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Influences of target stimulus probability and reinforcement probability on hens' performance on a signal detection task

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of the requirements for the degree

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Abstract

Hens' signal-detection performance was examined across a range of signal-present trial probabilities and reinforcement probabilities. These variables have been studied previously with the yes/no procedure, but have not been systematically evaluated using the go/no-go procedure. This study employed natural contingencies where hits were reinforced, but all other responses had no scheduled consequences. The hens were required to discriminate between a signal-present (bright light) and signal-absent trial (dimmer light) by responding on the stimulus key or bypassing the trial by responding on a second key. The hens were exposed to reinforcement rates of 100%, 75% and 50% and signal probabilities of 50%, 25%, 12.5%, and 6%. Manipulation of reinforcement rate across the range examined did not significantly influence performance at any stimulus probability. Specificity increased over sessions, suggesting a practice effect for signal detection tasks. The go/no-go procedure should be considered for operational signal detection applications as it was found to produce robust accuracy across a range of conditions.

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Introduction

Signal detection theory describes the accuracy of a detector by evaluating performance when discriminating between signal-present and signal-absent conditions. A detector must identify a target stimulus (S+) out from a situation where there are distractor stimuli (S-). These distractor stimuli are called “noise” (Wickens, 2002). Often in signal detection tasks the target signal can be faint, relative to the noise. Signal detection can be considered a “choice” that the organism must make to “decide” if the target stimulus is present or absent. The decision can be evidenced by the animal’s behaviour in the presence or absence of the signal. For example, if the signal was present and the organism identified that it was present, then this is deemed a “hit”. If the individual indicated the signal was absent when it was in fact present, then this is termed a “miss”. If the signal is absent but the identifier stated it was present, this is termed a “false alarm”. If the signal was identified as absent and it was absent, this is called a “correct rejection” (Nevin, 1969). These responses can be seen in *Figure 1*.

	“Yes Response”	“No Response”
Signal Present (S+)	Hit (w)	Miss (x)
Signal Absent (S-)	False Alarm (y)	Correct Rejection (z)

Figure 1: Matrix Illustrating "Yes/No" Responses when Signal is Present/Absent.

A goal of many signal detection tasks is to maximize hits and correct rejections and to minimize misses and false alarms. A detector's accuracy is measured using sensitivity and specificity. The term *sensitivity* refers to the proportion of signal-present trials with correct indications (i.e., hits). The term *specificity* refers to the proportion of signal-absent trials with correct rejections. There are many variables that can alter a detector's accuracy, such as signal strength, the detector's physical state, and the proportion of trials with targets (Boldero, Davison, & McCarthy, 1984). Many signal detection tasks use a yes/no procedure. In these yes/no procedures there are signal-present and signal-absent (noise) trials (Swets, 2014). After exposure to the stimulus, the detector then must "decide" if the signal was present or absent by performing a "yes" action to indicate the signal presence or performing a discrete "no" response action to indicate if the signal is absent. Correct "yes" responses and correct "no" responses are reinforced. Another procedure used in signal detection tasks is called the "go/no-go". This differs from yes/no procedure as the detector can make a "go" response or pass to the next trial, which results in moving onto the next stimulus. Ideally the organism would perform a "go" action during signal present trials and advance on to the next trial, without a "go" (no-go) response, on signal-absent trials. An example of this is when giant African pouched rats test sputum samples for tuberculosis (TB), they are trained to hold their noses above TB-positive samples for 3s and to move past samples that are identified as TB-negative (Poling et al., 2011). The "advance key procedure" is a go/no-go approach to signal detection research (Weisman, Gibson, & Rochford, 1984). In this procedure, the organism is required to indicate on signal-present trials and perform a different response on signal-absent trials in order to move on or "advance" to the next trial. Advance key is considered a go/no-go procedure as only hits are reinforced as there

is no explicit “no” response that is able to be reinforced (i.e. with an advance response, the trial ends and the next begins).

Signal detection theory and research on the topic has many practical uses that help benefit the lives of people. Often, animals are used as signal detectors, as their sensory abilities are often superior to humans’ and animals can be trained to indicate the presence of relevant signals. For example, the giant African pouched rats used in the research by Poling et al. (2011) demonstrates how signal detection theory is used with animals with positive outcomes for humans. The author describes how an organisation, Anti-Personnel Landmine Detection Product Development (APOPO), used pouched rats to detect Tuberculosis (TB) in human sputum samples. This is beneficial as the animals can conduct inexpensive, fast, and accurate testing of a large number of samples when compared to alternative TB testing.

Poling, Weetjens, Cox, Beyene and Sully (2010) also report results obtained by giant pouched rats trained to detect landmines in sub-Saharan Africa. In this research, the signal that the rats were trained to detect was TNT (trinitrotoluene). These animals were selected as they have a sensitive sense of smell and can work faster and safer than humans with metal detectors.

Moser and McColloch (2010) discussed studies exploring signal detection theory applications with the use of dogs to detect cancers in humans. This area of research is beneficial as many methods of testing for cancers are invasive and often have associated health risks. The authors state that dogs’ sense of smell has been used to detect bladder, lung, breast, prostate, ovarian and melanoma cancers through biological samples. The authors found that out of the 7 studies that were completed, 5 of them had statistically significant results with high accuracy on sensitivity and specificity (e.g. results of sensitivity and specificity varying from 75%-100%). It was found that the studies that

tested exhaled breath had higher sensitivity and specificity when compared to studies that used urine samples.

Humans also have value as detectors and have been used in tasks such as screening airport luggage for prohibited items and visually detecting cancers in medical settings. Wolfe, Horowitz and Kenner (2005) discuss how human detectors perform in visual screening tasks. The authors looked at detector performance on an artificial luggage-screening task that had either a high or low prevalence of target items. The luggage display was organized so that the number of objects displayed was either 3, 6, 12, or 18. The target prevalence was manipulated to be present in 1%, 10% or 50% of trials. With 50% target prevalence, detectors had a 7% error rate (misses and false alarms). With luggage tasks that had 10% target prevalence the detectors error rate increased to 16%, and the 1% target prevalence had an error rate of 30%. The findings of this study indicate that the less likely it is that the target stimulus is present, the higher the rate of misses and false alarms.

Researchers have also applied quantitative behavioural models to signal detection tasks. For example, Davison and Tustin (1978) examined the relationship between the generalized matching law and signal detection theory. The generalized matching law (Davison & Tustin, 1978) contains calculations that are used to determine how behaviour is distributed over a range of response options based on how the proportion of responses allocated to each option “matches” the proportion of reinforcement available under each option. The equation for the generalized matching law, as stated by Baum (1974) can be seen in equation 1:

$$\log \left(\frac{P1}{P2} \right) = a \log \left(\frac{R1}{R2} \right) + \log c \quad (1)$$

Where $P1$ and $P2$ are the numbers of responses emitted to each of two keys and $R1$ and $R2$ are the number of reinforcements obtained on each of these keys. The

parameter “ a ” is the sensitivity in regards to the ratio allocation of responses versus the ratio of obtained reinforcement. The variable “ c ” demonstrates bias. Davison and Tustin (1978) also proposed that with signal detection theory, two equations could be applied. In the presence of the S+ see equation 2 (see figure 1 for “events” w , x , y , and z):

$$\log \left(\frac{P_w}{P_x} \right) = ar_1 \log \left(\frac{R_w}{R_z} \right) + \log c + \log d. \quad (2)$$

and when the signal is absent see equation 3:

$$\log \left(\frac{P_y}{P_z} \right) = ar_2 \log \left(\frac{R_w}{R_z} \right) + \log c - \log d \quad (3)$$

Where P and R correspond to the numbers of responses and numbers of reinforcers obtained under each option, respectively. And “ $\log d$ ” demonstrates the bias caused by the target stimulus and “ ar ” is the sensitivity in regards to the ratio allocation of responses versus the ratio of obtained reinforcement. “ $\log c$ ” is described as a performance bias inherently due to equipment or the subject (Davison & Tustin, 1978).

In the matching equation (Baum, 1981), detection accuracy is represented by the degree of bias towards “yes” responses when the stimulus is present and towards “no” responses when the stimulus is absent. Davison and Tustin (1978) reported that this is due to reinforcement being gained for hits and correct rejections, while misses and false alarms are not reinforced. According to Davison and Tustin (1978), if only hits are reinforced, then there will be a bias towards “yes” responses.

McCarthy and Davison (1979) investigated the effects of varying reinforcement probability as well as probability of signal presentation. They used three procedures to examine these effects; in the first procedure, the target stimulus was presented on between 10% and 90% of the trials. Reinforcement for hits and correct rejections was delivered under a variable ratio (VR) 3 schedule, which produced either 3s of magazine light only without access to wheat or 3s access to wheat accompanied with the magazine light. In the second procedure, the stimulus probability was presented between on 10%

and 90% of the trials. Food delivery for this procedure occurred on two concurrent variable-interval (VI) 60s schedules. In the third procedure, probability of the target stimulus being presented was constant at 70% but reinforcement was varied for correct right and left-key (i.e., yes and no) responses by changing the values of the VI schedules (i.e., intervals ranged from 12-96s). A response bias was observed for procedure one and three but not in procedure two, where only stimulus probability was manipulated. It was found that changes in the subjects' behaviour were due to the manipulation of the reinforcement probability and not the probability of signal presentation. Changes to the reinforcement probability resulted in a response bias towards the option that was most likely to result in reinforcement.

Davison and McCarthy (1980) looked at how reinforcing false alarms can affect responding in pigeons by arranging errors that were previously punished by a 3s blackout, to be followed by a richer rate of reinforcement in comparison to correct responses (which were held constant at 70% reinforcement). It was found that pigeons formed a bias toward saying "yes" when the stimulus was absent, as they were more likely to receive reinforcement for these "errors". These findings suggest that the generalized matching law equation is useful for predicting performance in signal detection tasks as the pigeons have responded more to the option that is most likely to result in reinforcement.

Edwards et al. (under review) examined how reducing opportunities for reinforcement affects accuracy in pouched rats during a signal detection task. Pouched rats were given the task of detecting TB in sputum samples while the percentage of known positive samples was varied. The known positives in the array to be evaluated were varied from 10%, 8%, 6%, 4% and 2% while it was estimated that there were 5% of unknown positives in the array. Reinforcement was given if the rats correctly identified a

known positive, but not if they indicated an unknown sample as positive. Therefore by lowering the percentage of known positives, the opportunities to gain reinforcement also decreased. It was found that there was a significant decrease in accuracy when known positives made up 2% of the sample, in comparison to conditions with more opportunities for reinforcement.

Kamil, Lindstrom and Peters (1985) investigated natural contingencies for the detection of prey by blue jays. The blue jays were presented with a slide that either contained a camouflaged moth, or no moth. The birds could then peck a “giving up” key or a stimulus “attack” key. If the “giving up” key was pecked, the trial ended and blacked out for 2s. The stimulus key would provide reinforcement if correct, or result in 30s where responses had no effect if the moth was absent. This procedure, a go/no-go procedure, is similar to the procedure used in the present study as both experiments have a “response” key, and a form of “advance key”. Another similarity between the two procedures is that when the signal is absent there is no possibility of obtaining reinforcement when the signal is absent (e.g. for correct rejections). In the study by Kamil et al. the response cost for responding on signal-absent trials was 30s of responding not being recorded or reinforced, while in the present study the cost was the number of pecks needed to gain access to a reinforcement trial.

Voss, McCarthy & Davison (1993) also examined accuracy of responding and response bias between a standard signal detection procedure, where hits and correct rejections were reinforced (i.e. yes/no procedure) and a prey-detection based procedure where only hits were reinforced while correct rejections had no consequence (i.e., go/no go procedure). Procedure 1 used the standard signal detection method and Procedure 2 followed natural contingencies, as correct rejections would not be reinforced with food in a natural environment. Misses and false alarms produced blackout for both procedures,

with durations varying between 3s and 120s. The results showed that in Procedure 2 when correct left-key “yes” pecks produced reinforcement and correct right-key “no” pecks produced a 3s blackout, there was a response bias toward the left key. This was not the case for Procedure 1, where correct rejections were also reinforced. In Procedure 1 there was a tendency for responses to bias towards the option that would result in reinforcement (i.e., correct left-key “yes” pecks and correct right-key “no” pecks). It was found that all measures of stimulus control (proportion correct, A’ (average of maximum and minimum possible areas associated with each response), and log-d) were significantly higher in Procedure 2. Procedure 2 is similar to the procedure employed in the present research as hits are the only responses to be reinforced. However, the present procedure differs from that used by Voss et al. as they arranged different outcomes for correct rejections and false alarms in some conditions. In Procedure 1, correct rejections resulted in reinforcement while false alarms resulted in timeout that ranged from 3-120s. This illustrates a difference between Voss et al.’s procedures and those in the present study, which arranged the same consequence for correct rejections and false alarms (i.e., no reinforcement and advancing onto the next trial). Another procedural difference is that Voss et al. used a time-out to simulate the response cost associated with an incorrect “go” response, while in the present study the “indication” response serves as its own cost for these incorrect “go” responses.

At present there is little signal detection research that uses natural contingencies such as the ones that were used by Voss et al. (1993). The current study employed natural contingencies that are commonly encountered in natural environments in which only hits are reinforced, while misses, correct rejections, and false alarms have no programmed consequences. In many natural and artificial signal detection tasks, correct “no” responses are not reinforced (e.g. in natural examples, such as prey detection situations,

correct no responses mean that the detector has not used energy searching areas for prey). In a laboratory setting, this is often due to the status of many samples being unknown. Under these conditions, there is a chance that the unknown sample is positive (Poling et al., 2011). If no responses towards these unknown samples were reinforced, there would be a risk that false indications would be reinforced and that this type of error would increase in frequency. Interestingly, even though these correct rejections do not get reinforced in go/no-go procedures, detectors can still perform with high accuracy. The results of Voss et al. (1993) suggest that procedures using natural contingencies can produce higher accuracy than yes/no procedures.

