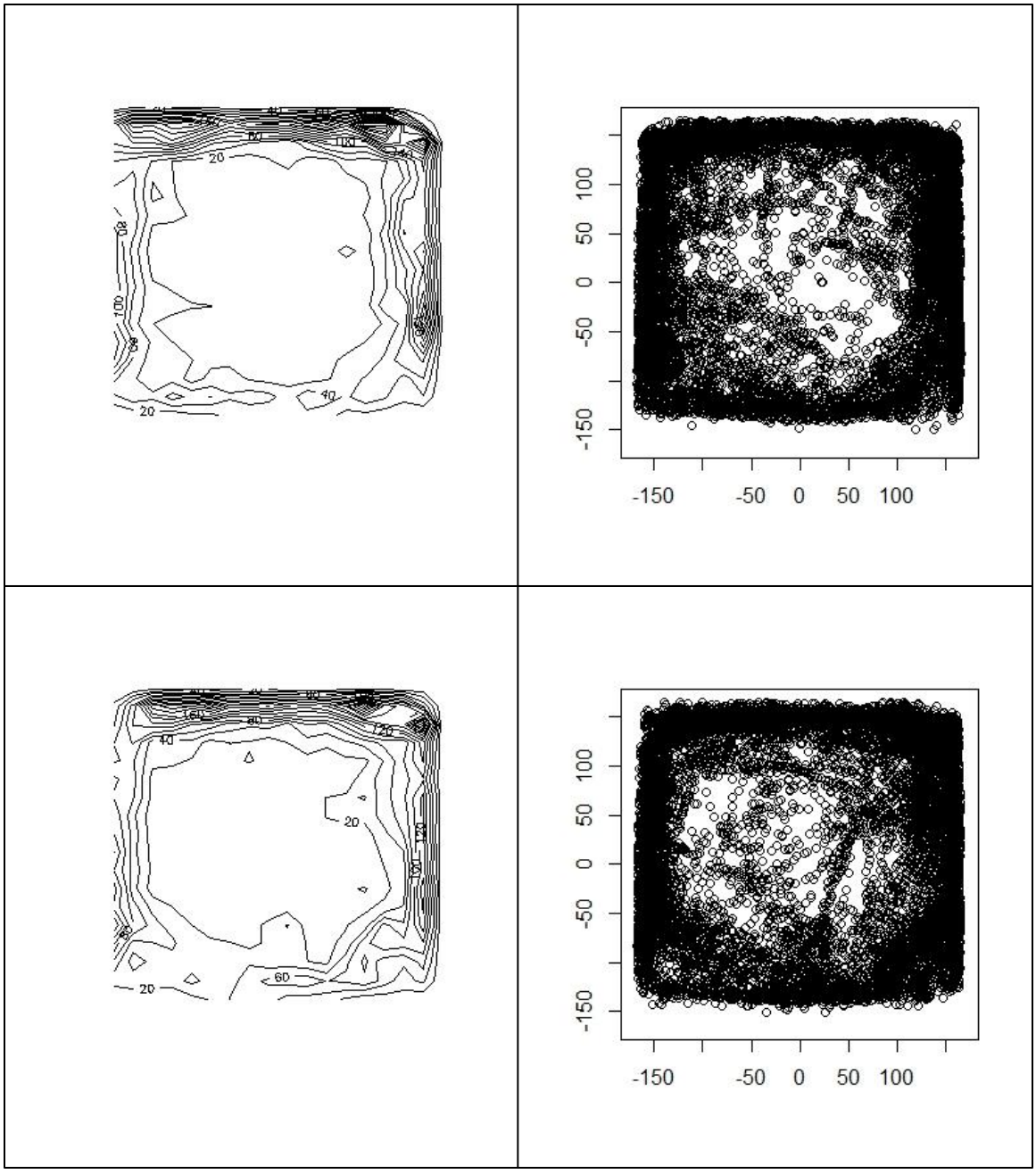


Figure 43. Swim maps (left) and scatter plots (right) of Big's location within sessions of the FR 2 phase. Top: FR 2 session 44. Bottom FR 2 session 51. S^D present in TA where RFS occurred with each response and darkness occurred every second response to TA. The swim map for session 44 does not differ from FR 1 session 43. But by session 51 in the FR 2 phase there was an increase in the activity between TA and TD.

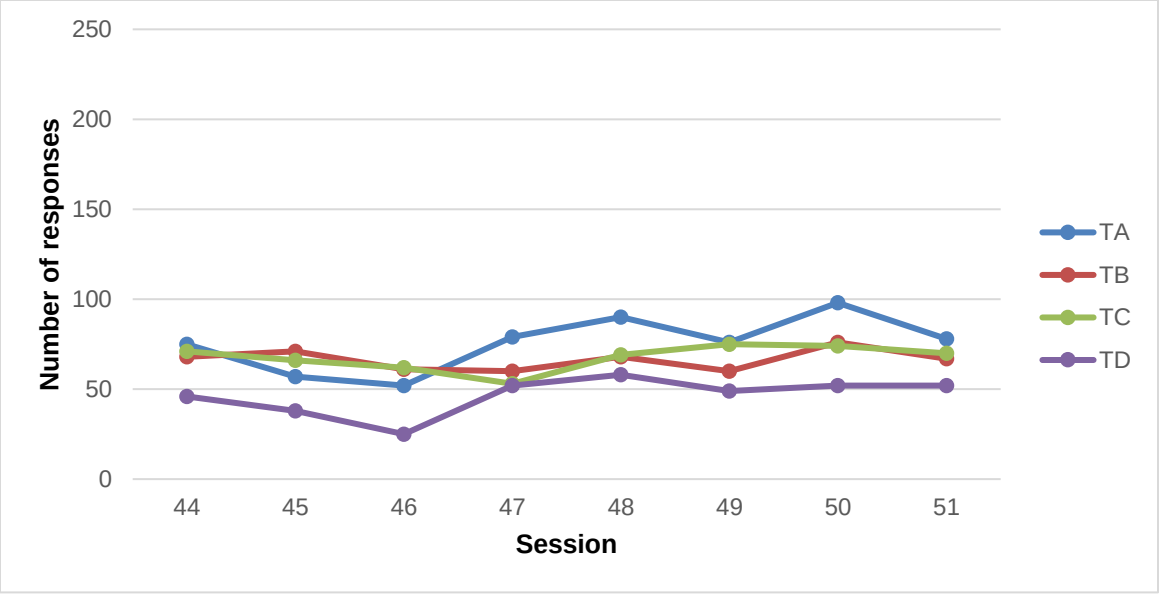


Figure 44. Number of responses for each target area for FR 2 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every second response to TA.

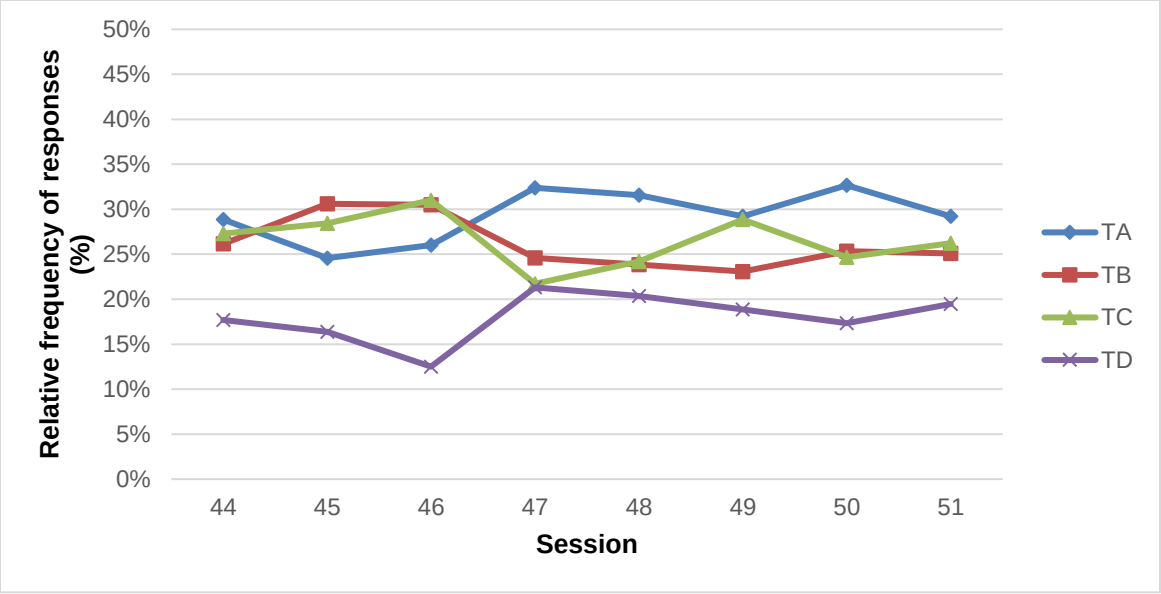


Figure 45. Relative frequency of responses for each target area during FR 2 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every second response to TA.

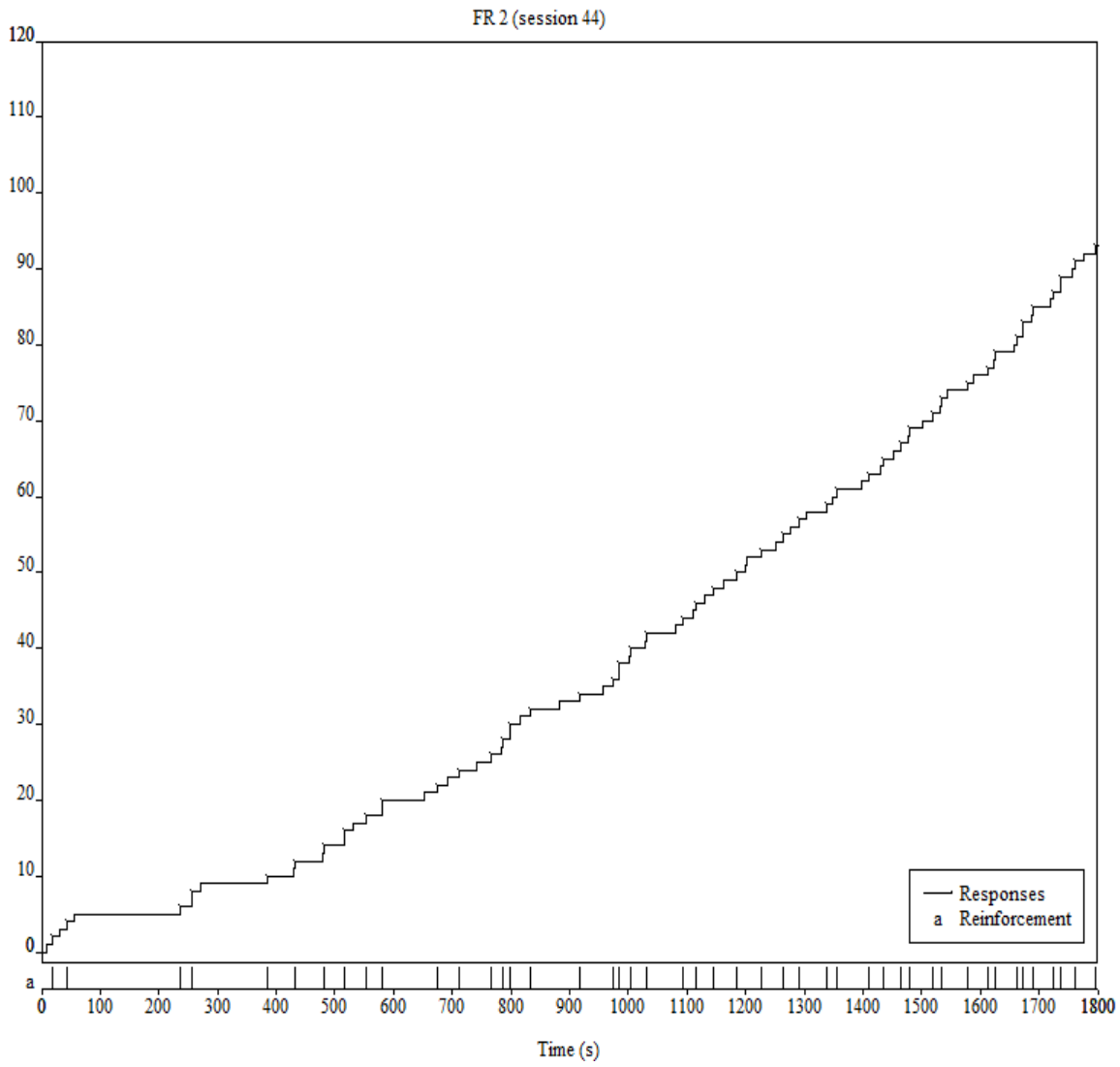


Figure 46. Cumulative record of Big's responses for FR 2 session 44 (first FR 2 session). Note the variability in responding, suggesting that the introduction of FR 2 had a disruptive effect on Big's responding (compare with Figure 42). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

