4. Auditory Vigilance

4.1. Material and Methods

4.1.1. Apparatus

The same integrated system described for the visual vigilance study was employed for investigating auditory vigilance in the dolphin. However here, *auditory* stimuli were presented to the dolphin.

4.1.2. Stimuli:

All auditory stimuli were created as midi files in the computer program Musicshop. Stimuli differed from each other in a variety of parameters including frequency contours, timbre and rhythm and were chosen by the experimenter to be highly distinguishable from each other. A Roland SC-7 midi sequencer (Figure 5) was used to play the stimuli. Each stimulus was played for one second. The output of the SC-7 was fed into a mixer/amplifier and from there to the transducer that was used as an underwater speaker. The transducer was mounted directly underneath the response paddle (Figure 4). Spectrograms of each sound were recorded (see Appendix A)

4.2. Subject

A 14-year old male bottlenosed dolphin named Hiapo participated in this study. Hiapo was housed together with three other bottlenosed dolphins at KBMML in the same habitat described in the visual study. He was fed approximately the same diet as the dolphin Elele (see visual vigilance). Hiapo had previous experience with motor imitation (Xitco 1998), matching- to-sample (Hoffmann-Kuhnt 1994, Herman et al 1993), creative behavior (Braslau-Schneck 1994), and auditory two-alternative-forced-choice task (unpublished data).

4.2.1. Software

A computer program (Auditory Random Generator, see Appendix B) was designed in Max 3.5 to construct session schedules. A computer rendering of the programming interface is shown in Figure 22. The software allowed for the creation of 10 trials in which the total number of stimuli, the number of critical stimuli per trial and