Another variable of interest in signal detection research is the response effort required to indicate the presence of a signal. Elsmore (1971) examined pigeons' performance on a discrete trial detection task. The pigeons were presented with either a red key, with probability of reinforcement being 25%, or a white key with probability of reinforcement being 50%. Elsmore examined pigeon's response effort through two experiments. In the first experiment the force required to operate the response key was increased. In the second, the number of responses to complete the trial was increased. It was found that when the effort requirement was low, there was little difference in behaviour between the white and red key. As effort requirements increased, so did the latency of responding to the red key. However, probability of responding on the red key decreased as effort requirements increased. This reduced probability of a discriminated response due to increased effort requirement may be important in regards to accurate performance on naturally occurring go/no-go signal detection tasks.

The current research topic aimed to provide new insight into the influences of reinforcer probability and signal probability on performance in a go/no-go signal detection task. While these variables have been investigated in previous research with the

yes/no procedure they have not been systematically evaluated with the go/no go procedure. In particular, the present study examined the effects of these independent variables on the sensitivity and specificity of responding. *Sensitivity* refers to the proportion of signal-present trials with correct indications (i.e., hits). The term *specificity* refers to the proportion of signal-absent trials with correct rejections.

The present study employed a visual signal detection task with six hens to evaluate the influence of stimulus probability, probability of reinforcement, and potential interactions between these two factors on detection accuracy. This research was a parametric analysis examining the influences of these variables. The findings of the present study may inform applications involving humans or other animals responding under signal detection tasks as, with many of these applications natural contingencies (i.e., go/no-go procedures) must be employed because yes/no procedures are not feasible.

It was hypothesized, based on the findings of past research, that when reinforcer probability is manipulated, the hens responding would be affected. However, due to hits being the only responses that are reinforced, it was predicted that there would be a bias towards “yes” responses. This would result in high sensitivity but low specificity. Based off the findings of Wolfe et al. (2005), it could be predicted that when stimulus presentation is at its lowest (6% of the time) the rate of detector errors (i.e., misses and false alarms) will increase as the stimulus presentation decreases. However contradictory evidence found by McCarthy and Davison (1979) shows that manipulating S+ probability did not lead to a bias in responding. The present study aims to clarify the role that S+ probability plays in detector accuracy on a signal detection task.

Method

Subjects

Six hens (*Gallus domesticus*) of a variety of strains, numbered 91 to 96, were maintained at 90-95% of their free feeding body weight. Wheat was used in the experimental chambers for reinforcement and supplementary post-feeding of commercial laying pellets was given in home cages after experimental sessions where necessary to maintain set weights. Hens were kept in individual home cages with lights controlled on a 12-hour light and dark cycle. Water was freely available in the birds' home cage and weekly grit and vitamins were given as part of their feeding routine. Most hens had previous operant training in a similar apparatus to the one used in the present study.

Apparatus

A standard light-proof experimental chamber measuring 520mm in height, 620mm in width and 440mm in depth was used. The chamber contained 2 response keys, 30mm in diameter and 50mm apart, located 400mm from the chamber floor. The illumination intensity of the left key was controlled by a device that adjusted the ratio of on-time vs off-time, with a value of 255 setting the key to its brightest (fully on) and a value of 0 setting the key to its dimmest (fully off). The refresh rate for the lights was 200kHz as this has been shown to be above critical flicker fusion frequency for chickens (Railton, Foster, & Temple, 2009). This means that the light is perceived as a constant light rather than a flickering light. When operative, the left-hand backlit LED key was trans-illuminated with the various intensities of green light, and the right-hand key was trans-illuminated red. The left-green light brightness began at 205 and systematically lowered closer to 50, which was the brightness of the noise stimuli (S-). Pecks on darkened keys were not recorded. When keys were pecked at a force of at least 0.1N they provided a brief feedback noise. A food magazine was located 170mm below the response keys. During reinforcement, the key lights were extinguished and the wheat

filled food magazine was raised and illuminated for 3s. A computer running the MedPC program was connected to an interface unit that controlled the apparatus, ran experimental sessions, and recorded data from the experiment. A summary of the data was also manually logged into a data book at the end of each session.

Procedure

Initial training. Subjects that had no prior training in the experimental chamber were trained to eat from the food magazine and then, were trained to peck both keys using a hand-shaping procedure. During the experimental training, the left/green key light would come on. For every trial the hens were trained to peck the left/green key once as an “observation response”. This observation response would illuminate the right/red key (advance key). Once illuminated, this advance key could be pecked at any time during the trial to advance onto the next trial. If the target signal (S+) was present in a trial, then the hens could peck the left green key 10 times (FR10). Once FR requirements had been met, the chamber lights would go out and the magazine would illuminate and lift to provide 3-s access to wheat. If the S+ was absent and the hens pecked the left/green key, nothing would happen until the right/red key was pecked. If the signal was absent, and the hens pecked the right/red key, they would advance onto the next trial. Pecking the left/green key during a signal-absent trial, had no programmed consequences. There was 2-s inter trial interval (ITI) between every trial. During this ITI, all chamber lights were extinguished and a new trial began at the end of the 2s.

There were 3 different trials that could occur during the experiment. During S+/R+ trials, the target stimulus was presented on the left/green light. After the initial observation response of pecking the green key, reinforcement could be obtained after reaching FR10 on the left/green key. During S+/EXT trials, the target stimulus was present, but reinforcement was not available when FR requirements were met on the left/green key. Hens were required to make an observation response on the green key and

then reach FR10 for the response to be recorded as correct, however no reinforcement was gained. The hens would eventually have to peck the advance key to end the trial. During S-/EXT trials, the target stimulus was absent and no reinforcement was available. On S-/EXT trials, hens were required to peck the green key once as an observation response and then peck the red key to end the trial.

Hens were initially trained exclusively on signal-present (S+/R+) trials where the light brightness was set to 205 until key pecking was stable. Discrimination training then began, where signal-absent (S-/EXT) trials were introduced for 50% of all trials.

Once the hens had specificity (correctly advancing on S-/EXT trials) of .8 or higher and sensitivity (reaching FR requirement on S+ trials) of .9 or higher for 2 consecutive sessions, the fixed ratio (FR) response effort was increased on the left-green key by 1 until it reached FR10. Once the hen reached FR10, if the S+ was present, reinforcement would follow (R+).

Specificity and sensitivity were combined as a dependent variable to be used when adjusting the S+, so that a score of 2.0 would be perfect performance and 1.0 would demonstrate chance performance. The S- brightness was at a set value of 50, while the target stimuli brightness (S+) was systematically lowered until the birds had a combined sensitivity and specificity that fell below 1.4. If the birds had 2 consecutive sessions with combined rates below 1.4, the S+ was increased. Once each hen had 5 consecutive sessions with a sensitivity plus specificity rate between 1.4-1.6, the S+ light brightness was set for that bird (either S+58, 60 or 63 depending on the bird; see Table 2). After the hens had 5 sessions with performance between 1.4-1.6 combined sensitivity and specificity, they were given brief exposure to S+ EXT trials, where reinforcement was available for some S+ trials. In these sessions, the S+ was presented on 50% of trials, but hits were only reinforced 75% of the time. This was done to reduce the likelihood of

behaviour extinguishing when the S+/R+ trials were decreased. Once hens had 5 consecutive days with sensitivity and specificity between 1.4-1.6, the experimental conditions began.

Experimental Conditions. The sequence of experimental conditions is displayed in Table 1. Daily experimental sessions ended in blackout after 100 trials had been completed or after 40 minutes, whichever event occurred first. Experimental conditions were changed after each hen met stability criteria that consisted of at least 10 days, at least 800 completed trials, and no visible trend in hens' performance data (combined hits and correct rejections) over the last 5 days. The order stimuli were presented in each session was determined randomly by the Med-PC program.

Table 1. Order of Experimental Conditions.

Condition	S+ Presentation	Reinforcement Probability for Hits
1 (Baseline)	50%	100%
2	50%	75%
3	50%	50%
4 (Baseline)	50%	100%
5	12.5%	100%
6	12.5%	75%
7	12.5%	50%
8 (Baseline)	50%	100%
9	25% or 6%	100%
10	25% or 6%	75%
11	25% or 6%	50%
12 (Baseline)	50%	100%

Table 2. Disparity Between S+ Number and S- (50).

Hen Number	S+ Number
91	60
92	58
93	58
94	60
95	63
96	63

Results

Figures 2, 3 and 4 show the performance (sensitivity, specificity and both combined) of hen 91 as the reinforcement rate was decreased over three different proportions of signal-present (S+) trials (50%, 12.5% and 25%). Sensitivity for all hens were calculated by adding together the trials that FR was reached with the total number of S+ trials. Specificity for all hens were calculated by taking all the trials where S- was not indicated and subtracting the proportion of correct rejections. Hen 91 met the extinction criteria (5 consecutive days with 10 or fewer completed trials) during the condition where S+ was presented in 12.5% of trials and reinforcement for correct responses was at 100%. Hen 91's performance improved again when signal presentation probability was increased to 25%. Sensitivity and specificity were similar for this hen, with the exception that sensitivity increased above specificity during the S+ 50%/Rft 50% condition and just before extinction occurred in the S+12.5%/Rft100% condition.

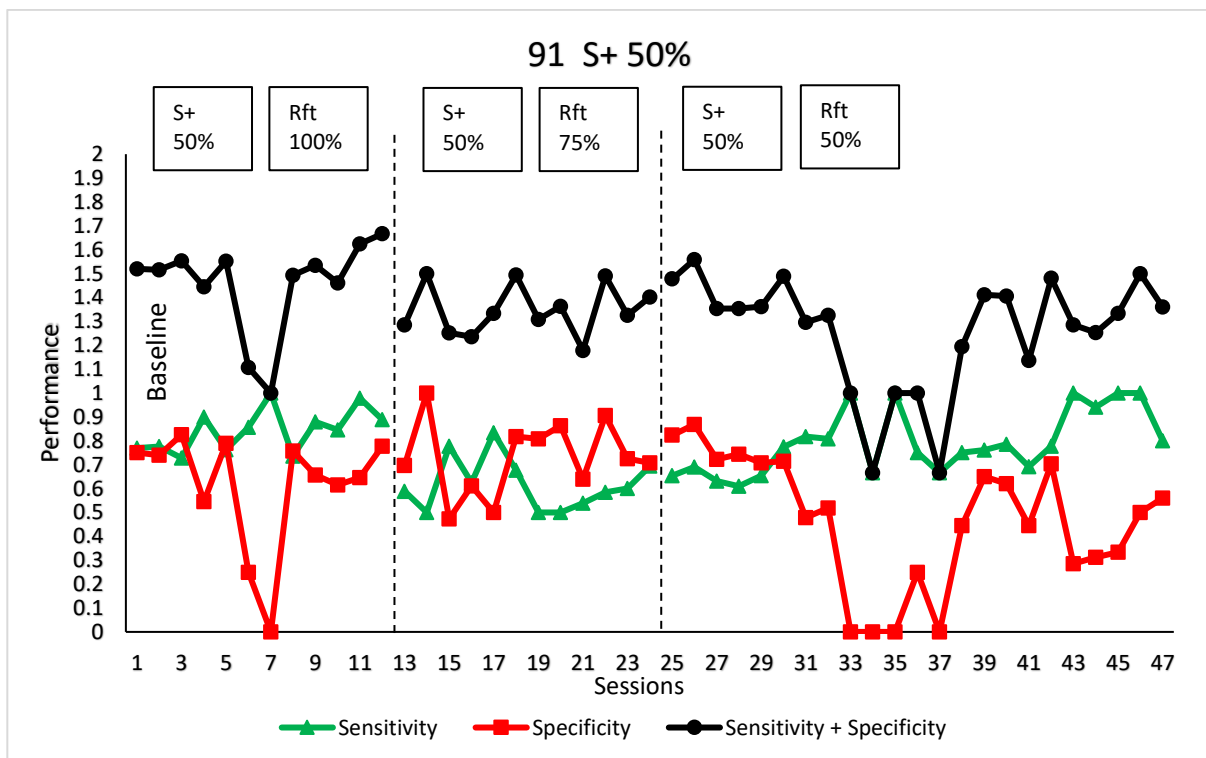


Figure 2: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 91.

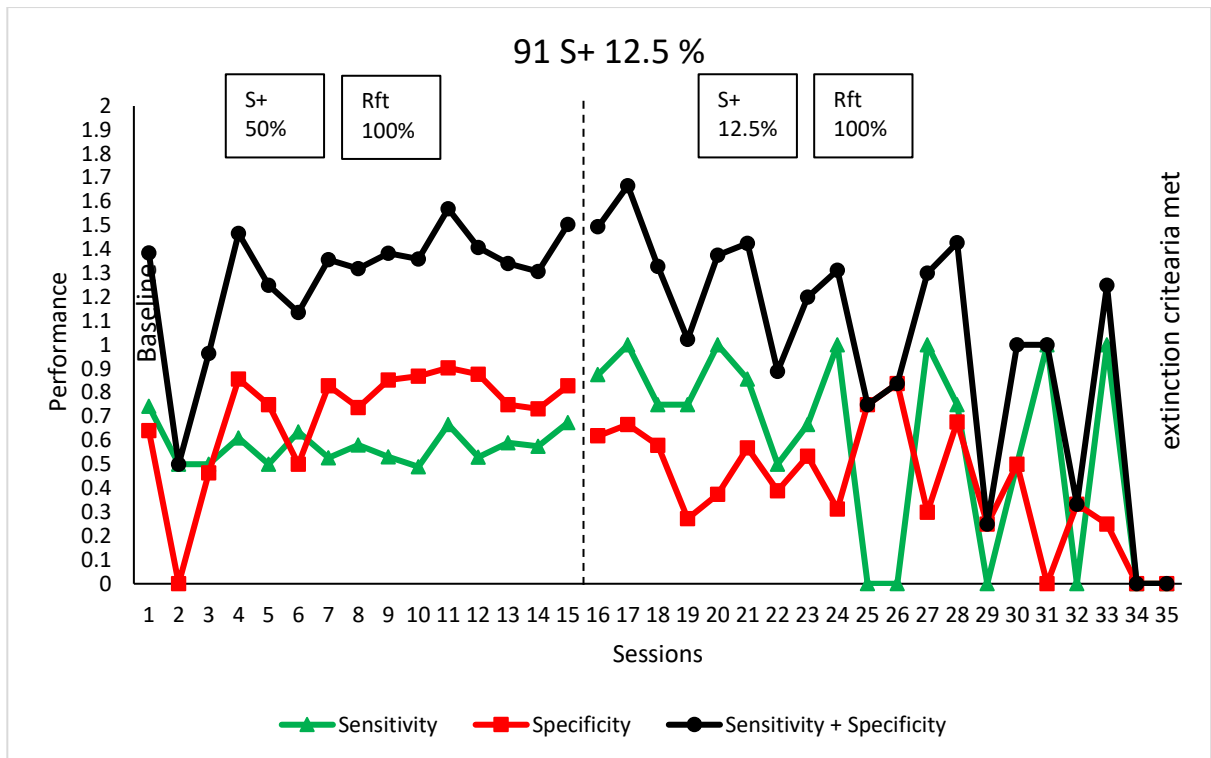


Figure 3: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 91.