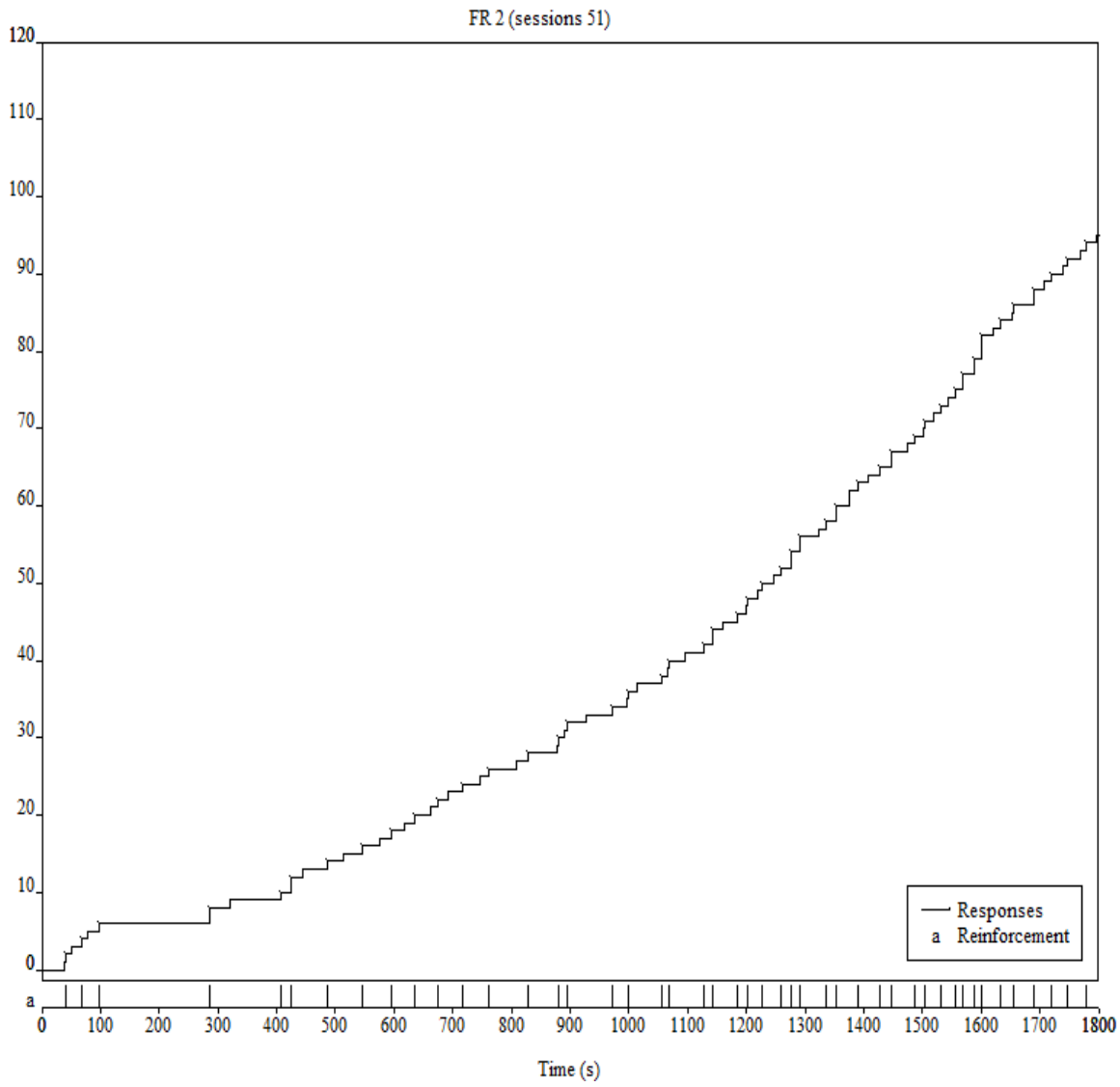


Figure 47. Cumulative record of Big's responses for FR 2 session 51 (last FR 2 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

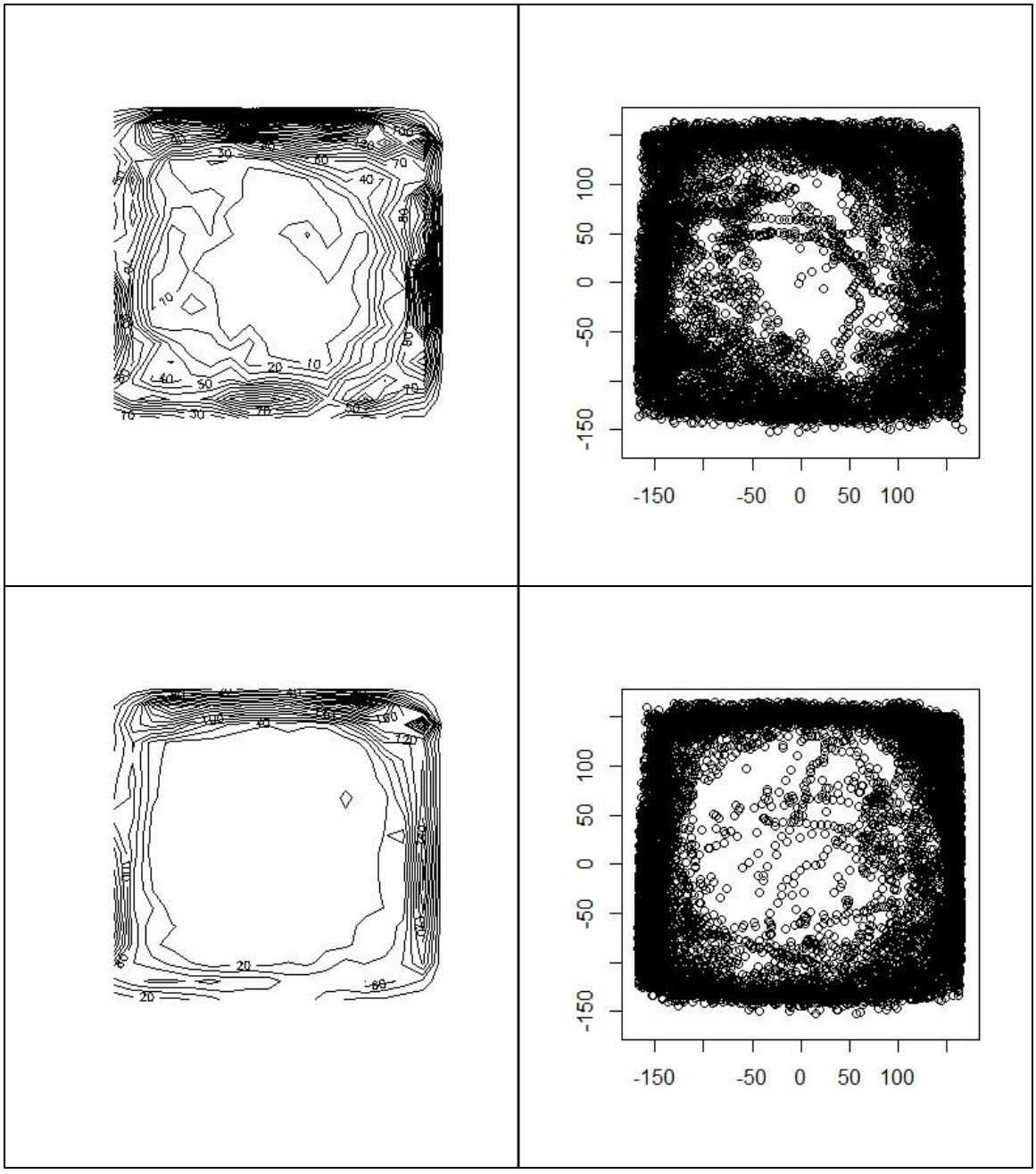


Figure 48. Swim maps (left) and scatter plots (right) of Big's location within sessions of FR 3 phase. Top: FR 3 session 52. Bottom FR 3 session 59. S^D present in TA where RFS occurred with each response and darkness occurred every third response to TA. In the swim map of session 52 the amount of activity in TA increased from session 51. By session 59 Big's activity is more focal to the interior perimeter of the ET near TA.

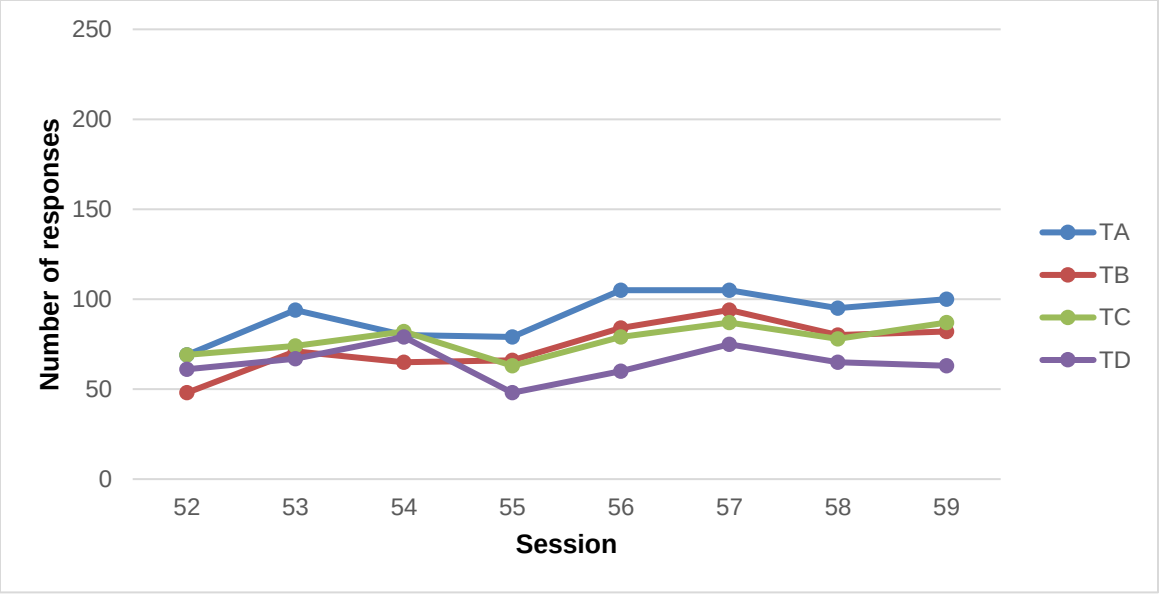


Figure 49. Number of responses for each target area for FR 3 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every third response to TA.