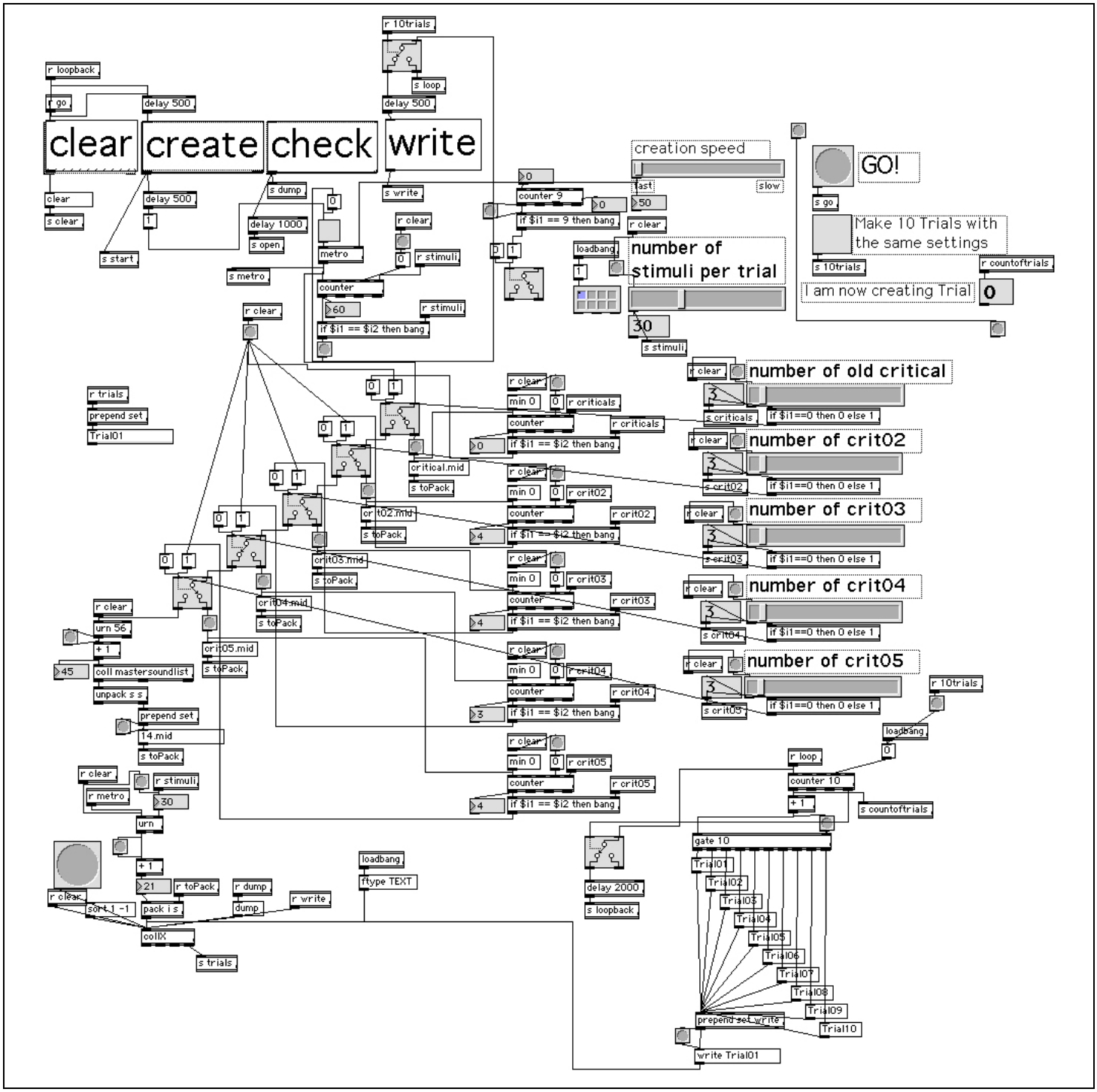


Figure 22: Image of the flow diagram for the auditory random generator written in Max

the number of different critical stimuli used per session could be manipulated. A second computer program (Auditory Player, see Appendix A) was also designed in Max to control the sequence of events for each trial, manipulate the ISI and record the dolphin's responses to all stimuli. A computer rendering of the programming interface is shown in Figure 23. Sessions schedules were pre-planed to allow for the control of all parameters as mentioned above.