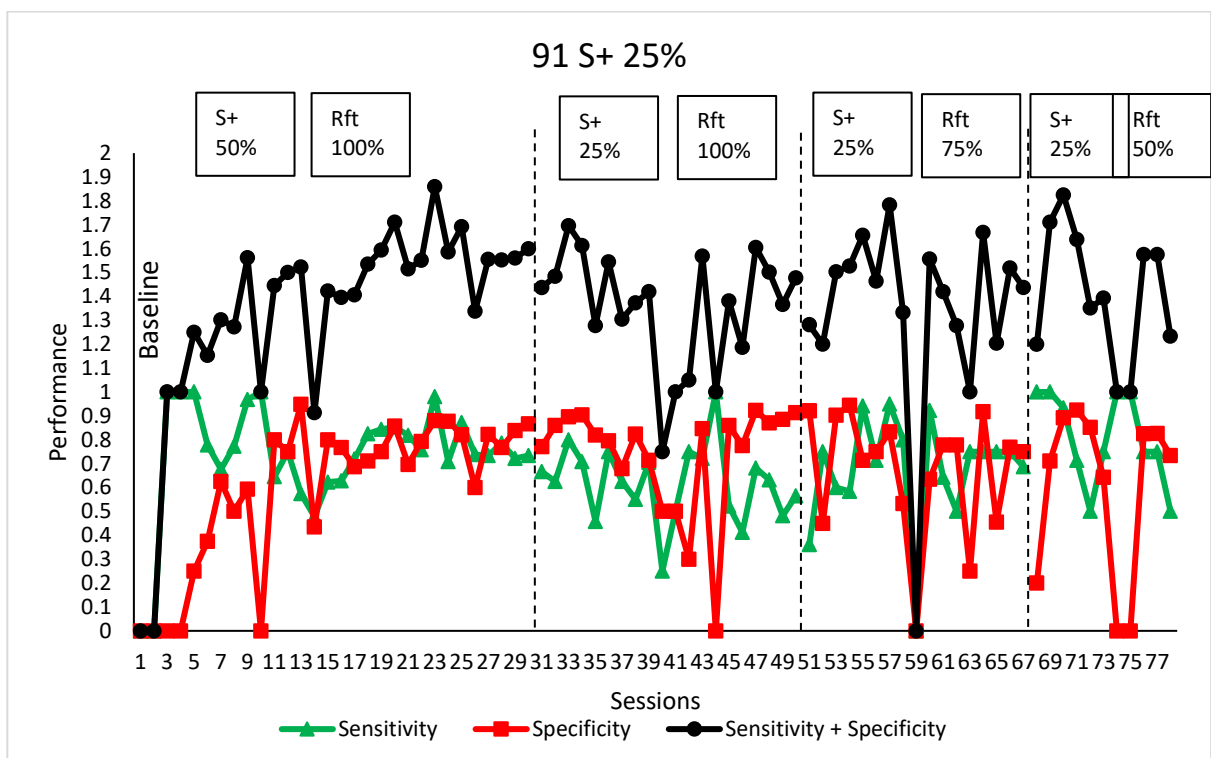


Figure 4: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 25% for hen 91.

Figures 5, 6 and 7 show performance of Hen 92 across conditions. The hen's sensitivity was higher than specificity across most of the conditions, except in the return to baseline before S+ was dropped to 6%. During this baseline, specificity increased to be similar to sensitivity. As the reinforcement became leaner across conditions (i.e., 6% target stimulus presentation with reinforcement at 100% and 75%) the hen's sensitivity reached a ceiling (100%). Extinction criteria were met in the S+ 6% condition with reinforcement at 50%.

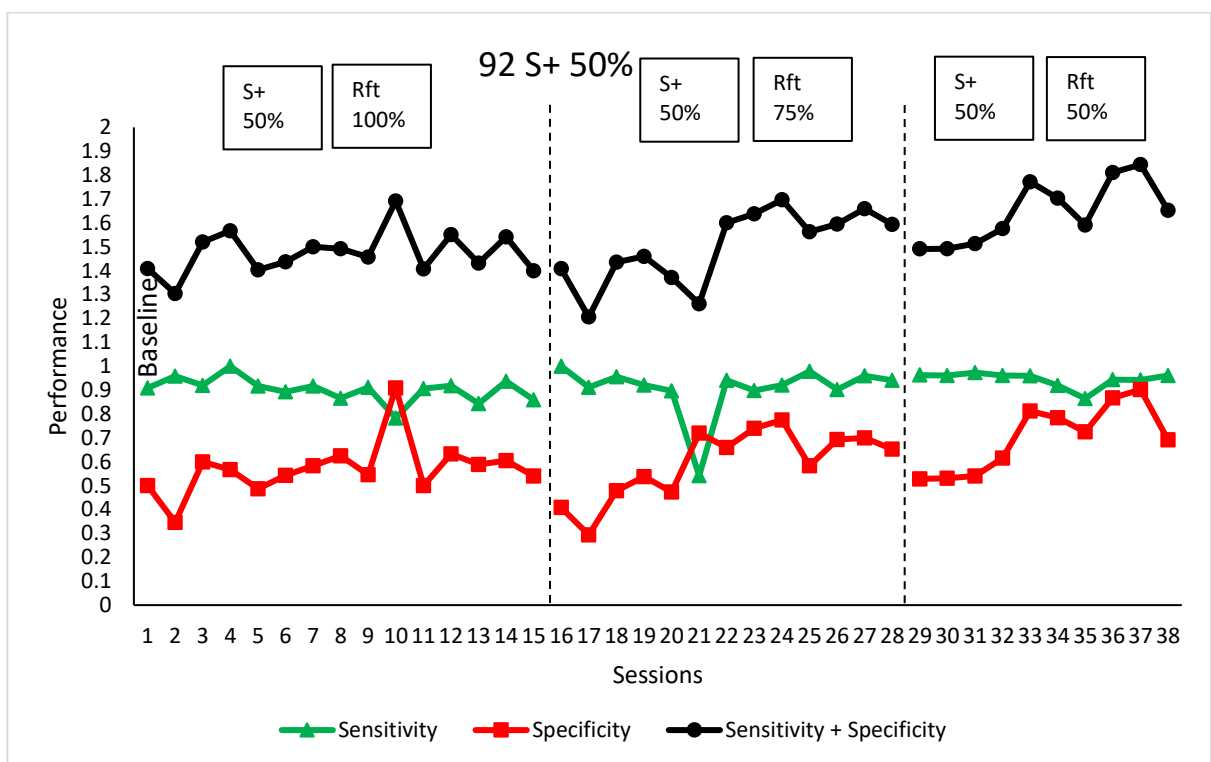


Figure 5: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 92.

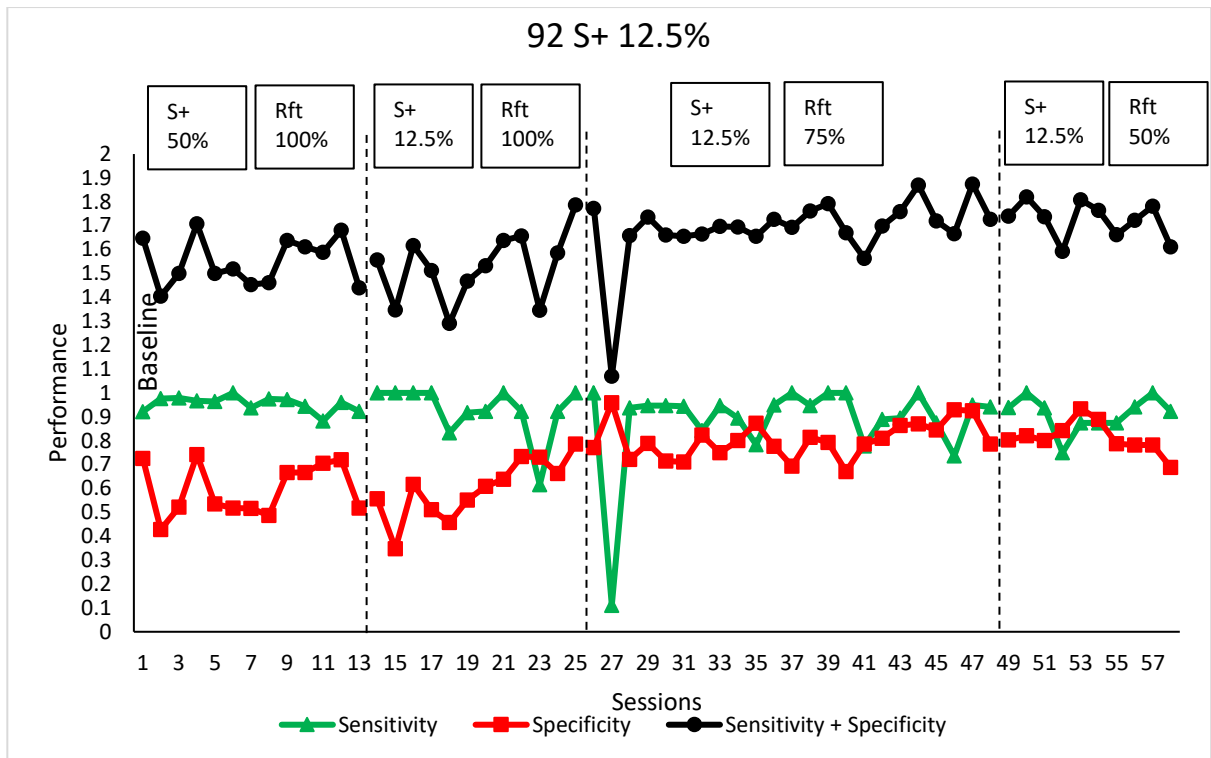


Figure 6: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 92.

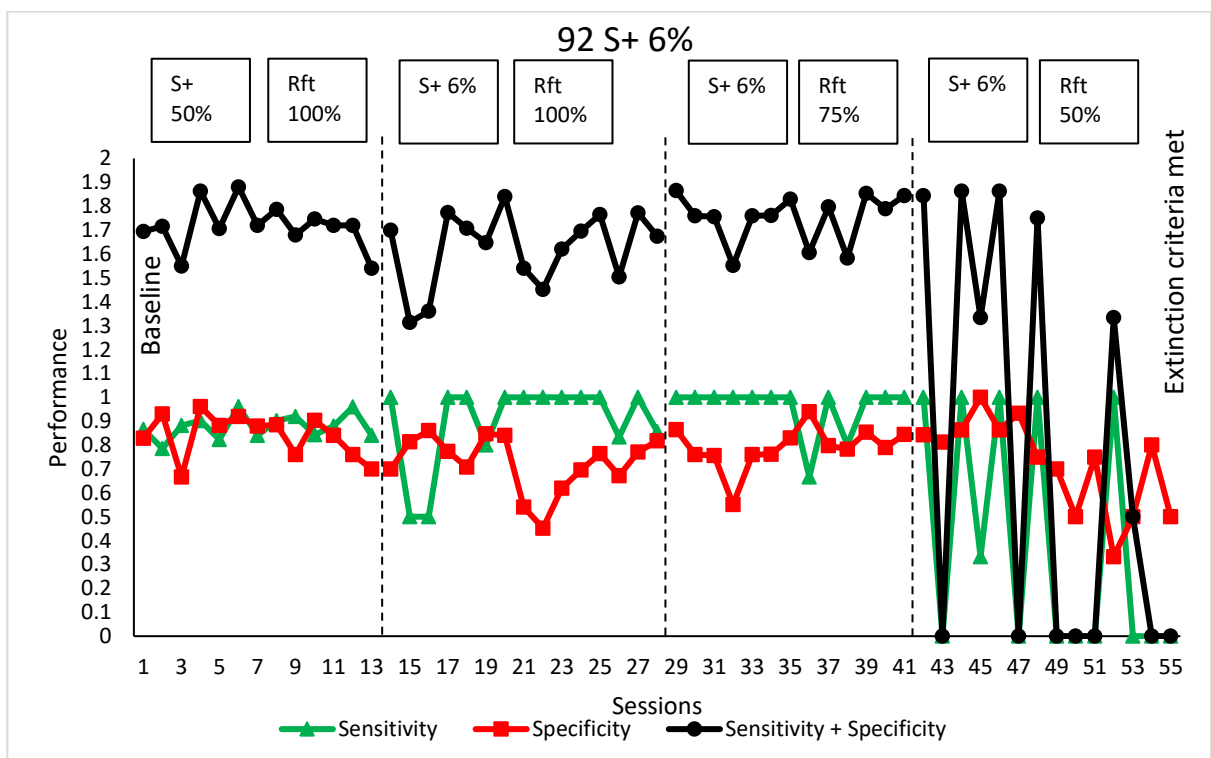


Figure 7: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 6% for hen 92.