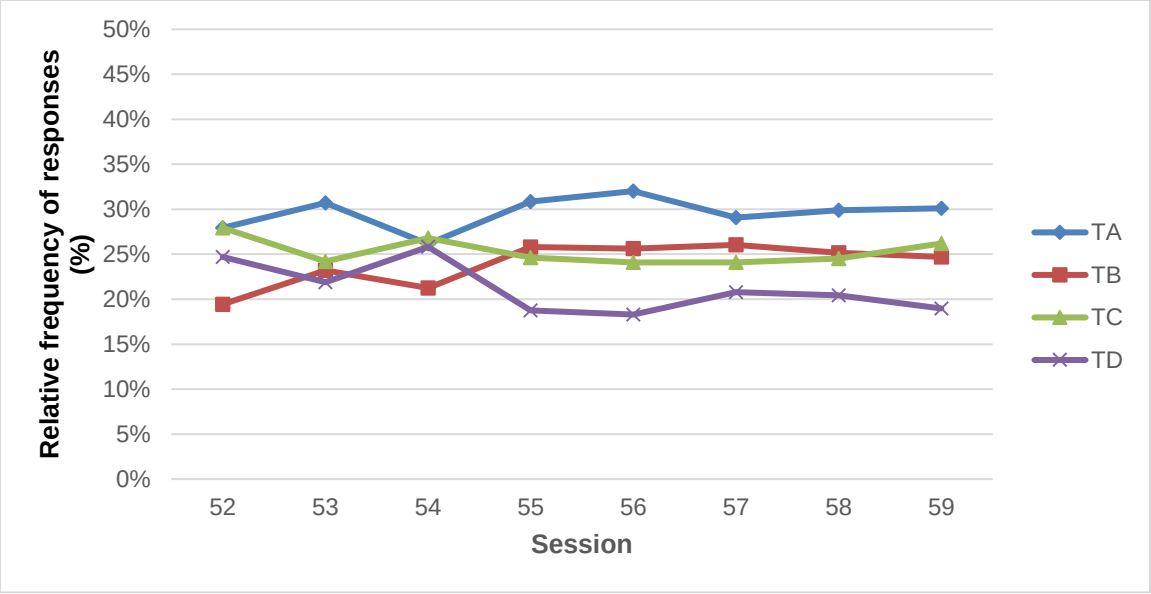


Figure 50. Relative frequency of responses for each target area during FR 3 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every third response to TA.

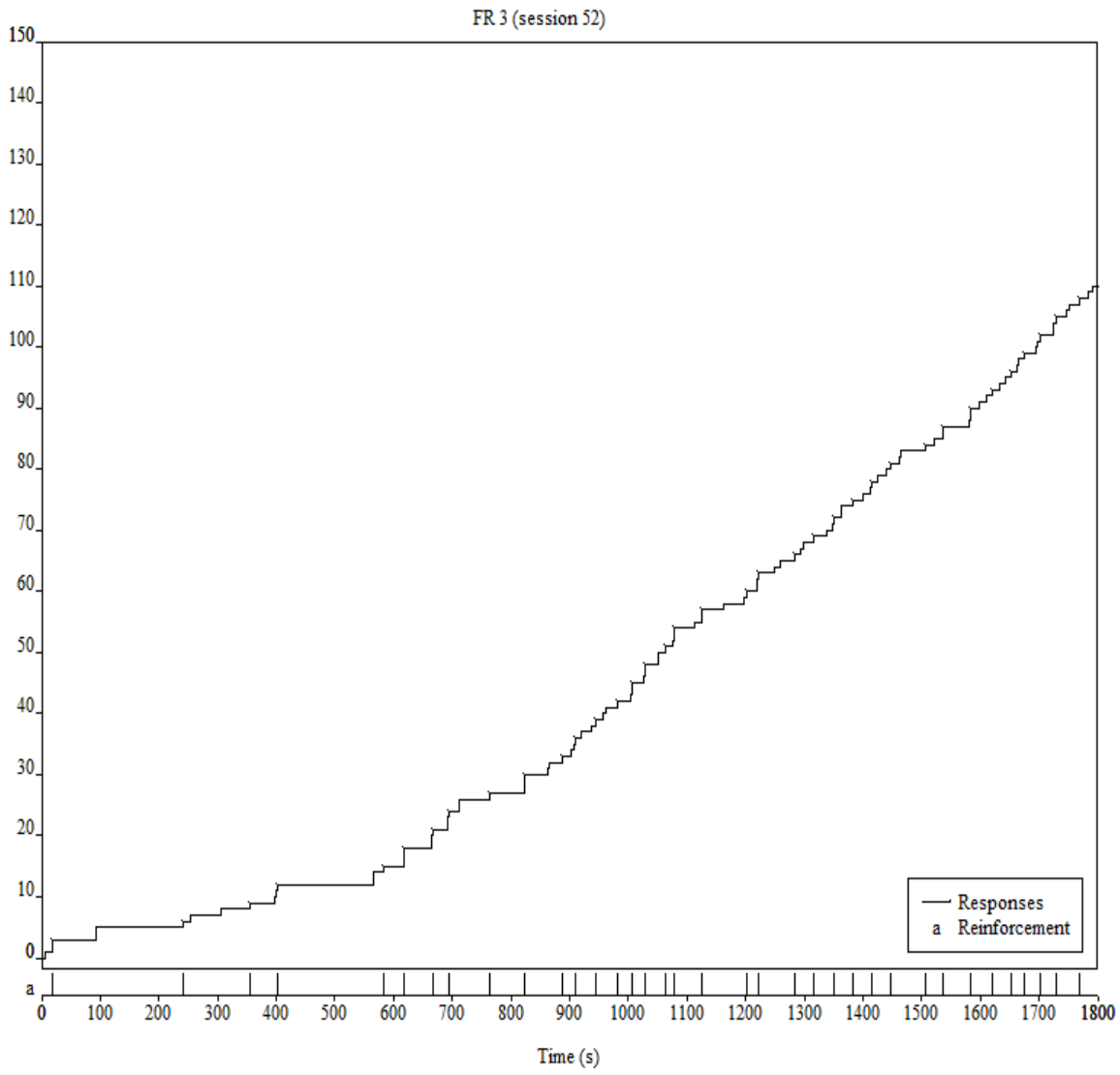


Figure 51. Cumulative record of Big's responses for FR 3 session 52 (first FR 3 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

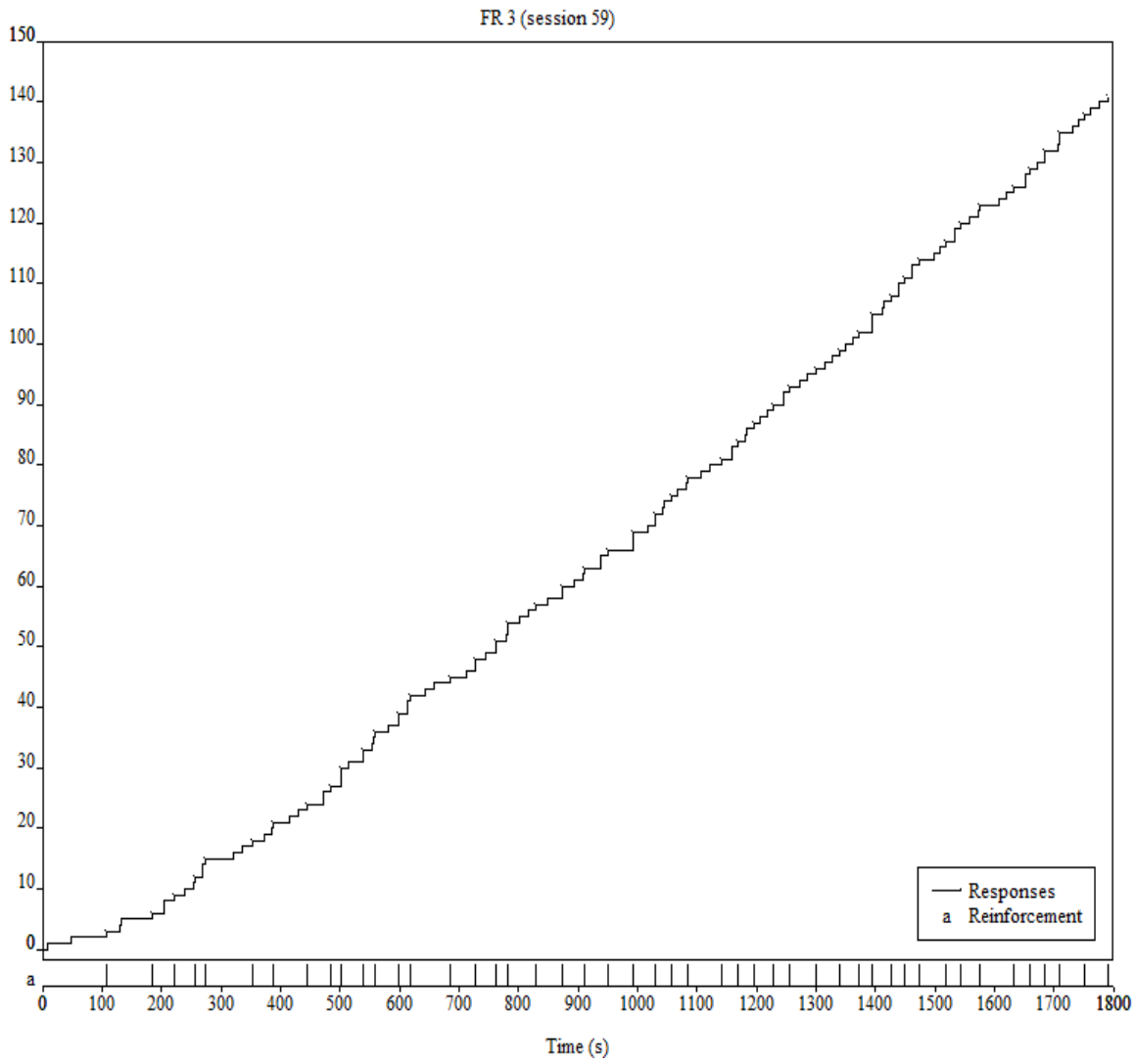


Figure 52. Cumulative record of Big's responses for FR 3 session 59 (last FR 3 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