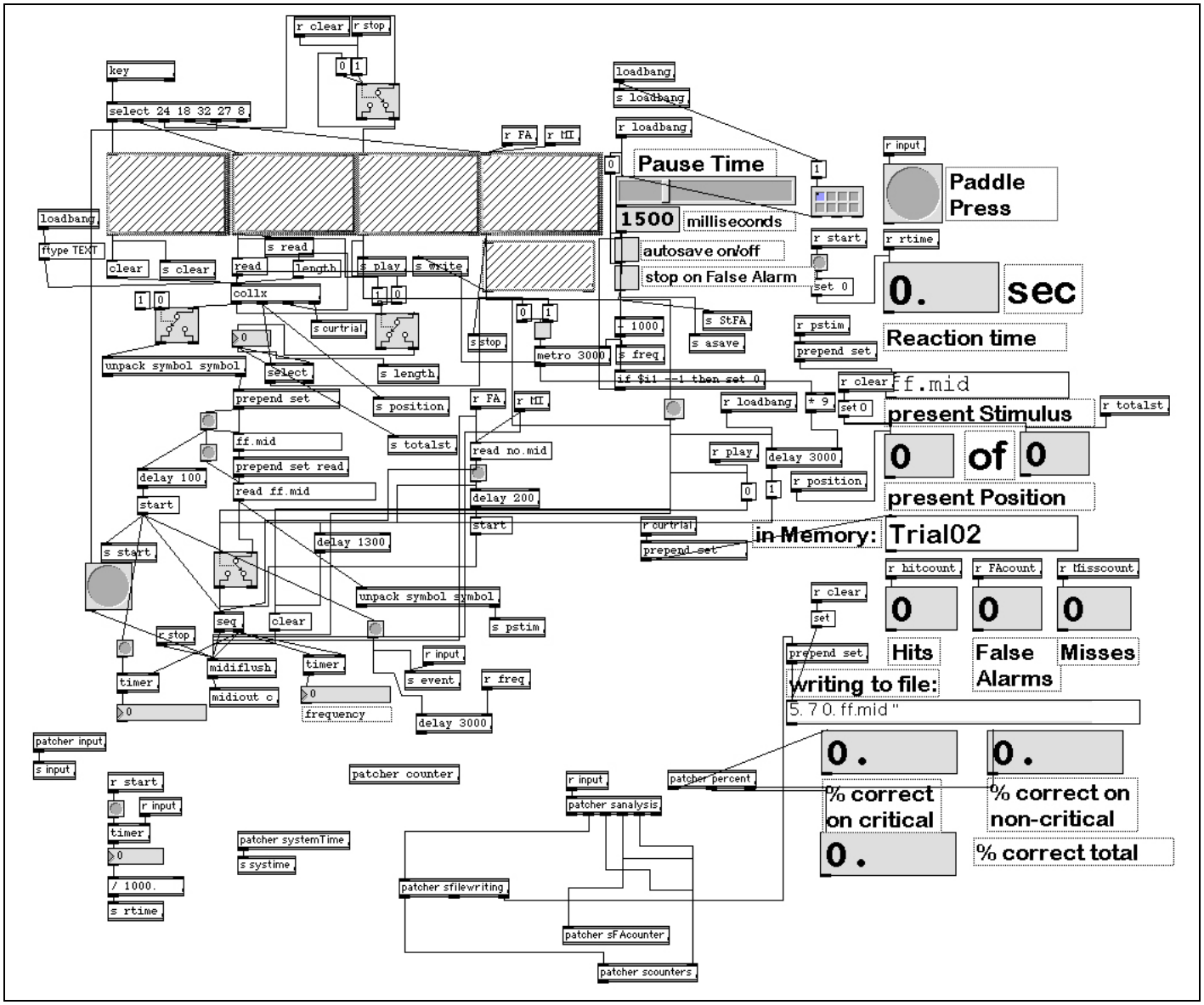


Figure 23: Computer display of the program that controlled the presentation of the auditory stimuli and recorded the reactions of the dolphin

4.3. Procedure

In the final experimental setting test sessions consisted of 10 trials with 60 stimuli each. On each trial, Hiapo was sent by his tank-side trainer to the underwater window and he stationed in front of the apparatus. A video trainer was visible on the television monitor. The video trainer gesturally instructed Hiapo to wait. Then, the image on the screen was switched to black to avoid unintentional cueing or distraction during a trial. The sequence of sounds constituting a trial then began. The same light display that was used in the visual experiment was shown to Hiapo to indicate the end of a trial. Following a trial, Hiapo returned to his tankside trainer to receive fish and social praise. After a one minute inter-trial-interval, the next trial began.
During the auditory vigilance experiments, the following parameters were manipulated:

- The total number of stimuli per trial
- The Inter-Stimulus-Interval (ISI): the time between stimuli
- The number of "critical" stimuli (i.e., the probability of the occurrence of a critical stimuli for any given position)
- The number of different critical stimuli used

In contrast to the visual experiment, the exposure time for stimuli was not changed in the auditory task because the auditory stimuli changed over the time of their exposure to allow for greater variability between stimuli.

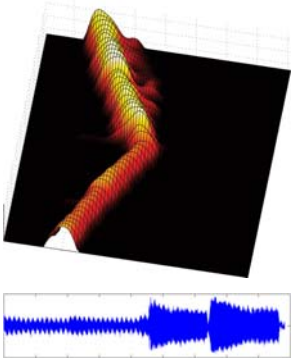
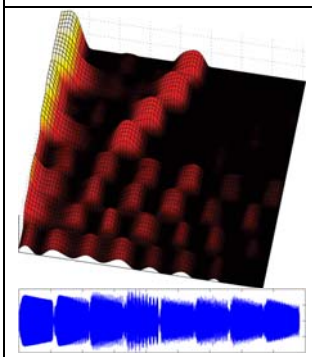
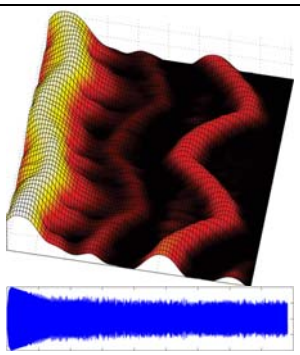
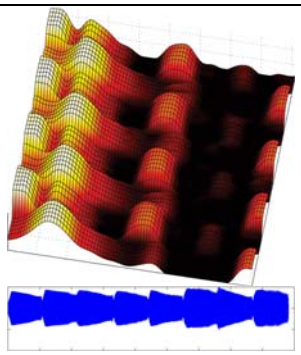
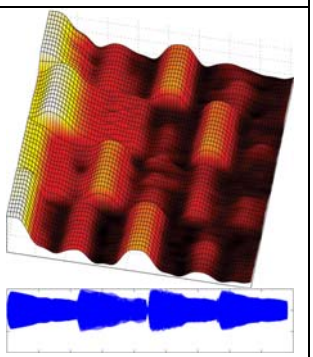
4.4. Training

Over a period of two months, Hiapo was habituated to the SRD. He learned how to station in front of the apparatus and how to press the response paddle. The training of the auditory vigilance task was conducted in the following phases.