Figures 8, 9 and 10 show performance across conditions for Hen 93. Sensitivity was higher than specificity until the leanest S+ presentation of 6%, where during the 75% reinforcement condition, specificity steadily increased until it was similar to sensitivity. This was also seen during 50% reinforcement.

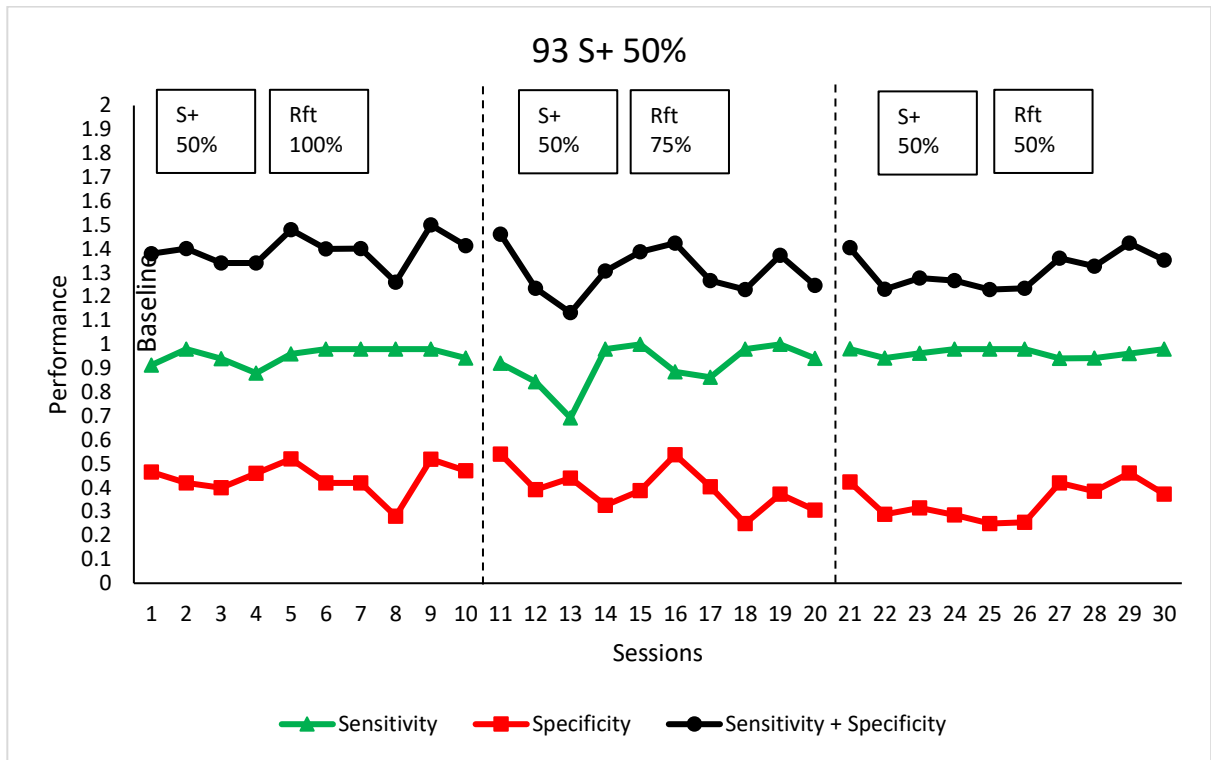


Figure 8: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 93.

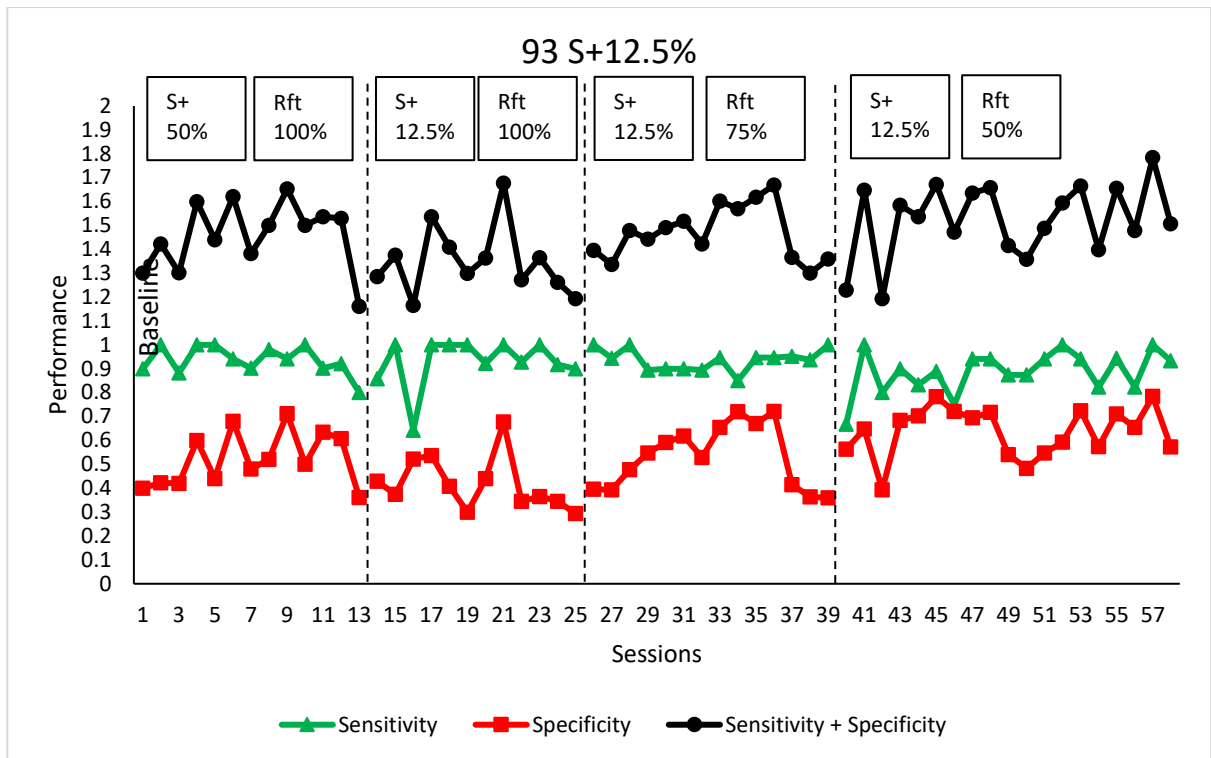


Figure 9: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 93.

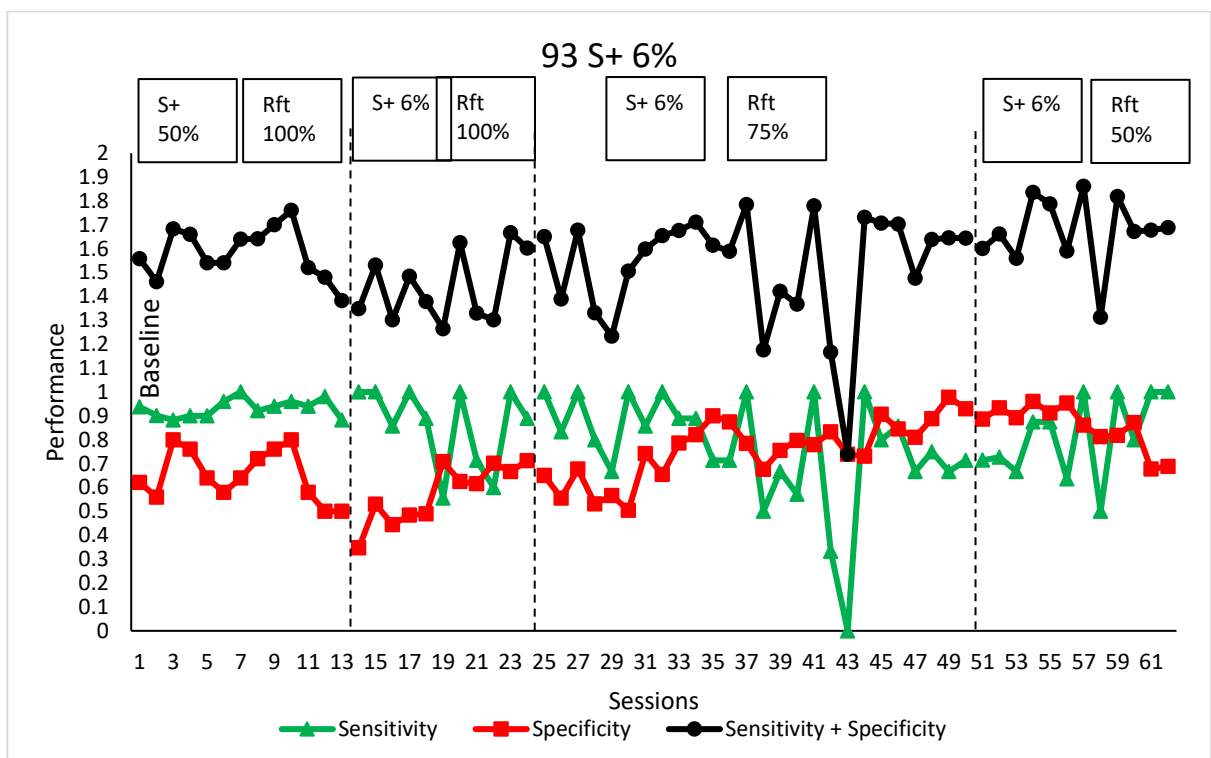


Figure 10: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 6% for hen 93.

Figures 11, 12 and 13 show 94's performance across conditions. Sensitivity and specificity were similar across all conditions, with specificity being slightly below sensitivity, but occasionally peaking above it. Extinction criteria were met during S+ presentation at 12.5% and reinforcement at 75%. During 25% S+ conditions, sensitivity and specificity remained similar, however, specificity increased above sensitivity as reinforcement was thinned.

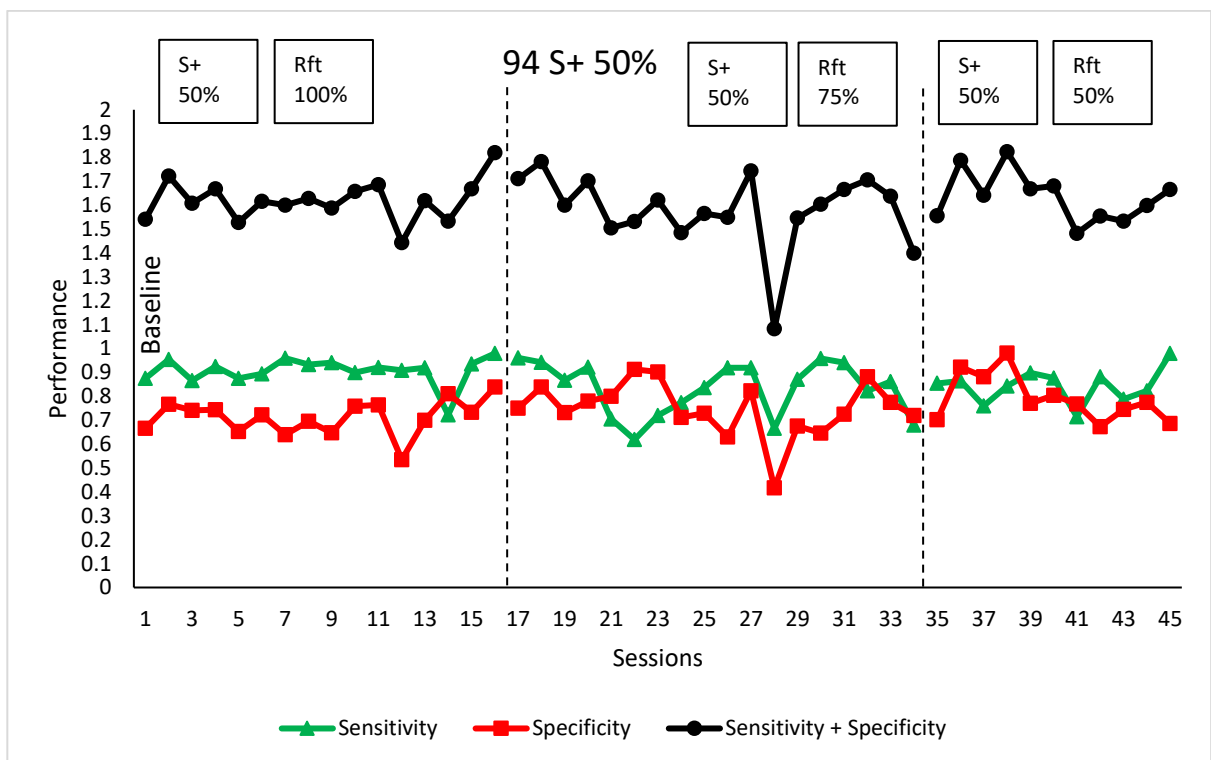


Figure 11: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 94.