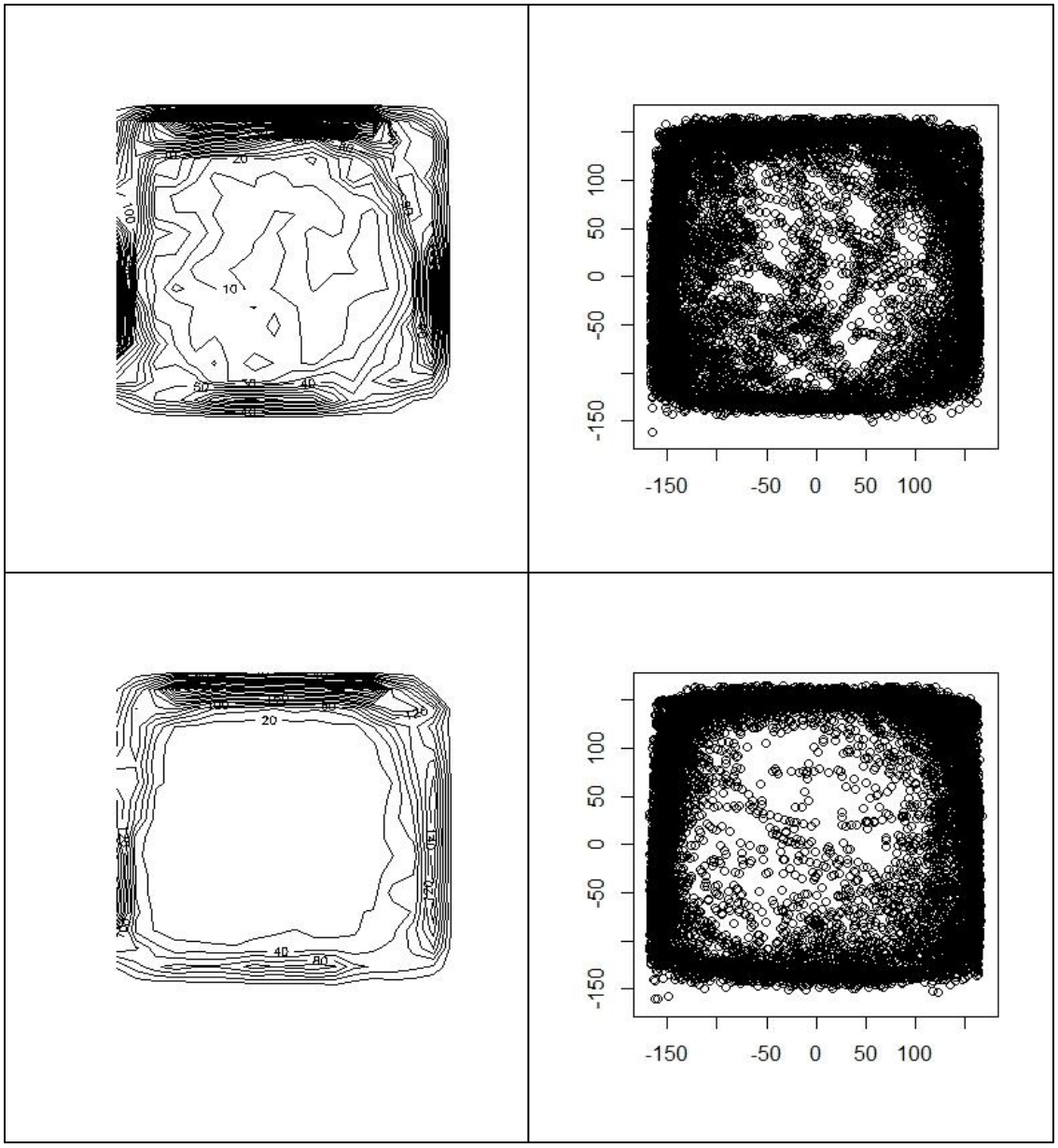


Figure 53. Swim maps (left) and scatter plots (right) of Big's location within sessions of FR 4 phase. Top: FR 4 session 60. Bottom FR 4 session 67. S^D present in TA where RFS occurred with each response and darkness occurred every fourth response to TA. It can be seen in the swim map of session 60 that the presentation of darkness on an FR 4 schedule caused Big to increase the amount of activity in the center of the ET and the interior perimeter area of the ET. By session 67 the activity observed during session 60 has dissipated and Big's swim map for session 67 resembles session 59 from FR 3 phase.

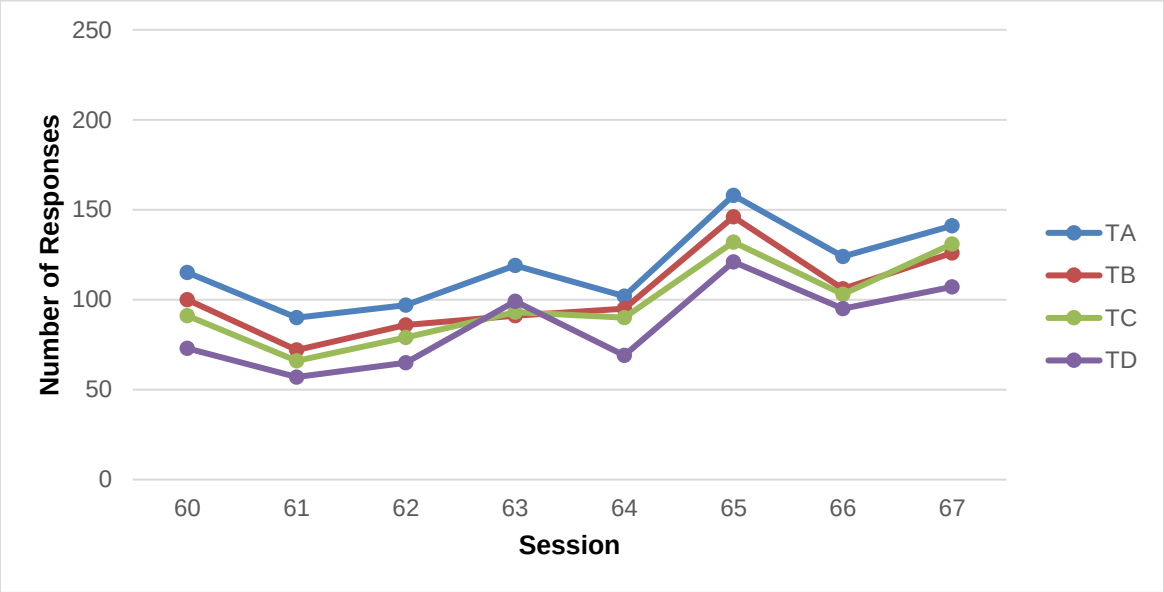


Figure 54. Number of responses for each target area for FR 4 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every fourth response to TA.

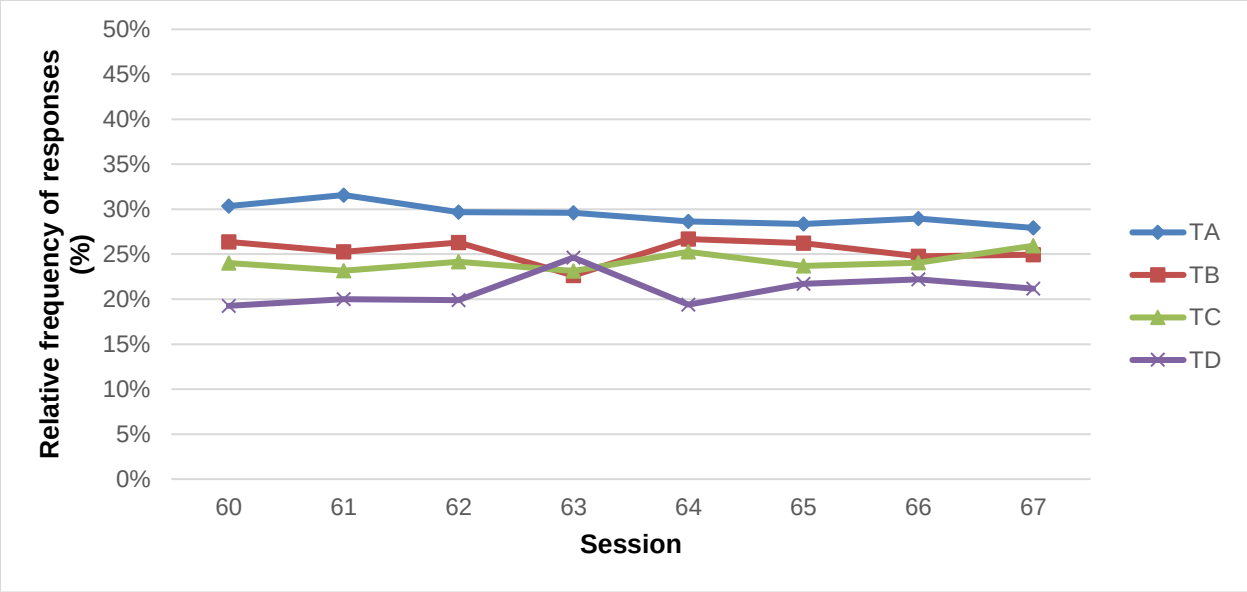


Figure 55. Relative frequency of responses for each target area during FR 4 for Big. S^D present in TA where RFS occurred with each response and darkness occurred every fourth response to TA.

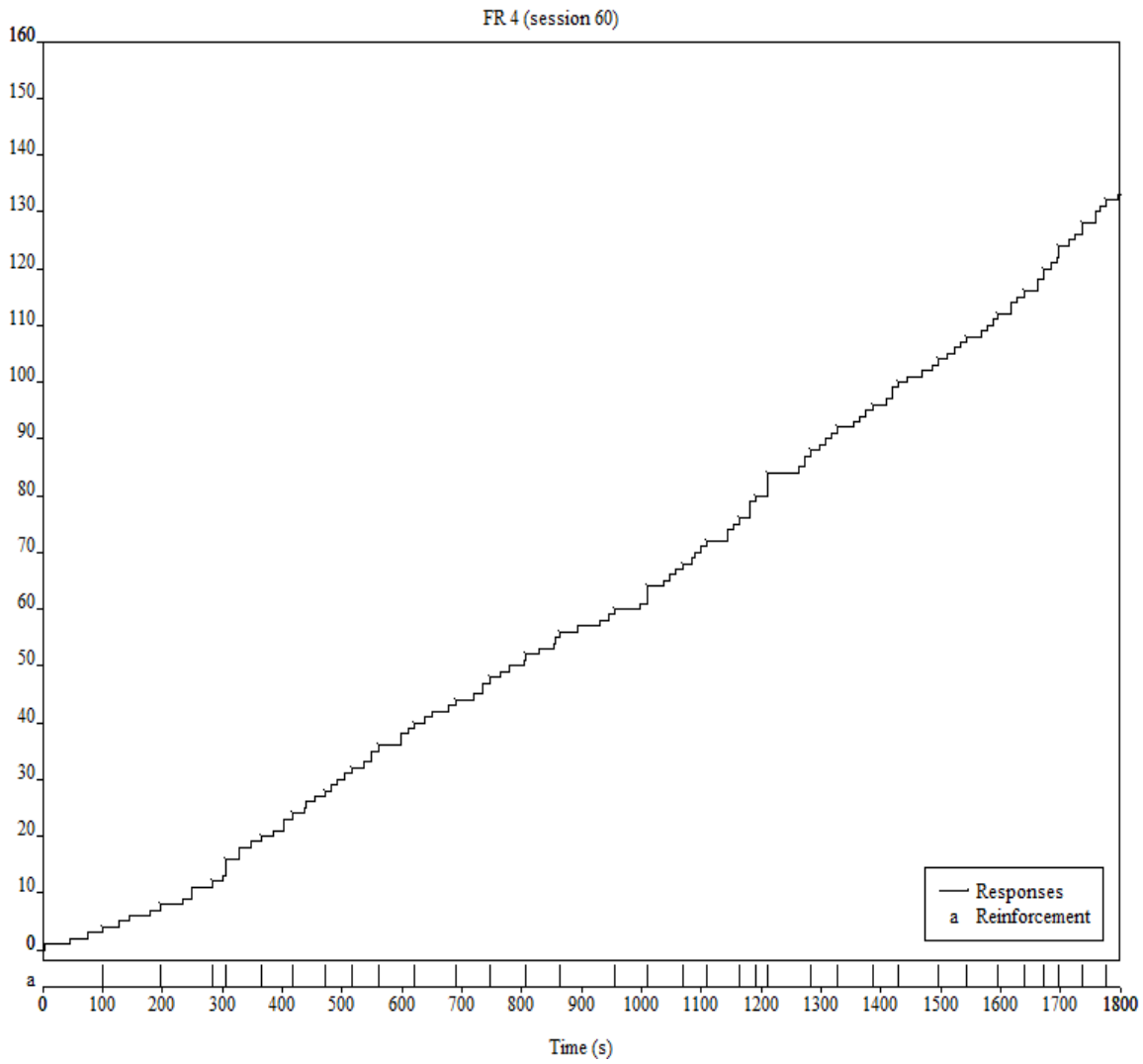


Figure 56. Cumulative record of Big's responses for FR 4 session 60 (first FR 4 session). Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