4.4.1. Phase I

In Phase I, Hiapo was taught to press the response paddle when a critical stimulus was played and to withhold response to any other "non-critical" stimuli. The SRD was placed in the dolphin's habitat in front of the underwater window. The experimenter stood behind the underwater window. On each trial, Hiapo's tankside trainer signaled him (by pointing, see Herman et al., 1999) to station in the SRD. On a signal by the experimenter, a critical auditory stimulus (critical 1, see Table 7) was played through the transducer. Simultaneously the experimenter gestured Hiapo to press the paddle by pointing at it. In response Hiapo pressed the paddle downward with his rostrum. Upon the presentation of a non-critical stimulus Hiapo was signaled to withhold pressing the paddle by the experimenter signing "wait" (a hand gesture that he knew from daily training). Correct paddle presses in response to the presentation of the critical stimulus and withholding response upon a presentation of a non-critical stimulus were rewarded with a whistle, fish and social praise following each presentation. Upon incorrect responses Hiapo was called back to station by his trainer and no reward was given. Once Hiapo had learned to correctly respond with a paddle press only to the critical sound

Table 7: spectrograms and time series of the auditory stimuli used during Phase I.

	 Critical 01		
 AA	 BB	 CC	 CGEC

stimulus, the number of critical and non-critical stimuli presented per trial was increased to three. During this part of Phase I trials consisted of any combination of stimuli containing between zero and three critical stimuli. The experimenter at the window gave reinforcement (whistle and clapping only) after each correct response (i.e., paddle press on critical stimulus and withholding response on a non-critical stimulus). Fish reward was given only at the end of a trial by the tankside trainer. Once Hiapo's performance accuracy reached 85% or above over four consecutive sessions training advanced to Phase II.

4.4.2. Phase II

In Phase II, a television monitor was placed behind the underwater window and the experimenter was moved from behind the underwater window to the remote room (see Figure 5). Thereafter the trainer's signals to the dolphin were presented on the television. Additionally, the number of stimuli presented during a trial was increased to six. Furthermore the reinforcement given after each correct response was reduced in steps until clapping occurred only at the end of a trial and a whistle and fish was given by the tankside trainer. Once Hiapo performed 85% correct or higher over four consecutive sessions training advanced to Phase III.

4.4.3. Phase III

In Phase III the number of presentations per trial was increased to 12 while simultaneously introducing new non-critical stimuli to enlarge the pool of non-critical stimuli. To ensure that Hiapo had no discrimination difficulties with any of the new stimuli, only *one* of these parameters was varied per session: First, two new non-critical stimuli were introduced using the same number of stimuli as in the previous session. The new stimuli were interleaved within the rest of the non-critical stimuli over the course of two consecutive sessions. Each of the non-critical stimuli appeared only once per trial. If Hiapo's performance accuracy was at or above 85% correct, the number of stimuli per trial was increased by six. During the previous phase the video trainer had been visible on television to the dolphin throughout the whole trial to be able to cue Hiapo if necessary during a trial. Once Hiapo had learned the basic concept of the task however, this

procedure was not longer necessary. To exclude any unintentional cues or distraction by the video trainer, the task procedure was modified: after the dolphin had stationed if front of the apparatus in any given trial and had been given a gesture to “pay attention”, the display for the dolphin was switched to a black screen before the presentation of stimuli began. Once Hiapo had demonstrated performance accuracy of at least 85% over the course of four consecutive sessions in this final training phase the test phase begun.

4.5. Experiment 1: Pause Time Variation

This experiment investigated the effect of changes in pause time (ISI) between auditory stimuli on Hiapo's performance accuracy and reaction time.

4.5.1. Methods and Material

The same apparatus and general methods as described in Phase III were used here. The probability of occurrence of a critical stimulus in any given position was set to 50%. Initially, the ISI was set to 2.0 seconds. Table 8 shows the order in which parameters were varied over the experiment. At the beginning of the experiment a trial consisted of 12 stimuli, 6 of which were criticals. In order to be able to examine a trial with a total of 60 stimuli without repeating any of the non-criticals in any given trial, the pool of non-critical stimuli had to be increased as testing progressed. This was done the following way: First two new non-critical stimuli were interspersed among the existing non-criticals over the course of two sessions. If Hiapo's performance accuracy was at or above 85% on these new stimuli during the two consecutive sessions then the number of stimuli per trial was increased. Furthermore, as the length of a trial increased, the ISI was reduced successively to avoid the dolphin leaving the SRD and interrupting the trial (e.g. if the final configuration with 60 stimuli per trial would have had an ISI of 2.0 seconds then the total length of a trial would have been 3.0 minutes).