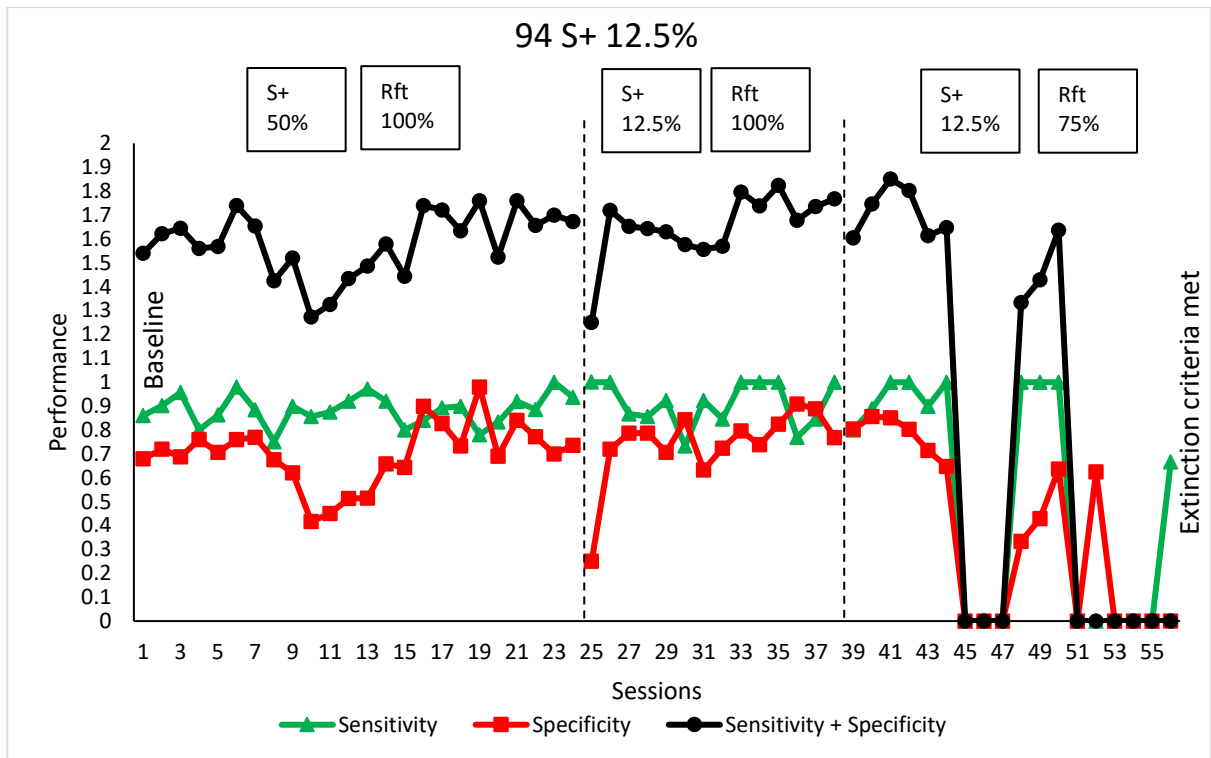


Figure 12: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 94.

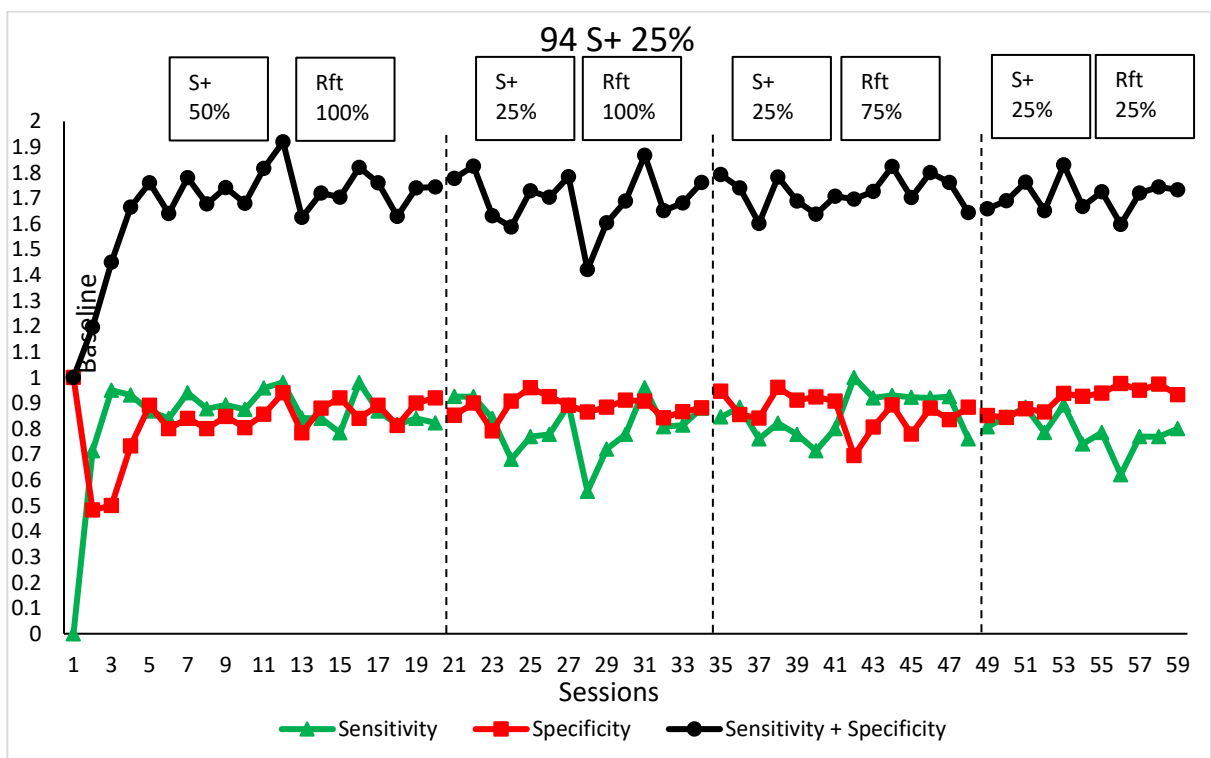


Figure 13: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 25% for hen 94.

Figures 14, 15 and 16 show performance of 95 across conditions. It can be seen that for S+ presentations of 50% and 12.5% sensitivity was above specificity during baseline, however, as the reinforcement was thinned, specificity increased. Sensitivity during S+ 12.5% and reinforcement 50% reached ceiling, with specificity dropping back down. During S+ 6% sensitivity gradually decreased until extinction criteria were met during 50% reinforcement.

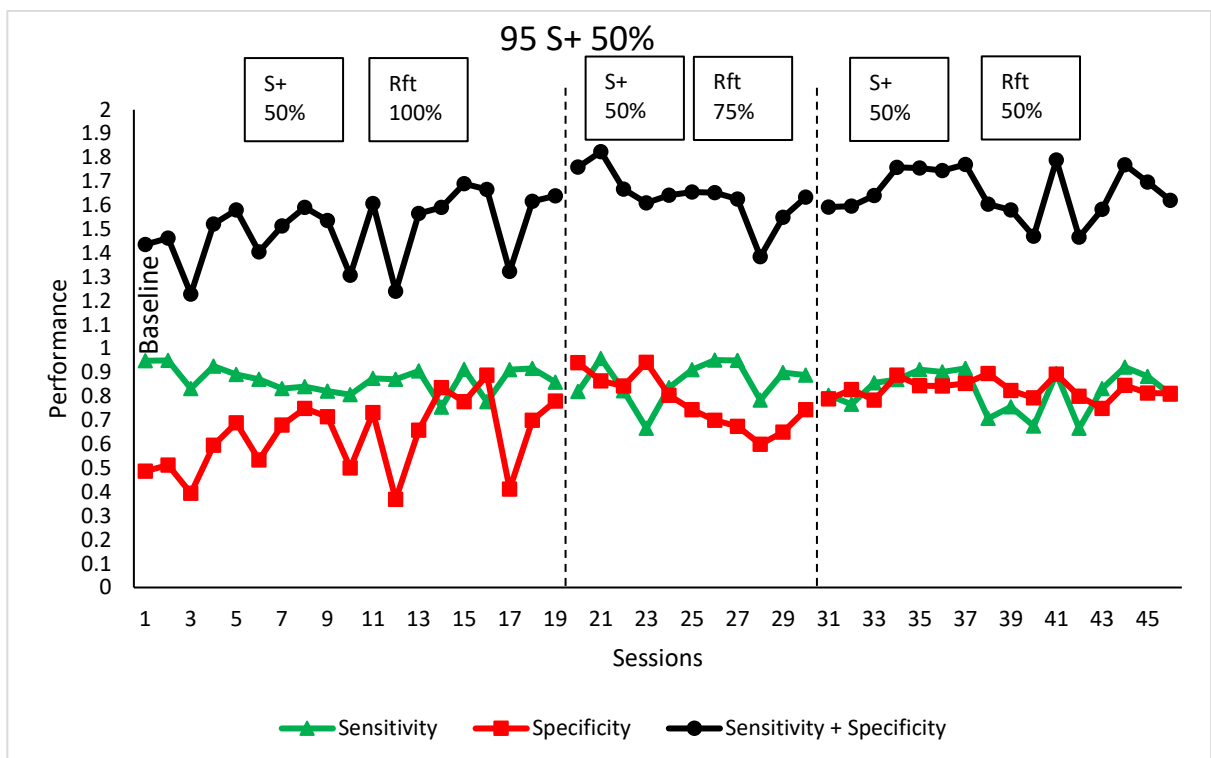


Figure 14: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 95.

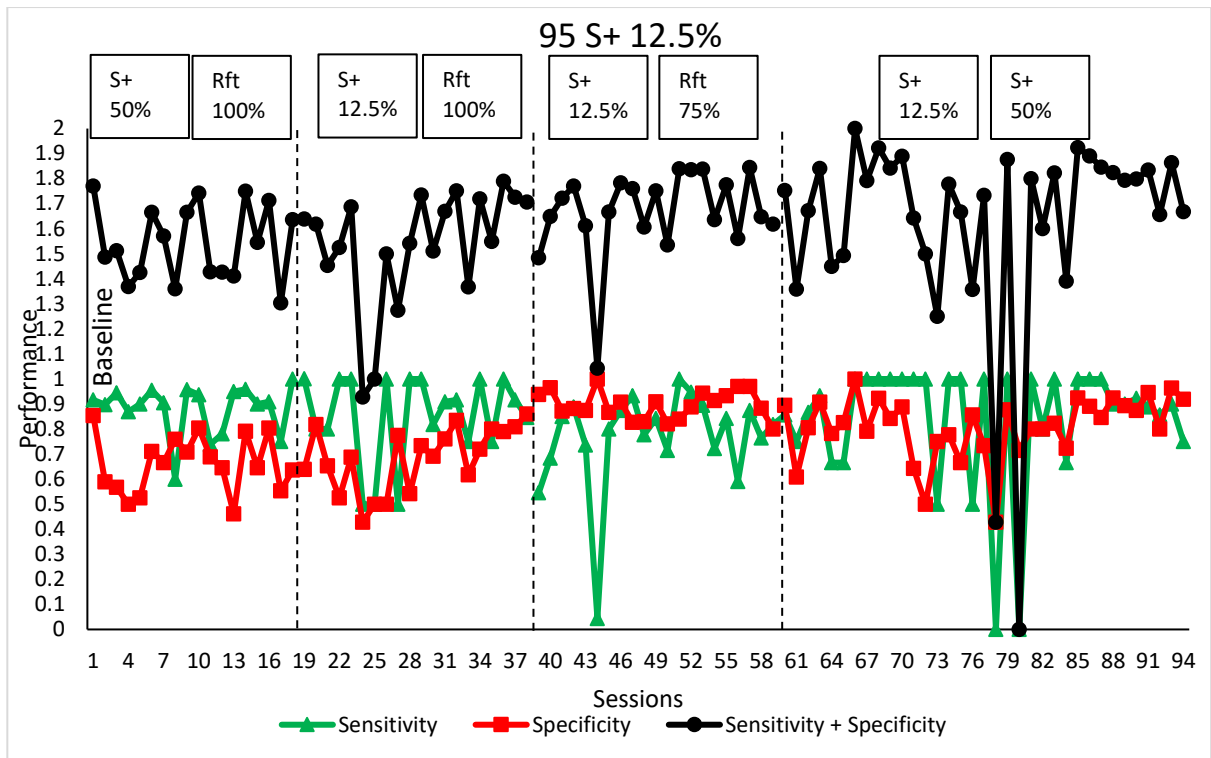


Figure 15: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 95.

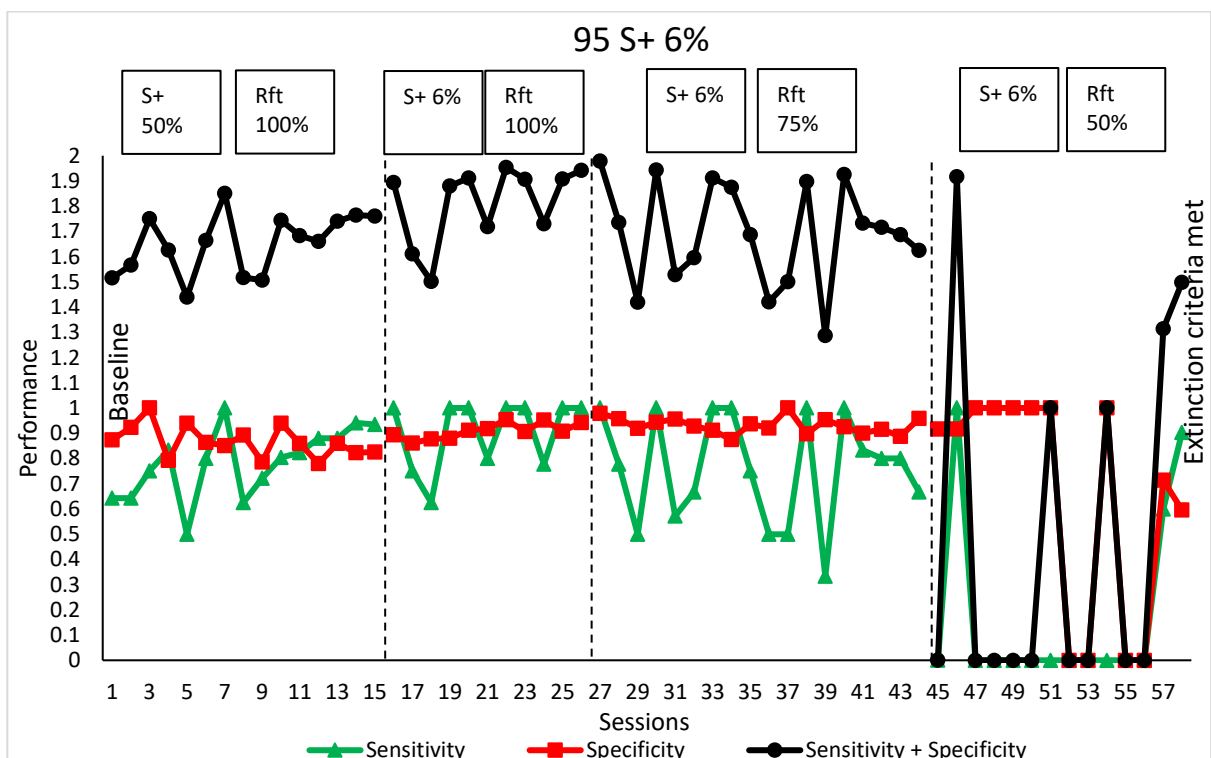


Figure 16: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 6% for hen 95.