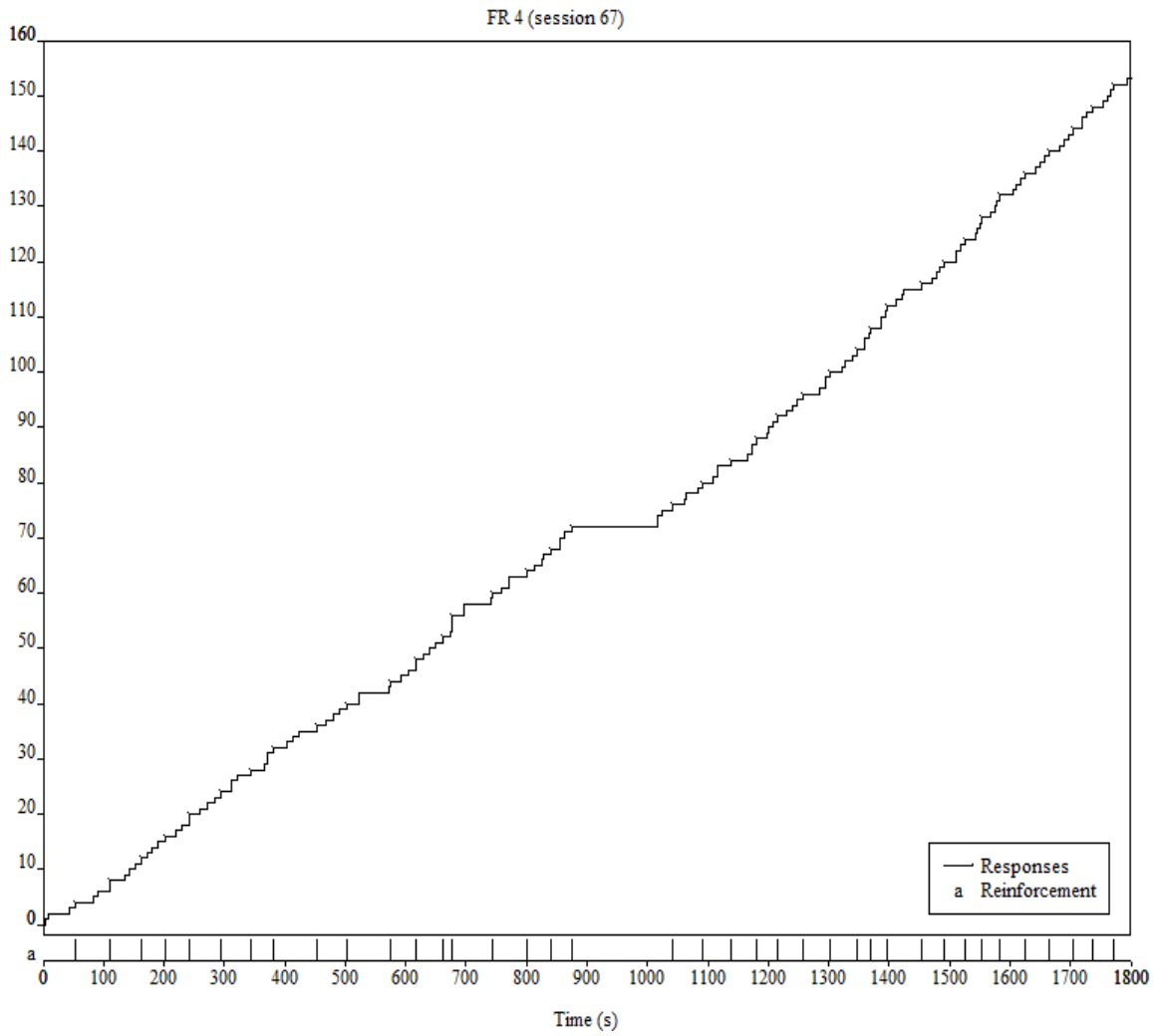
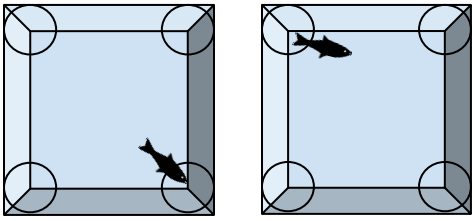


Figure 57. Cumulative record of Big's responses for FR 4 session 67 (last FR 4 session). Note that a break-run pattern had developed. Upward deflections of the graph and tick marks along the bottom both indicate 10-s presentations of darkness.

Appendices

Appendix A
Response Requirements for Visual Observation and IOA



- ❑ A response consists of the entry into any of the designated target zones (marked by the black dots/circles) with any portion of the subject's body.

- ❑ If subject is in a target area when the session begins (0s) it does NOT constitute a hit.

- ❑ The subject must leave the target area and re-enter or go to a new target area to constitute a response.

- ❑ Any response that occurs between the start and end of session are to be recorded for data analysis.

Appendix B

Lab Session Procedure (STURGEON)

******Requires security clearance to enter the biological sciences facility independently.***

1. Enter lab and turn on lights.

2. Fill kettle with dechlorinated water from the BRUTE water barrel using the water pitcher.

3. Place the filled kettle on its base and turn the kettle on. In the winter you may want to fill up both kettles.

4. Turn on the white computer by pressing the red switch (labelled 1 with red sticker) on the power bar that is on the floor to the left side of the desk.

5. Turn on the black computer by pressing the power button on the DELL computer tower (power button is labelled 2 with red sticker).

6. Allow both computers time to load fully.

7. On the white computer the screen will have a menu with the word catfish highlighted. JUST PRESS ENTER. The white computer is now ready.

8. Press the power button on the television monitor and VCR below. Then on the VCR press the channel down button.

9. Enter the password on the black computer to log it on. Allow the computer to fully load.

10. Select Fishcamp program from desktop by right clicking and selecting open.

11. Go to file and open. Then select the program that is for your experiment.

12. Select start and a small window (start experiment) will pop up. Put in your fishes ID and decrease the time to 5 seconds. This computer is ready to go.

13. Retrieve the jugs of cold water from the walk-in fridge. Bring the jugs back to the experimental room one at a time as they are heavy; use the Rubbermaid cart if you prefer for transport.

14. Fill the ET ½ way to the indicated fill line (5 cm) using the room temperature water from the BRUTE barrel. If you go over the fill line remove excess water with the pitcher and dump it down the sink. **(Note: once water has been removed from BRUTE water barrel it cannot be put back, simply dump in the sink if needed).**

15. For this step you need the thermometer, CT (Betty Crocker one) with a lid, and the opaque container and lid. Take all supplies and go to the room the sturgeons are kept in biological

sciences to get temperature of the subject's home tank (HT). There is no heater in the sturgeons HT so just hold the thermometer in the HT until temperature stabilizes. Also, make sure you look where the fish is in the HT before placing the thermometer in the HT so that you do not hurt the fish. The temperature should be around 16°C. The range of temperature for the sturgeons is 15°C to 18°C.

16. After you have noted the temperature of the HT, retrieve the desired subject (note all subjects are kept in the same HT so be sure to attain the correct subject) using a net and CT. Nets are located at the front of the sturgeon room by the sinks. Don't worry about wearing a glove. Before retrieval, select the net in back behind the other nets. Rinse the net you plan to use with the spray nozzle at the sink to remove sanitizer residue. You may now use the net to retrieve the subject. For more of a visual demonstration see the demo video for the nets.

17. Once the subject is in the CT close the CT with its lid and place it in the opaque container and cover with its respective lid.

18. Return the cover the sturgeons HT as was found. Be sure that the water drips into the HT and is not blocked by the lid as the dripping water is how fresh water gets in and if the water cannot continuously flow the fish will die. Rinse the net again using the nozzle at the sink and dip the net into the sanitizer bath after catch is complete. Hang this net in front of the other nets.

19. Exit the biological sciences facility and return with your subject to the psychology facility and lab. Be sure to walk carefully while holding the travel container to ensure that you do not drop it or bump the container.

20. Once in the experimental room, add hot or cold water as necessary. Mix the water with the pitcher until you are within a +/- .5°C temperature range of the HT temperature. Mix thoroughly. THIS IS IMPORTANT FOR THE FISHES SAFETY! Allow the thermometer sit for about 10 s to make sure temperature is stable.

21. Once the temperature is stable in the ET, record it on your data sheet and then use the Shamwow (orange cloth) to clean up any water on the tabletop in the ET. If you have gone over the fill line remove the excess water with the water pitcher and pour into the sink.

22. Turn off lights in the ET room.

23. Remove the lid to the opaque travel container and retrieve the CT. Take the CT to the ET room, remove the CT cover and place the subject in the center of the ET using to same angle used during catch.

24. Close door to ET room and let the subject sit in darkness for 2 minutes (use a watch or stopwatch for this). This is called an acclimatization period.

25. Once the 2 minutes are up begin the program by hitting “ok” on the small Fishcamp window on the black computer.

26. Record the data manually on data sheet by observing the subject on the TV. Follow posted guidelines for coding hits.

27. Once the session is complete and the lights turn off in the ET room place your data sheet and pen on the desk (leave the computer alone, returning the subject is first priority).

28. Using the CT retrieve the subject from the ET in a gentle and slow manner. Using the CT to corner the subject works the best generally.

29. Remove subject from ET with the CT placing it back in the box in the Rubbermaid cart so you can return the subject to their HT.

30. Reverse steps 23 - 17 to return your subject back to their HT and put back all equipment. Note, you do not require a net to return the subject.

31. Once you’ve returned to the lab, close both doors (to prevent sound from leaving the room).

32. Bring wet vacuum into ET room and plug in. Suck all the water out of the ET.

33. Using paper towel to then dry out the rest of the tank.

34. Remove lid of vacuum and dump contents into sink (pour slowly to prevent overflow).

35. Use Oxivir to clean CT, thermometer and the opaque container. Spray thoroughly allow to sit for 30s and rinse with tap water. Place CT upside down beside the sink to allow it to dry.

36. Record target area values and error values from Fishcamp for record on your data sheet and be sure to write down any behavioural observations you may have noticed. Hit Ok on Fishcamp data box on the black computer and then exit Fishcamp program. Using the start button then select shut down computer. If you want to view your data hit view data. When done viewing your data hit the X and then Ok on Fishcamp.