Table 8: Sessions of Experiment 1 in the order they were tested. Gray fields indicate a change in one of the three parameters (number of non-criticals, stimuli per trial and ISI) varied throughout the experiment.

Session NR:	Non-criticals	Sounds/ Trial	ISI (sec)	% total correct	% critical correct	% non-criticals correct	Average RT
1	6	12	2.00	100.00	100.00	100.00	0.99
2	6	12	2.00	100.00	100.00	100.00	1.02
3	8	12	2.00	97.22	94.44	100.00	1.08
4	8	12	2.00	98.61	97.22	100.00	1.07
5	10	12	2.00	97.92	98.61	97.22	1.03
6	10	12	2.00	100.00	100.00	100.00	0.96
7	10	18	2.00	99.07	98.15	100.00	0.98
8	10	18	2.00	99.54	100.00	99.07	0.83
9	12	18	2.00	97.22	98.15	96.30	0.89
10	12	18	2.00	98.15	98.15	98.15	0.83

Session NR:	Non-criticals	Sounds/ Trial	ISI (sec)	% total correct	% critical correct	% non-criticals correct	Average RT
11	12	18	1.75	99.07	100.00	98.15	0.76
12	12	18	1.75	97.69	100.00	95.37	0.71
13	12	24	1.75	95.83	100.00	91.67	0.74
14	12	24	1.75	96.88	97.22	96.53	0.79
15	12	24	1.75	91.67	85.42	97.92	1.00
16	12	24	1.75	89.93	81.94	97.92	0.99
17	12	24	1.75	96.53	93.06	100.00	0.94
18	12	24	1.75	96.18	93.06	99.31	0.94
19	14	24	1.75	98.61	97.90	99.31	0.96
20	14	24	1.75	98.61	97.92	99.31	0.82
21	16	24	1.75	97.57	96.53	98.61	0.83
22	16	24	1.75	98.96	99.31	98.61	0.76
23	16	24	1.50	98.96	97.92	100.00	0.73
24	16	24	1.50	99.30	98.61	100.00	0.69
25	16	30	1.50	98.89	97.77	100.00	0.72
26	16	30	1.50	99.17	100.00	98.33	0.72
27	18	30	1.50	98.61	97.78	99.44	0.85
28	18	30	1.50	99.17	98.33	100.00	0.81
29	18	36	1.50	98.61	98.14	99.08	0.83
30	18	36	1.50	97.22	94.44	100.00	1.19
31	20	36	1.50	98.61	97.69	99.54	0.81
32	20	36	1.50	98.15	96.76	99.54	0.76
33	20	36	1.25	98.15	96.76	99.54	0.77
34	20	36	1.25	98.15	97.22	99.07	0.80
35	22	36	1.25	98.15	96.76	99.54	0.72
36	22	36	1.25	98.15	97.22	99.07	0.68
37	22	42	1.25	96.03	94.44	97.62	0.72
38	22	42	1.25	98.21	98.41	98.02	0.71
39	24	42	1.25	97.02	96.83	97.22	0.67
40	24	42	1.25	97.22	96.83	97.62	0.68
41	24	42	1	97.42	99.21	95.63	0.68
42	24	42	1	87.57	78.31	96.83	0.81
43	24	42	1.25	92.46	90.44	94.47	0.82
44	24	42	1.25	90.10	90.87	89.33	0.82
45	24	42	1.25	94.64	90.08	99.21	0.82
46	24	42	1.25	92.29	84.89	99.56	0.79
47	24	42	1.25	96.63	94.05	99.21	0.75
48	24	42	1.25	97.42	95.62	99.21	0.81
49	24	42	1.25	96.23	92.46	100.00	0.79
50	24	42	1.25	98.02	96.03	100.00	0.73
51	24	48	1.25	97.22	94.44	100.00	0.80
52	24	48	1.25	96.18	92.71	99.65	0.79
53	26	48	1.25	98.26	97.57	98.96	0.79
54	26	48	1.25	98.61	98.26	98.96	0.72