Figures 17, 18 and 19 show performance of 96 across conditions. Sensitivity and specificity stayed similar across all condition changes for this hen. Specificity dropped slightly during S+ presentation 12.5% and reinforcement 100% but gradually increased as the sessions continue.

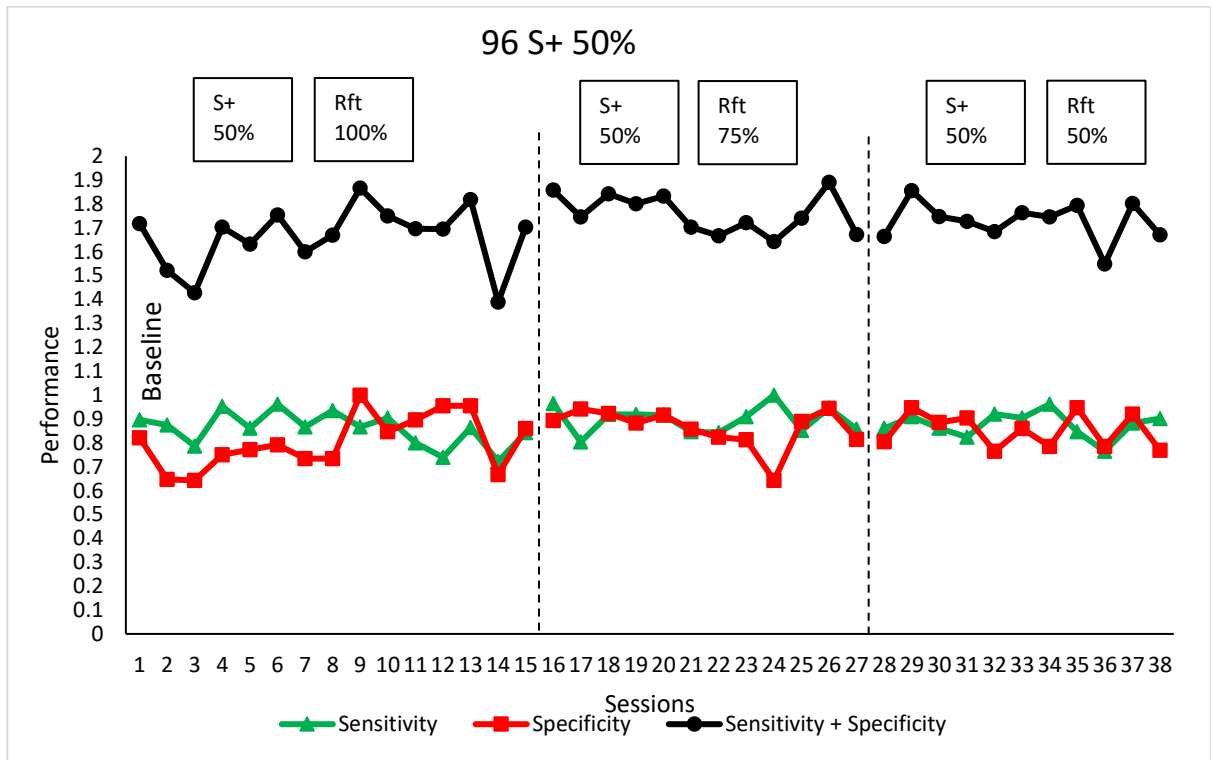


Figure 17: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 50% for hen 96.

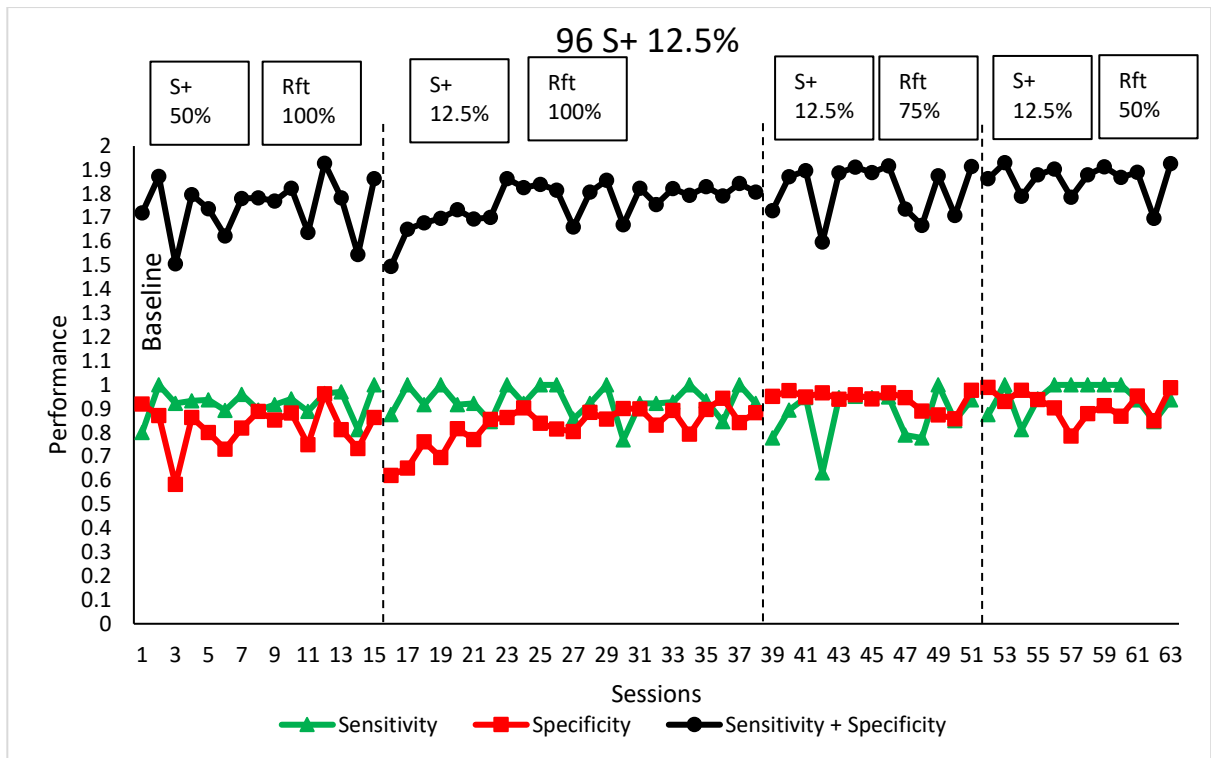


Figure 18: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 12.5% for hen 96.

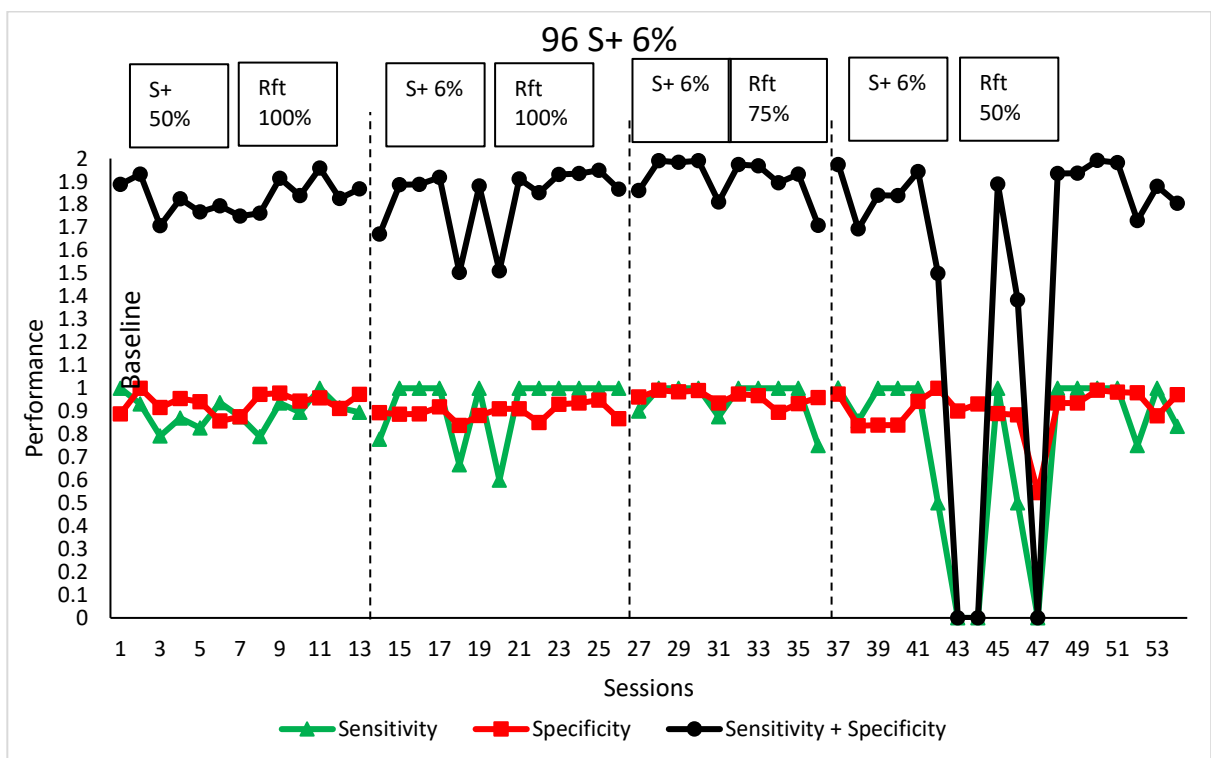


Figure 19: Hits (green), correct rejections (red), and combined hit and correct rejection (black) under S+ 6% for hen 96.

For several hens (e.g. 92, 95 and 96), as the S+ probability was lowered and the chance of reinforcement on positive trials decreased, sensitivity reached the ceiling. For Hens 92, 93, and 96, overall sensitivity was higher than specificity for most conditions. There was also a common finding that specificity tended to improve over conditions for most hens. This is seen in Figure 20 where it is observed that specificity increased with each return to baseline.

Figure 20 shows the average baseline data for all six hens and the subsequent returns to baselines between evaluations of performance at each S+ probability. This graph shows that there was an overall increase in performance over conditions. This increase can be attributed to the gradual increase in specificity, as sensitivity was stable across the baseline conditions.

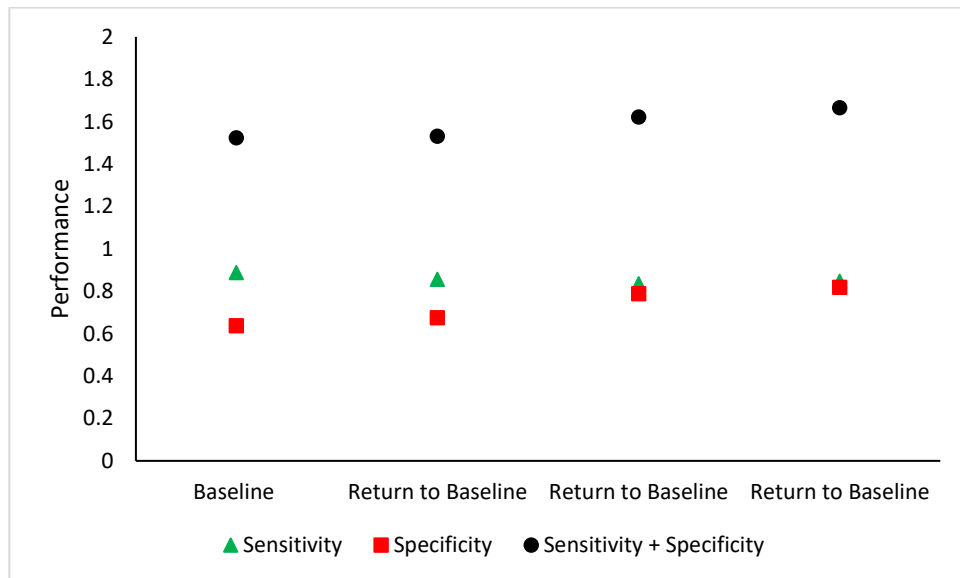


Figure 20: Average performance (hits, correct rejections, and combined) in initial baseline and subsequent returns to baseline.

Table 3 shows that when conditions were returned to baseline after low S+ presentations and lean schedules of reinforcement, obtained reinforcement would increase back to similar numbers obtained in initial baseline. The condition where most

reinforcement was gained was the return to baseline after S+ 25% and reinforcement at 50%; the average number of reinforcers gained was 38 per session. The lowest average reinforcement gained was at S+ 6% and reinforcement at 50%, here the average number of reinforcers gained was 1 per session.

Table 3. Average Reinforcement Obtained During Conditions Across Hens.

Condition	Average Reinforcement Obtained
S+ 50%/ Rft 100% (initial baseline)	34
S+ 50%/ Rft 75%	26
S+ 50%/ Rft 50%	20
S+ 50%/Rft 100% (baseline)	32
S+ 25%/ Rft 100%	16
S+ 25%/ Rft 75%	13
S+ 25%/ Rft 50%	7
S+ 50%/ Rft 100% (baseline)	38
S+ 12.5%/ Rft 100%	10
S+ 12.5%/ Rft 75%	10
S+ 12.5%/ Rft 50%	7
S+ 50%/ Rft 100% (baseline)	37
S+ 6%/ Rft 100%	5
S+ 6%/ Rft 75%	3
S+ 6%/ Rft 50%	1

Average sensitivity across hens was lowest (0.66) at S+ 25% and reinforcement 100%. Sensitivity was highest (0.92) at S+ 6% with 100% reinforcement rate. Specificity

was lowest (0.62) at S+ 50% and reinforcement 100%. Specificity was highest (0.90) for S+ 6% and reinforcement 75%. The lowest combined performance score (sensitivity and specificity) across conditions was at S+ 6% with reinforcement at 50% as the combined hit and correct rejection rate was 1.45. The highest performance across conditions was at S+ 6% with reinforcement at 100%, as the combined performance score was 1.75. This information can be seen in Figures 21, 22, 23 and 24. Average performance data in each condition is based only on data from the hens that completed the respective condition (refer to Table 4 for a description of the conditions completed by each hen).