37. Shut down the white computer by the red switch on the power bar on the floor left of the desk (labelled with red sticker with a “1”), this will also shut down the television and VCR.

38. Shut down the black computer by opening the start menu and shutting the computer down.

39. Fill out tank status clipboard.

40. Refill the cold water jugs using the BRUTE barrel refill procedure and return filled jugs to the walk-in fridge for the next session.

41. If you have time update your excel spreadsheet on the computer in the student office.

42. Before exiting the lab ensure that kettles are off of their bases, doors are locked, the BRUTE water barrel is covered and lights are off.

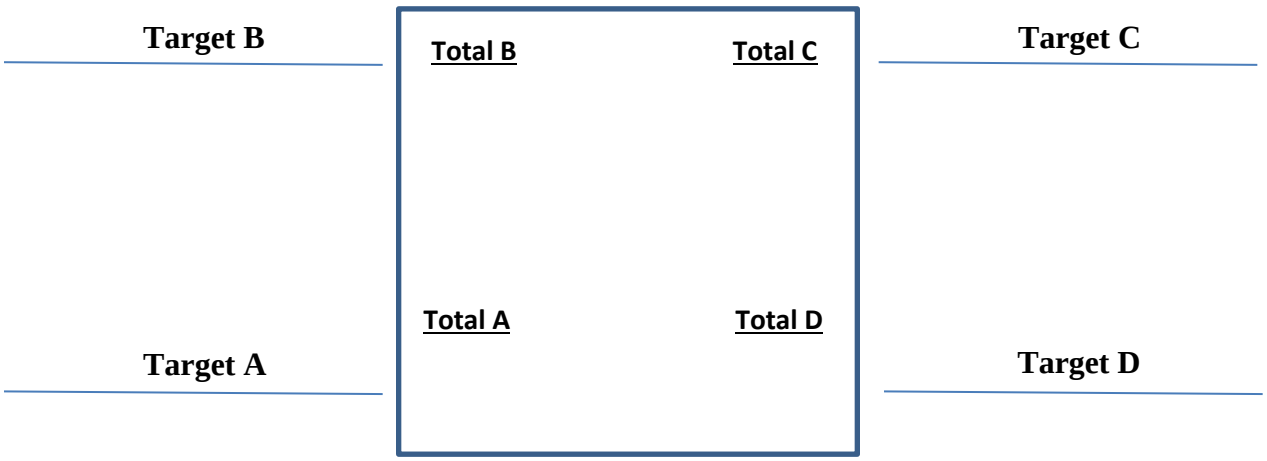
If you have any problems or questions, please call the applicable person from the contact list.

Appendix C

Data Collection Sheet and IOA

Session #: **Date:** **Subject ID:** **Condition:**

HT Temp: **ET Temp:** **Researcher:** **Observer:**



Total hits = _____

Computer Data

Tracking error count = _____

TA	TB	TC	TD

Observational notes (example: subjects behaviour, environment, time of day etc.):

Appendix D

Contour Maps MA Thesis

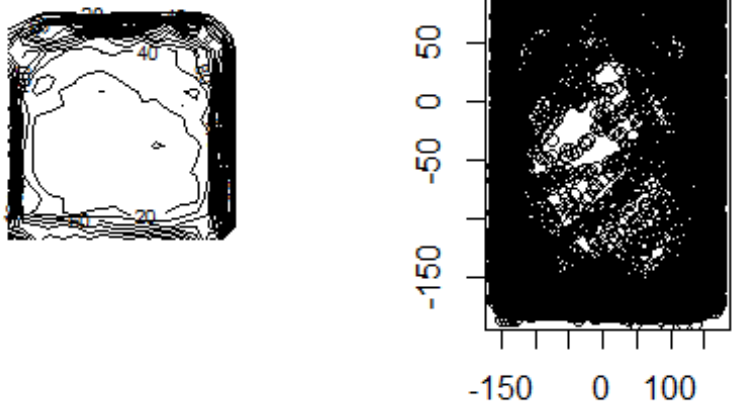
Brittany Cook

May 2, 2019

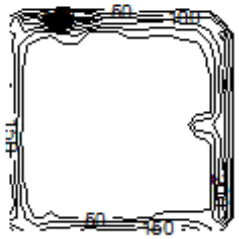
Making Contour plots in R (a step by step)

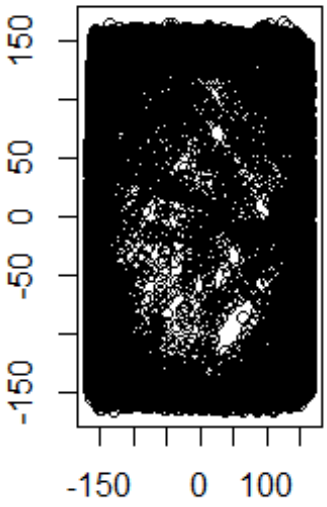
Cheese

```
#Import Fishcamp Data (Cheese session 10)
df<-read.delim("E:/MA Thesis/Cheese DAT/Cheese_2019-01-31_12-01-06.dat")

#Edit the data. remove first 10 lines and the last 16 lines
df<-df[11:(nrow(df)-16),]

#Assign NA to loss of tracking samples
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA

#How many 'bins' (so boxes) do we want. Other system (P130B) used 200x200 so
20 which can be changed based on the coordinate. Fishcamp in P130A was 168x16
5 so lets use 18 bins.
nbins <- 18

#Define x and y bins (the limits of x and y)
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)

#Put the fish camp data into the bins that we set up. So for each data point
which x bin and which y bin did it fall into
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=15,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-160, 175),ylim=c(-180,150))
```



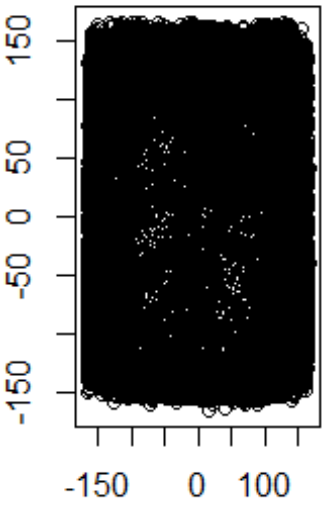

```
##Cheese Session 12
df<-read.delim("E:/MA Thesis/Cheese DAT/Cheese_2019-02-05_12-00-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```





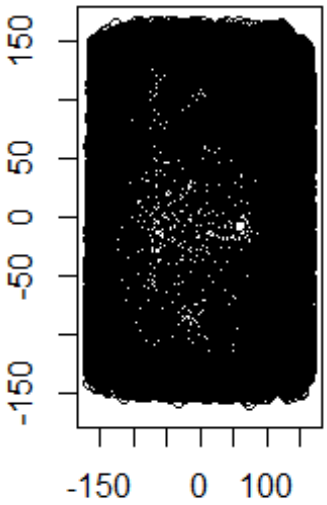
##Mac

```
#Mac Session 10 (DSB session 1, Fishcamp edited to improve tracking)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-02-05_10-57-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



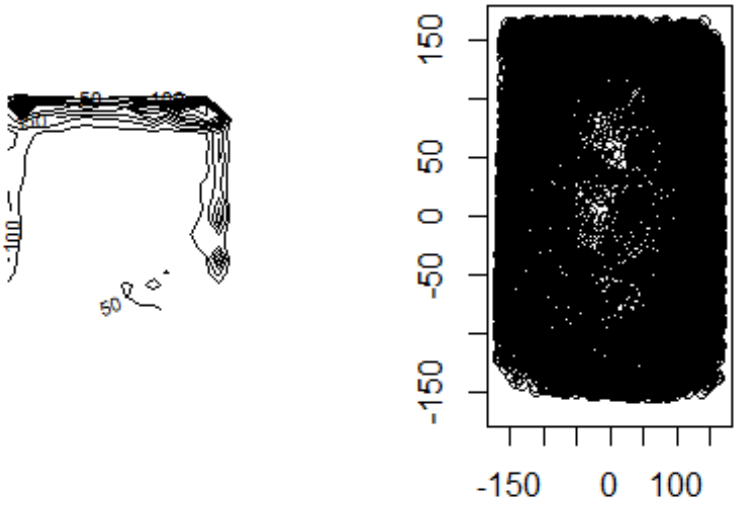

```
#Mac Session 14 (DSB)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-02-05_10-57-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))

#Mac Session 15 (RFSB)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-02-13_13-33-09.dat")
```

```
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



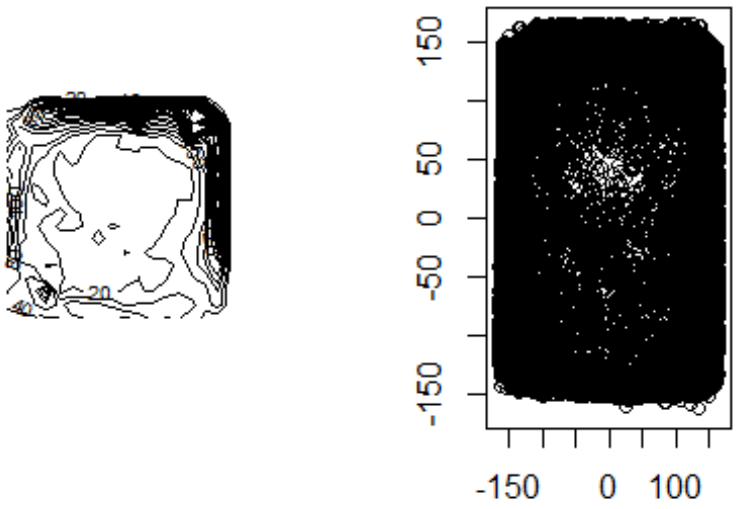

```
#Mac Session 28 (RFSB)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-03-05_11-15-11.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
```

```
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



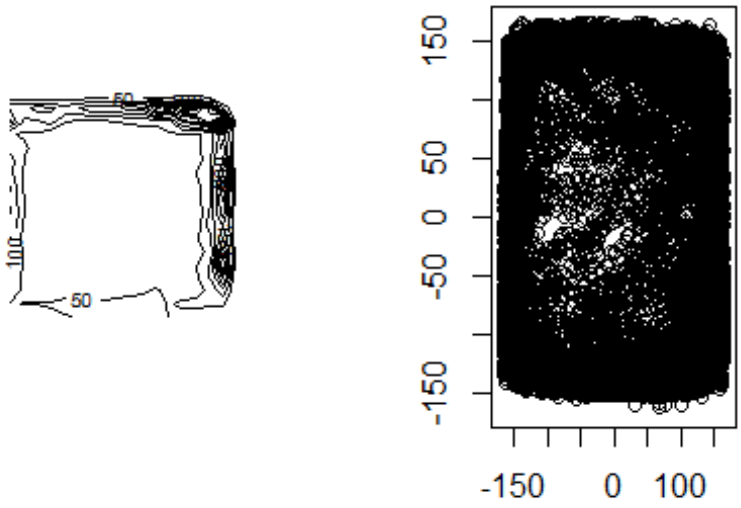

```
#Mac Session 29 (DSB2)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-03-06_13-28-07.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
```

```
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



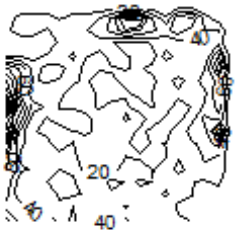