Session NR:	Non-criticals	Sounds/ Trial	ISI (sec)	% total correct	% critical correct	% non-criticals correct	Average RT
55	28	48	1.25	98.26	96.53	100.00	0.80
56	28	48	1.25	98.61	97.22	100.00	0.82
57	28	54	1.25	95.68	91.67	99.69	0.82
58	28	54	1.25	96.14	93.19	99.08	0.81
59	30	54	1.25	93.89	87.78	100.00	0.79
60	30	54	1.25	96.64	94.03	99.25	0.78
61	30	60	1.25	97.66	95.32	100.00	0.77
62	30	60	1.25	97.50	95.67	99.33	0.77

4.5.2. Results and Discussion

Figure 24 and Figure 25 show Hiapo's reaction times, his performance accuracy and the changes in the ISI over the course of the 62 sessions tested. Several interesting results can be observed: First, Hiapo's average reaction times decreased from an average of 0.97 sec for an ISI of 2.0 sec, to an average of 0.85 sec for an ISI of 1.75 sec, to an average of 0.81 sec at 1.50 sec and an average of 0.72 sec at 1.25 sec ISI. In session 41 and 42 the ISI was set to 1.0 sec and here Hiapo's performance accuracy dropped to 78.3% on the critical stimulus. A detailed analysis of his responses shows that most of his misses occurred when a second critical followed right after a critical. A possible explanation for these results is that he did not have enough time to return to the "start position" after he just pressed the paddle and therefore was not able to respond fast enough to the second stimulus. Because his performance accuracy had dropped below 85% the ISI was raised back to 1.25 sec for the rest of the experiment. These results are similar to those obtained in the visual vigilance experiment in which the dolphin Elele showed a similar pattern of performance and appearance of errors (see results and discussion visual experiment 1). In both cases the performance accuracy dropped when the presentation frequency was too high for the dolphins to respond to every occurrence of a critical stimulus if several critical stimuli were presented in sequence. These error patterns did not occur when critical stimuli were interspersed between several non-critical stimuli. A Comparison with human vigilance tasks is difficult if not impossible in this case as the conditions under which the experiment is conducted are very different.