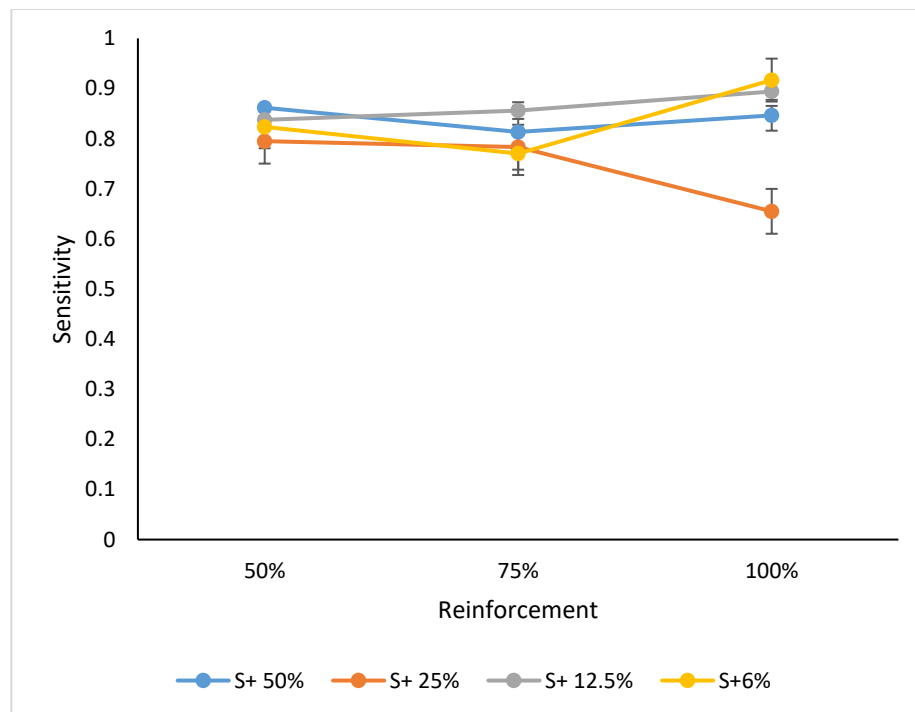


Figure 21: Average sensitivity with each signal probability across reinforcement.

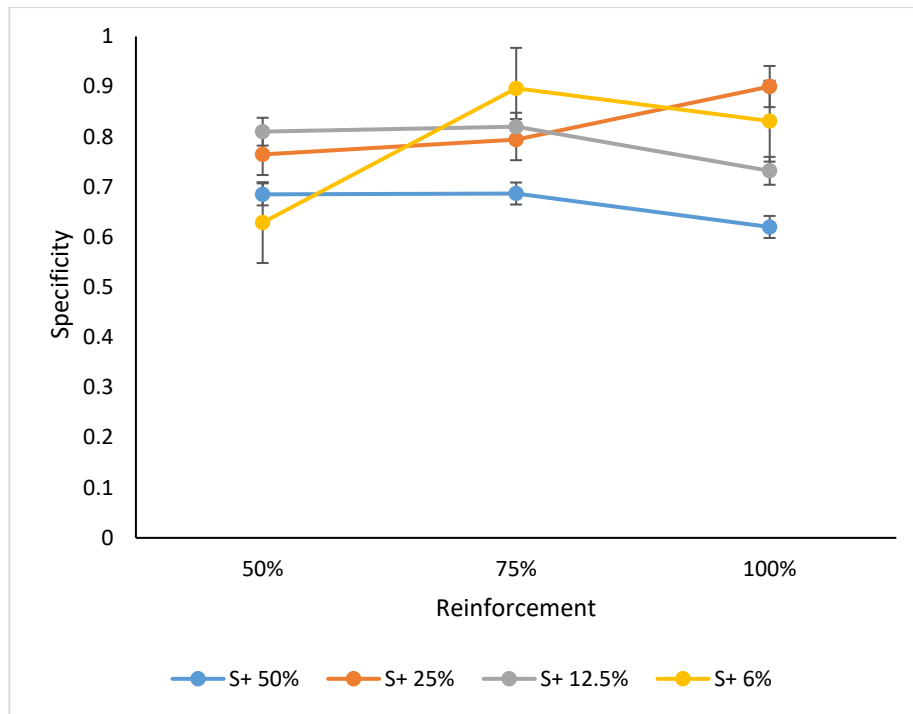


Figure 22: Average specificity with each signal probability across reinforcement.

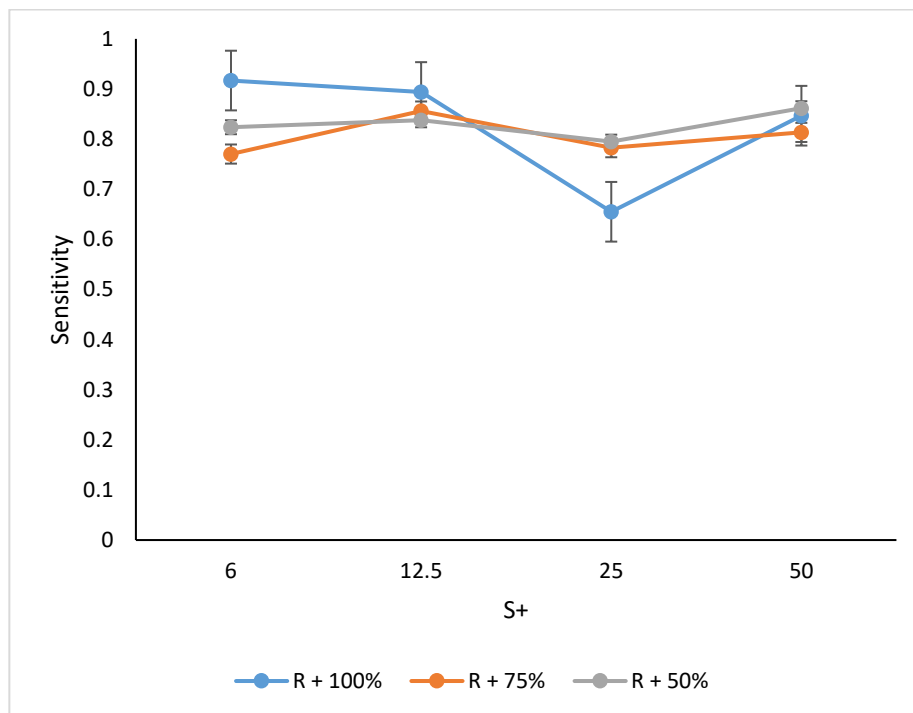


Figure 23: Average sensitivity with each reinforcement rate across signal probabilities.

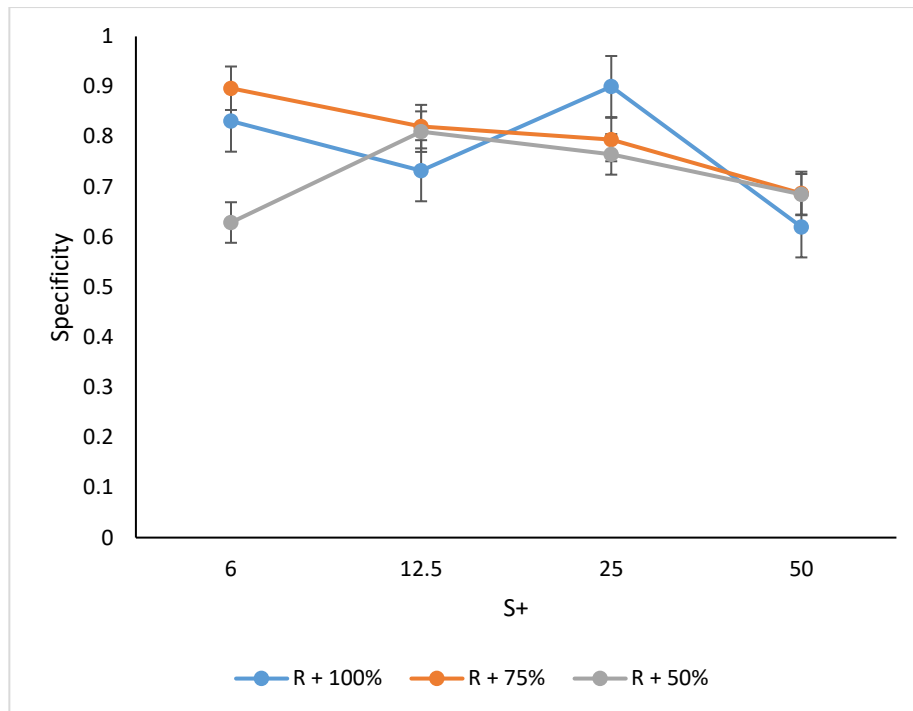


Figure 24: Average specificity with each reinforcement rate across signal probabilities.

Mauchly's sphericity tests were conducted on the combined sensitivity and specificity data obtained under the three rates of reinforcement (100%, 75%, and 50%) and revealed that the assumption was not met. Because the assumption of sphericity was not met in any of the conditions, three non-parametric Friedman's tests were completed to evaluate the influence of S+ probability on sensitivity and specificity. As the Friedman test uses ranked ordered data, the missing data from the intermediate condition (25%) were given an intermediate value that was estimated from the data from the surrounding conditions (50% and 12.5%). The missing data for the uncompleted conditions where hens met termination criteria (e.g. 94 met termination criteria during S+ 12.5%) was estimated using a lower number than those obtained in other conditions. The first Friedman's test examined the results from 100% reinforcement rate conditions across all S+ conditions, chi-square = 4.25, $p = .210$. The second Friedman's test examined the data from 75% reinforcement rate conditions across all S+ conditions, chi-square = 4.32, $p =$

.229. The third Friedman's test was conducted on reinforcement rate 50% conditions across all S+ conditions, chi-square = 1.63, $p = .652$. The differences in performance across S+ conditions were not statistically significant in any of the three reinforcement conditions. Another four Friedman's tests were completed for each S+ condition, to determine any differences across reinforcement rates. The same method for estimating missing data was used as stated above. The first Friedman's test was conducted on S+ 50% across all reinforcement rates, chi-square = 1.33, $p = .513$. The next Friedman's test examined the results of S+ 25% condition across all reinforcement rates, chi-square = 3.00, $p = .223$. The third Friedman's test examined the data from the S+ 12.5% conditions across all rates of reinforcement, chi-square = 1.60, $p = .449$. The fourth Friedman's test examined the data from S+ 6% conditions across all reinforcement rates, chi-square = 2.00, $p = .368$. It was found that there were no statistically significant differences between reinforcement rates for all S+ conditions. This suggests that manipulations to the stimulus presentation and rate of reinforcement within the range tested had no effect on hens' performance.

Figure 25 illustrates the average number of trials that each hen completed per minute across all sessions, as S+ presentation probability and reinforcement rate were manipulated. The number of completed trials stayed relatively stable across conditions, with slight drops for some hens as the S+ and reinforcement availability became lean (e.g., S+ 6% and reinforcement 50%). For some hens, such as 92 and 95, the number of completed trials was progressively lower leading up to the conditions before termination criteria were met.

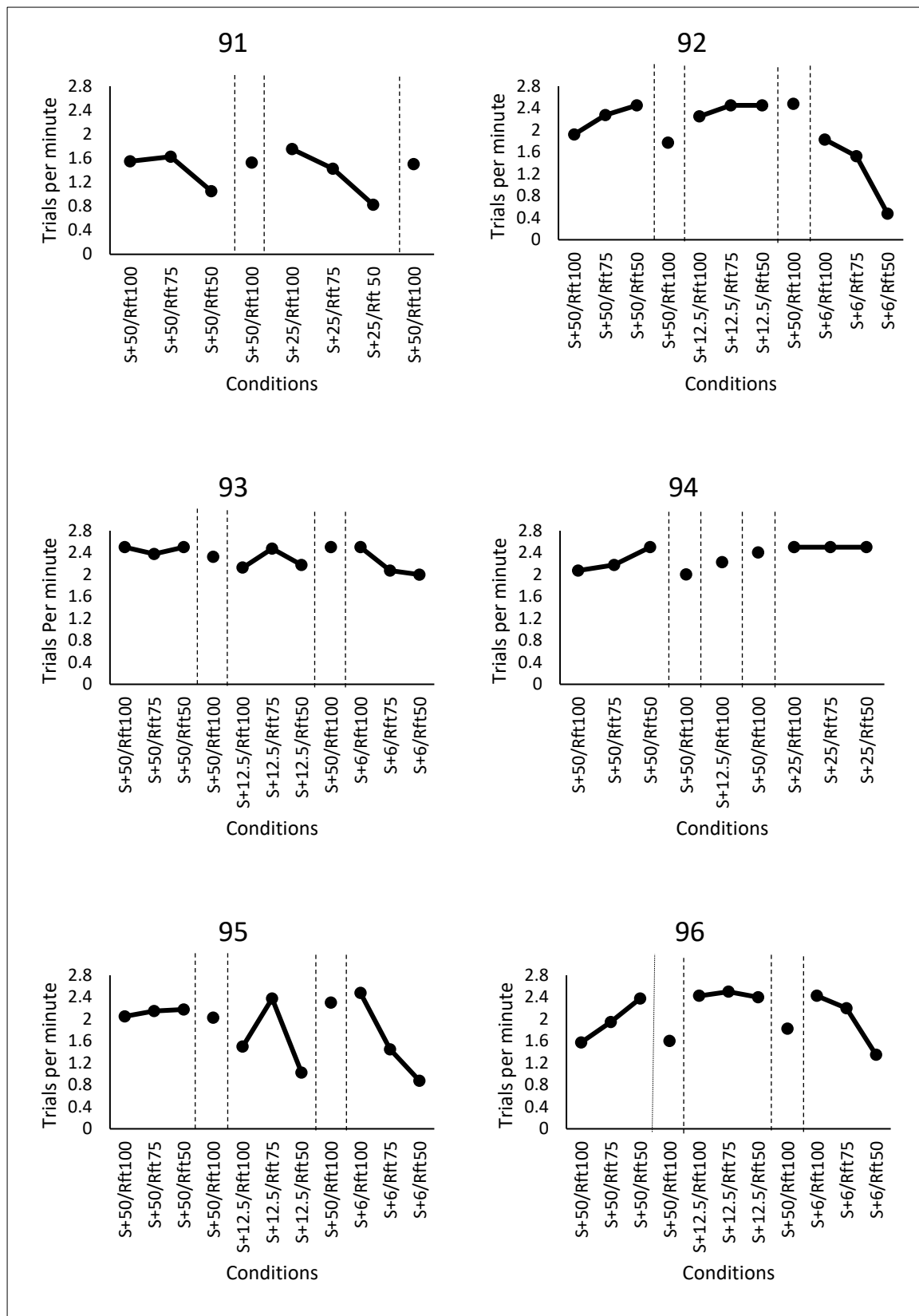


Figure 25: Average completed trials per minute for individual hens across conditions.