```
#Mac Session 43 (DSB2)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-03-26_12-06-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
```

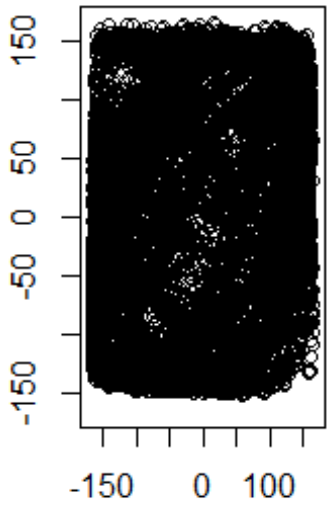
```
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```




```
#Mac Session 44 (FR1)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-03-27_12-43-07.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
```

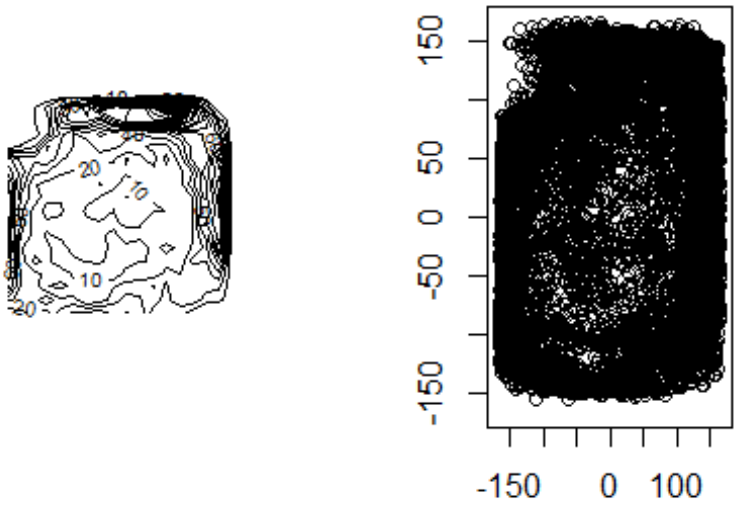
```
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```





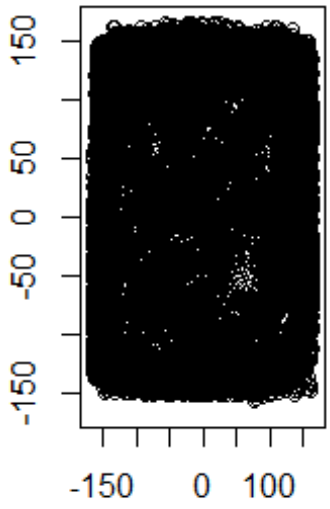

```
#Mac Session 58 (FR1)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-04-16_10-08-11.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))
```

```
#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



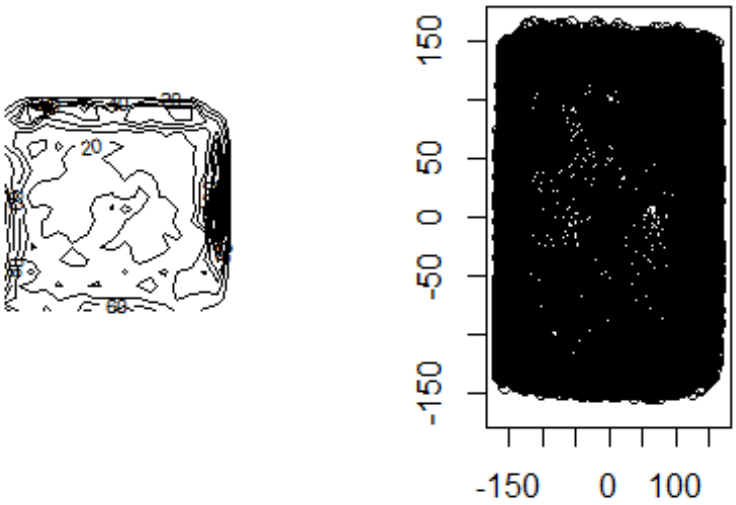

```
#Mac Session 59 (FR2)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-04-17_13-07-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)
```

```
#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



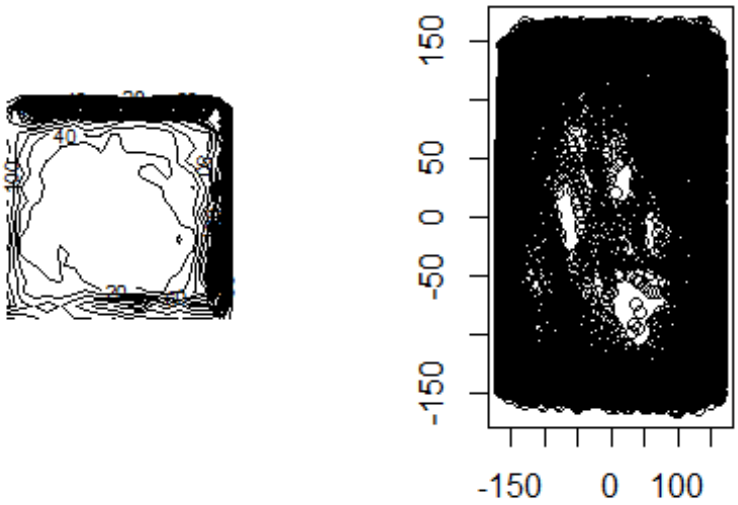

```
#Mac Session 67 (FR2)
df<-read.delim("E:/MA Thesis/Mac DAT/Mac_2019-04-30_11-04-08.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
```

```
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

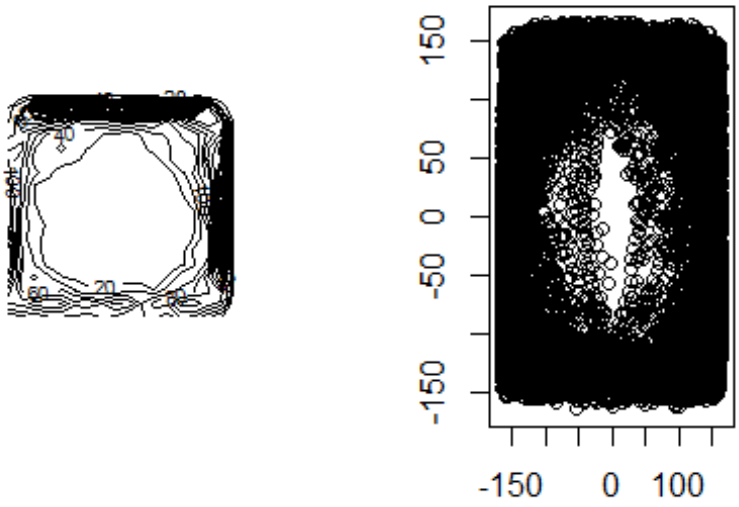



```
##Big
#Big Session 1 (NFB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-02-11_11-41-07.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
```

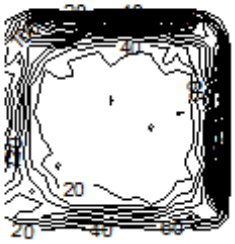
```
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

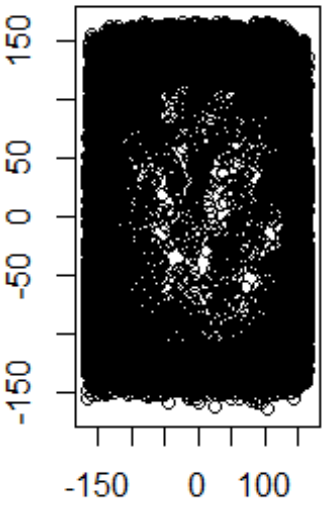



```
#Big Session 7 (NFB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-02-19_11-02-10.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

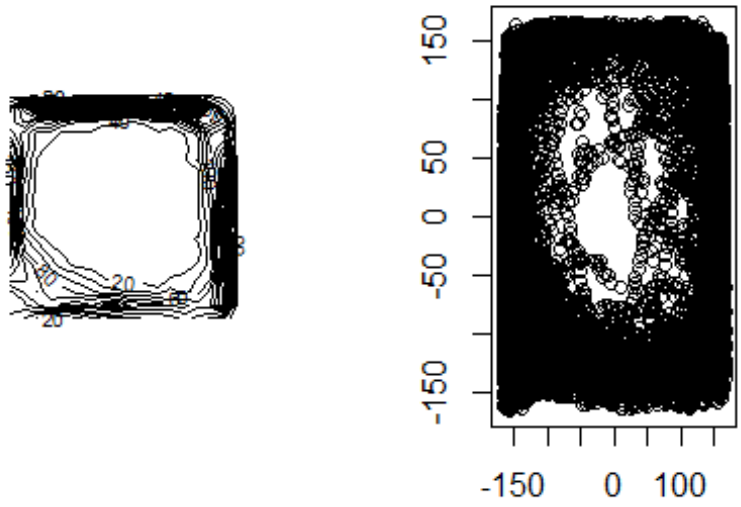



```
#Big Session 8 (DSB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-02-20_12-01-05.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

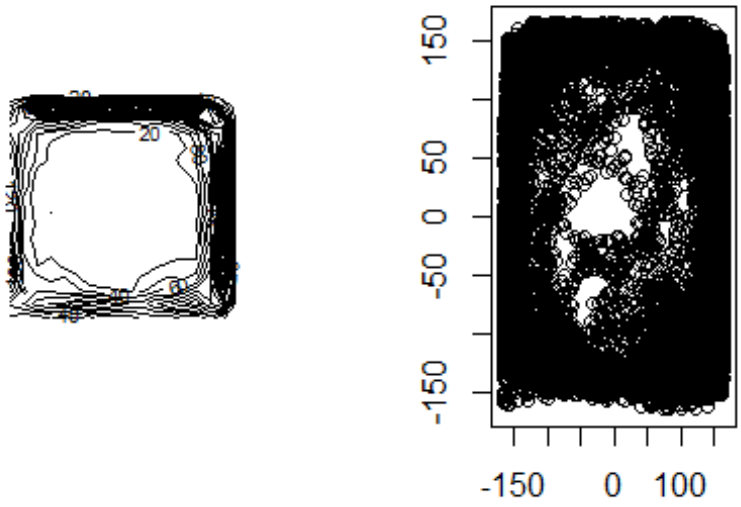




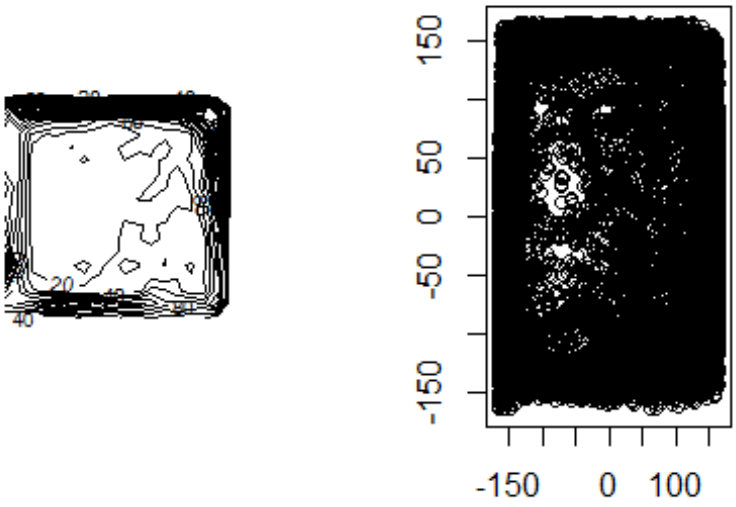

```
#Big Session 19 (DSB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-03-08_09-53-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