Table 4 demonstrates the conditions which hens completed, and at which ones they met termination criteria. Table 4. also illustrates the order in which the conditions

were arranged and run. It can be seen that for hen 91, behaviour extinguished during the condition where target stimulus presentation was 12.5% and reinforcement was at 100%. Therefore 91 was put onto the intermediate S+ condition presentation of 25% instead of the more difficult presentations. Hens 92 and 95 met termination criteria at the lowest S+ presentation (6%) and the lowest reinforcement rate (50%). Hens 93 and 96 completed all conditions, and therefore it is unknown at what probability of S+ presentation and reinforcement their responding would extinguish. Hen 94 met termination criteria at S+ 12.5% and reinforcement probability at 75%, this hen was also placed on the intermediate S+ presentation of 25%.

Table 4. Conditions that each hen completed.

	91	92	93	94	95	96
S+ 50/Rft 100	completed	completed	completed	completed	completed	completed
S+ 50/Rft 75	completed	completed	completed	completed	completed	completed
S+ 50/Rft 50	completed	completed	completed	completed	completed	completed
S+12.5/Rft100	extinction	completed	completed	completed	completed	completed
S+12.5/Rft 75	no	completed	completed	extinction	completed	completed
S+12.5/Rft 50	no	completed	completed	no	completed	completed
S+25/Rft 100	completed	no	no	completed	no	no
S+25/Rft 75	completed	no	no	completed	no	no
S+25/Rft 50	completed	no	no	completed	no	no
S+6/Rft 100	no	completed	completed	no	completed	completed
S+6/Rft 75	no	completed	completed	no	completed	completed
S+6/Rft 50	no	extinction	completed	no	extinction	completed

The responses on S+/R+ (where reinforcement was available) trials and S+/R- (where reinforcement was not available) were calculated for all hens. These responses were averaged to give the average number of responses across all hens. It is observed that the average indication for S+/R+ trials was 9.1 which is below the FR requirement (10). For the conditions where the S+ was present, however, reinforcement was not available for hits, the average indication was 10.5, which was above the FR requirement.

Discussion

Findings

The aim of this experiment was to determine the effects of signal probability and reinforcement probability on hens' responding in a signal detection task. It was hypothesized that sensitivity would increase and specificity would decrease as reinforcement probability was lowered. It was also predicted that when stimulus presentation was at its lowest, the hens would make more errors on the signal detection task.

The results showed that the hens' performance did not change significantly as the target signal presentation and the reinforcement probability were lowered over conditions. For some hens, sensitivity increased during the conditions with low S+ probability and reinforcement (e.g., 92 had 100% for hits in the S+ 6% conditions when reinforcement rates were at 100% and 75%). Correct rejections (i.e. specificity) also increased during low S+ probability and reinforcement. Given the results obtained by Davison and Tustin (1978), I hypothesized, that as the target signal presentation and reinforcement for hits decreased, the hens would be biased towards options that would most likely provide reinforcement. Therefore, it was expected that the hens would indicate more stimuli as positive as this would increase the chance to gain reinforcement. This was not found. Instead the hens continued to correctly indicate when S+ was present and correctly reject when S+ was absent with high accuracy. Most hens' sensitivity and specificity remained high throughout all conditions, except the conditions where termination criteria were met as accuracy and trial completion declined. High accuracy was observed throughout the conditions with low target stimulus presentation and low rate of reinforcement with most hens' "hits" and "correct rejections" increasing. This

demonstrated the opposite of what we predicted, as the hens did not have a bias for indicating on the key with potential reinforcement available.

Based off the findings by Wolfe, Horowitz and Kenner (2005), it was predicted that as the prevalence for the target signal decreased (i.e., in the 12.5 and 6% conditions), the hens would make more errors in comparison to the higher prevalence conditions (50% and 25%). This means that it would be expected that the hens' misses would increase, resulting in low sensitivity and low specificity. It was found that the hens' errors did not increase during the experiment, as the target stimulus probability and reinforcement was decreased. Wolfe, Horowitz and Kenner (2005) found a decrease in sensitivity, but not specificity. One reason for the different finding could be that Wolfe, Horowitz and Kenner (2005) used a detection task where the organism was required to scan an area for a target. This additional behavioural requirement may have influenced the detector's accuracy. In comparison, the current study found that neither sensitivity nor specificity declined. This demonstrated that the current findings align with those of McCarthy and Davison (1979) as they found that changes in behaviour were not controlled by signal probability, but rather reinforcement probability. The hens had high correct rejection rate (specificity), and for some hens this measure of accuracy increased as reinforcement thinned over conditions. Based on these results, it can be speculated that in conditions with low chances to gain reinforcement, the hens would correctly reject the noise stimuli more often. This high accuracy could mean that trials were completed more quickly because this reduced the delay to a positive trial and, therefore, a chance to gain reinforcement.

It was observed that hens' accuracy on a signal detection task was stable up until a "breaking point", where the hens met termination criteria. This breaking point differed for each hen (refer to Table 4). Variations in this breaking point across hens, suggests

that care needs to be taken when selecting individuals for operational work, as the range of conditions under which a signal can be accurately detected may differ depending on the individual. This individual breaking point may be influenced by a variety of factors that might be controlled. Future research that targets these factors to identify them and influences they have may be beneficial. The S+ and R+ range at which the organism can accurately detect before the “breaking point” should be determined, so that animals are selected that are able to perform under operational conditions. The point at which individuals of other species would meet termination criteria might differ.

The results of this study could be relevant to applied work with giant African pouched rats screening for tuberculosis. The findings showed that, for some hens a signal can be reliably indicated when it is present in only 6% of trials (92 & 93). This study could be replicated with pouched rats and other operational signal detection animals to determine if accuracy would also increase with repeated practice and to establish “breaking points” for individuals of those species. Edwards et al. (under review) found that pouched rats’ accuracy significantly decreased when the known positives were reduced to 2% of all samples. This decrease in accuracy suggests that rats begin to “break down” when they only have the opportunity for reinforcement with 2% of samples. While the type of signal between the study by Edwards et al. and the current study was different (olfactory versus visual) both used low prevalence of target samples (2% versus 6% with 50% reinforcement). While a termination criteria was not determined across all hens for the current study, the findings still align with those from Edwards et al. The current findings would be of interest when applied to the pouched rats, as it is often unknown how many of the screened sputum samples are positive, and it is possible that only a small number in the array of samples that are being evaluated are positive. If the

results were to generalize to the application with pouched rats, it could be that they would perform accurately with very low numbers of positive samples.

The hen's accuracy was observed to increase as target stimulus probability was thinned and as reinforcement probability decreased. It is possible that their performance on the signal detection task was influenced by a practice effect. This would mean that over time and exposure to the task, the hens' performance improved. A practice effect could account for why hen's performance improved as the stimulus probability and reinforcement probability was lowered. This was evidenced by the hens who met termination criteria in the S+ 12.5% conditions (91 and 94) and were placed in the conditions where S+ was presented in 25% of trials. The hens' accuracy on the task increased when the S+ was at 25%, indicating a practice effect. The rate of reinforcement was systematically lowered (i.e., 100%, 75% and 50%) so that the hens' responding would not extinguish as soon as they experienced low rates of reinforcement. This method of lowering reinforcement may have led to the hens' high accuracy on the task due to exposure over time. Referring back to *Figure 25*, it is seen that baseline performance increases over the conditions. This suggests that practice did influence performance, however this does not rule out the possibility that performance improved due to the lower target stimuli presentation and lower rates of reinforcement. It is possible that the increase in performance was related to a mixture of both the changes in conditions, and the hens' repeated exposure to experimental conditions. While a practice effect is difficult to avoid, it would have been interesting to determine if randomly rotating conditions, rather than systematically lowering them could have had a different impact on the hens' performance. One way that this could be done would be to randomize the reinforcement and signal probability so that each session had a randomly selected condition with no order. This would mean that rather than having repeated

exposure to a particular reinforcement rate and S+ rate over multiple sessions (e.g., S+ 50%/Rft 100% for 10 sessions), the S+ and reinforcement rate would vary each session (e.g., S+50%/Rft100% during session 1 and S+ 6%/Rft50% in session 2) until the total session criteria had been met over time. This method, however runs a risk for hens' responding to extinguish more quickly, particularly if the first session of a low stimulus probability by chance had a low reinforcement rate.

One aspect of the methods that may have affected the individual hens' performance was the disparity between the target (S+) and the noise (S-). When the S+ was set for each hen, it was done using a titrating procedure to determine the point where each hen was responding between perfect and chance accuracy. Due to the procedure that determined the S+ disparity, hens ended up with different S+ numbers (See Table 2 for hens' S+ numbers). The S- brightness was fixed at 50 (see Methods for a description of the dimmer apparatus). For hens 91 and 94, responding extinguished under S+ 12.5% conditions. Both of these hens had a S+ number set at 60. Hens 92 and 93 had an S+ set to 58, which was the smallest discrepancy between S+ and S- of all the hens. However, both of these hens performed accurately on the task into the leanest S+ presentation condition of 6% (92 extinguished at the end of this condition when reinforcement was at 50%). Hens 95 and 96 had an S+ number of 63, the highest of all the hens. 95 performed accurately on the task until the leanest S+ presentation of 6%, before termination criteria was met. Hen 96 did not meet termination criteria, even in the leanest conditions (S+6% with reinforcement 50%). It was seen that for 96 in particular, that there was little difference between sensitivity and specificity. It is possible that the S+ disparity influenced the rate at which certain hens' responding extinguished as the signal probability and reinforcement probability decreased. However, S+ values that were closer to the S- values did not appear to result in lower accuracy.

The overall number of responses that were required to gain reinforcement may also have played a role in why some hens' responding extinguished. For S+ trials, the hen would ideally peck the green key once as an observation response and then peck 10 times, to gain access to reinforcement. However as reinforcement probability was lowered, hits would get reinforced less often on these positive trials (as low as 50% of the time when FR was reached). It was shown in *Table 5* that the average indication response increased during low probability of reinforcement which suggests that the hens pecked the green key more than the required FR10 on S+/R- trials. This increase in average indication response was the result of hens pecking green on trials that had target stimulus present but with no reinforcement for "hits". In the leanest condition, the target stimulus was only presented in 6% of all trials. A session consisted of 100 trials, meaning that during the lowest rate of reinforcement (50%) the hens only had the opportunity to gain reinforcement on 3 out of 100 trials. This low chance to gain reinforcement could suggest why hens stopped responding on the signal detection task. Most of the hens that met termination criteria would accurately complete trials in the condition for a couple of sessions (e.g. Hen 94 during the S+ 12.5% and Rft 75% condition), which indicated that they could still detect the signal during these lean conditions, but that the response requirement was too great.

Limitations

This study used a discrete trial procedure, rather than a free operant procedure. This means that there were discrete opportunities for the hens to respond and gain access to reinforcement rather than responding being able to occur and gain access to reinforcement at any time during the experiment. This means that the results obtained from this experiment may not generalize to free operant situations.

A practical limitation of the current study could be that the hens' body weight was not strictly controlled and was kept loosely around 90-95% of free feeding body weight as a motivating operation (MO) for food. The reinforcing effectiveness of food was likely to differ for each hen due to no strict control over the establishing operation, this may have influenced the "breaking down" points, where the hens reached termination criteria due to lack of MO. Future research to determine the effect of stricter and lower body weights (80%) on accuracy of a signal detection task would be useful.

Another limitation of the current study was that only two hens completed the conditions where the target stimulus was presented in 25% of trials (91 and 94). As a result, a large portion of the data was interpolated to conduct the statistical analysis. A larger sample size for this condition may have provided data that were more reliable, particularly as hen number 91 could have numerous sessions of unstable data before it stabilized to meet criteria (e.g. session 7 during S+ 50%/Rft 100% and sessions 33-37 in S+ 50%/Rft 50% to name a few).

Conclusion

The main finding of this study was that there were no statistically significant changes to hens' performance prior to the "breaking points". While there were some systematic changes to hens' accuracy (i.e. increases specificity) on the signal detection task, this was likely the result of repeated exposure to the stimulus conditions and training procedures and may have also been the result of exposure to low rates of reinforcement. Some hens' behaviour did not extinguish at low S+ and reinforcement probability (93 and 96 were still responding at S+ 6% and reinforcement at 50%). This suggests that the average number of responses the hens needed to make to get to an R+ trial was not too high, as they still performed accurately at the lowest presentations (see Table 4 for the conditions in which hens' behaviour extinguished). For these hens, it is

unknown under what conditions they would continue to work if the S+ and reinforcement probability were lowered further.

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