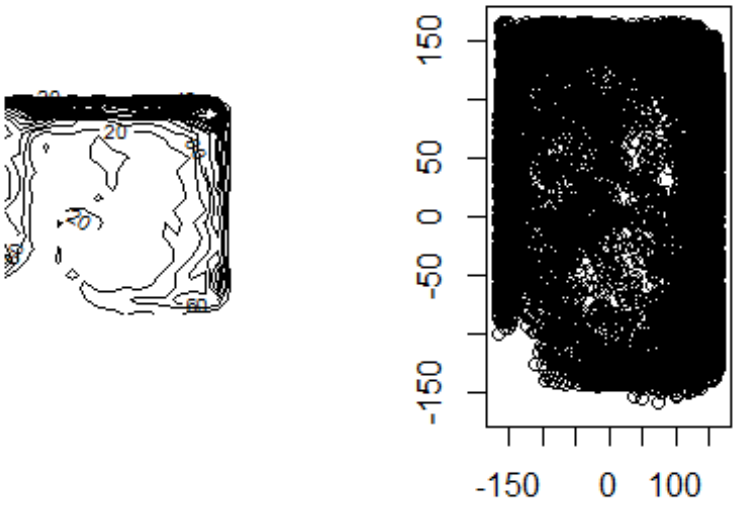

```
#Big Session 20 (RFSB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-03-11_12-20-07.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



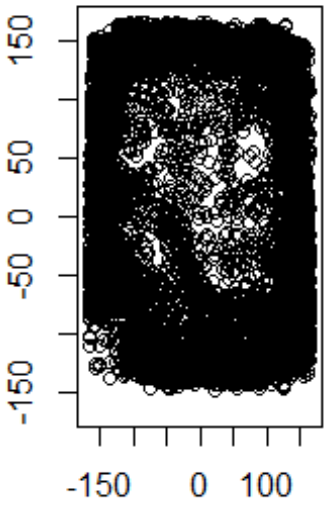

```
#Big Session 26 (RFSB)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-03-20_12-27-05.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



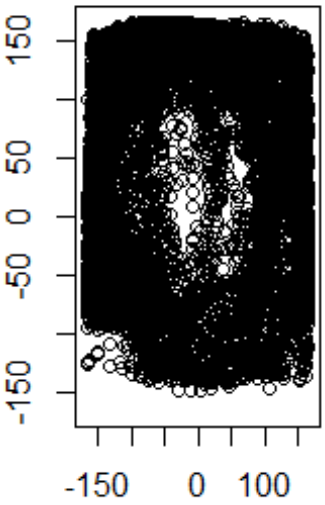

```
#Big Session 27 (FR1)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-03-21_12-01-05.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



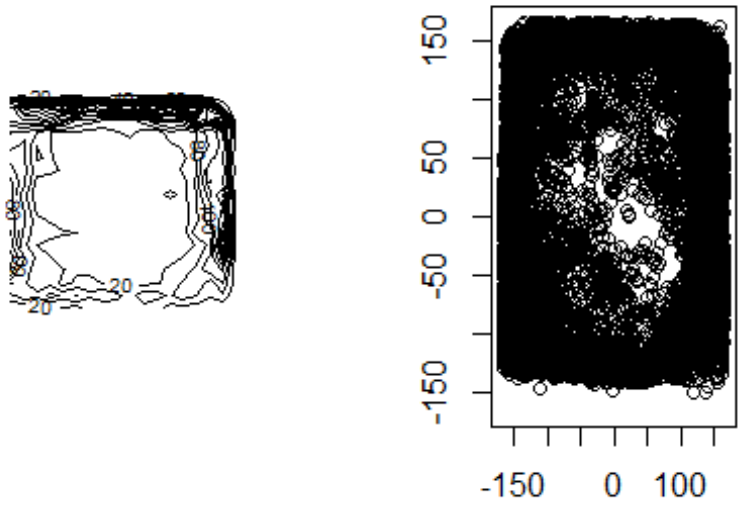

```
#Big Session 35 (FR1)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-04-02_11-51-10.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



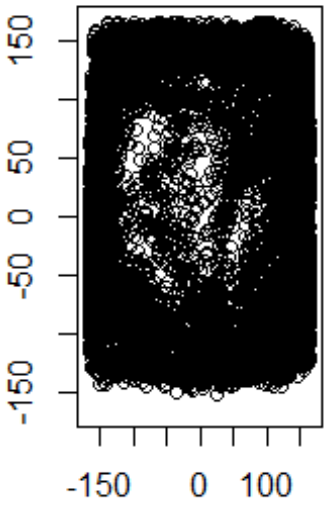

```
#Big Session 43 (FR1)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-04-12_11-30-23.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```



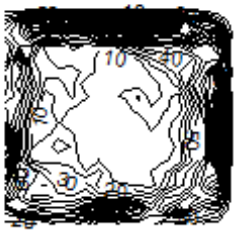

```
#Big Session 44 (FR2)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-04-15_10-15-13.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

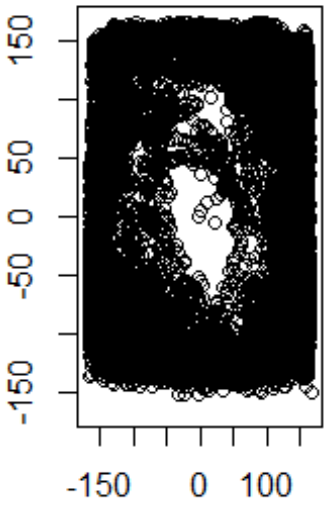



```
#Big Session 51 (FR2)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-04-25_10-36-25.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

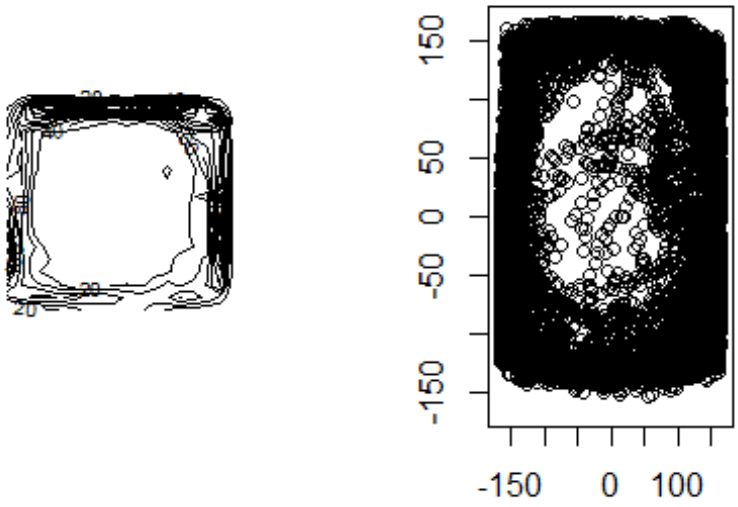



```
#Big Session 52 (FR3)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-04-26_10-32-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```

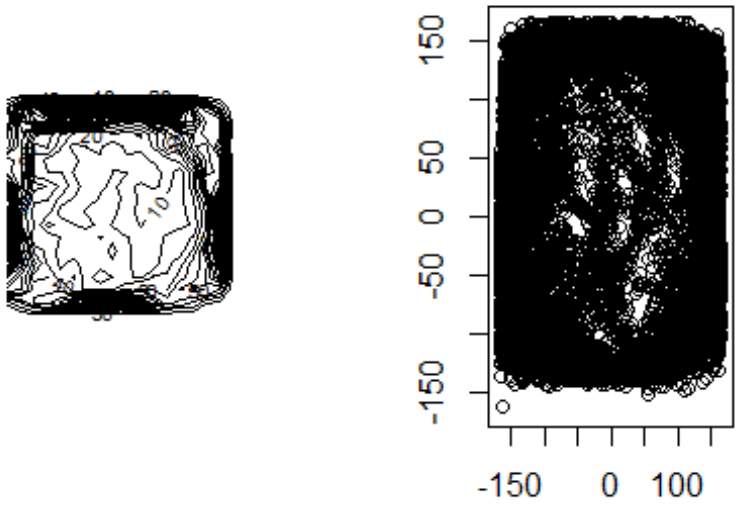




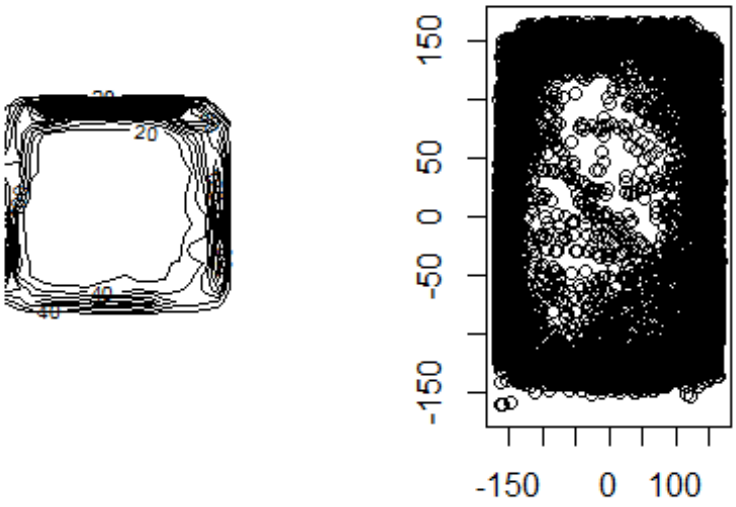

```
#Big Session 59 (FR3)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-05-07_10-52-06.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```




```
#Big Session 60 (FR4)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-05-08_10-16-09.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```




```r
#Big Session 67 (FR4)
df<-read.delim("E:/MA Thesis/Big DAT/Big_2019-05-17_10-39-53.dat")
df<-df[11:(nrow(df)-16),]
df$X[df$Error==1]<-NA
df$Y[df$Error==1]<-NA
nbins <- 18
x.bin <- seq (floor(min(df$X,na.rm = TRUE)),ceiling(max(df$X,na.rm = TRUE)),
length=nbins)
y.bin <- seq (floor(min(df$Y,na.rm = TRUE)),ceiling(max(df$Y,na.rm = TRUE)),
length=nbins)
freq <- as.data.frame(table(findInterval(df$X, x.bin), findInterval(df$Y, y.b
in)))
freq2D <- diag(nbins)*0
freq2D[cbind(freq[,1], freq[,2])] <- freq[,3]
par(mfrow=c(1,2))

#Now generate the contour plot
contour(x.bin, y.bin, freq2D, col="black",xlim=c(-160, 175),ylim=c(-180,150),
asp=1,nlevels=20,axes=FALSE)

#The below code produces what the old swim maps looked like when we used the
Cartisian Graphing Software
plot(df$X,df$Y,xlab=NA,ylab=NA,xlim=c(-170, 170),ylim=c(-165,165))
```


20
40
150
50
0
-50
-150
-150
0
100

Appendix E

Glossary

NFB- No feedback baseline
DSB- Discriminative stimulus (S^D) baseline
S^D – Canadian one Dollar coin (loonie)
RFSB- Response-feedback stimulus baseline
FR n- Fixed Ratio phase of experiment, n stands for sub-phase
RFS- Response-feedback stimulus, metal bat hitting a ball sound AKA automatic click
Fishcamp- custom made software used to track the subject and automate the beginning and end of session as well as automatically deliver reinforcers.
VTS- Video track system which was part of the apparatus used to track the subjects. This was also custom built.
ET- Experimental tank
HT- Home tank