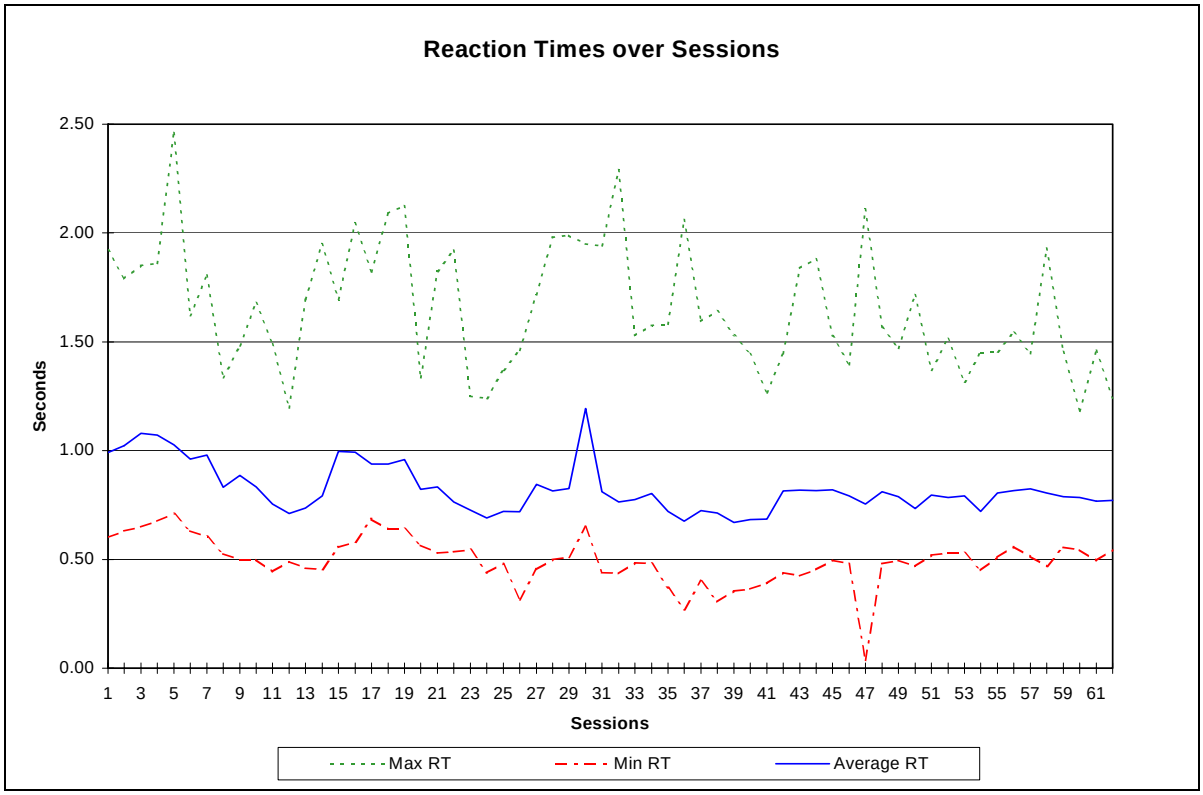


Figure 24: Hiapo's reaction times over session 1-62.

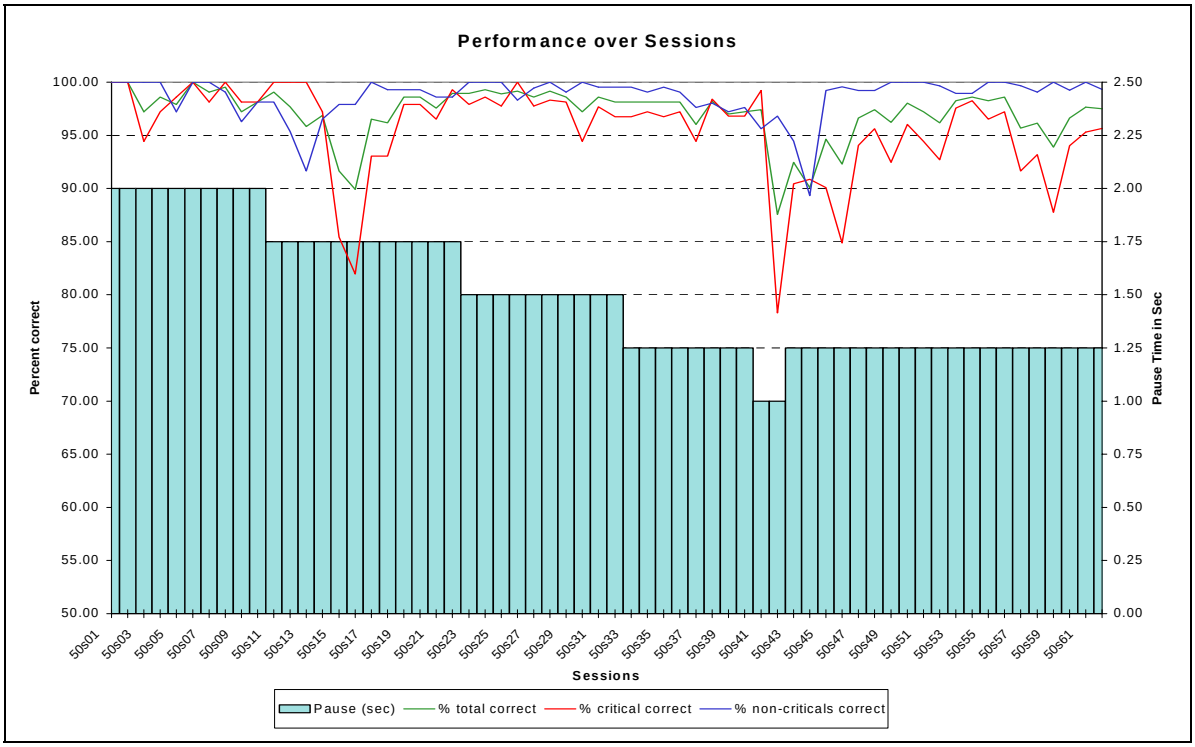


Figure 25: Hiapo's performance accuracy and the varied ISI over sessions 1-62.

In human tasks the time the subject needs to indicate a detection is much shorter, as covered distances (pressing of a button) are a fraction of the distances the dolphin has to cover under water. Furthermore, movement under water is much slower due to higher density – together these factors make it impossible to compare these particular results to those obtained with humans.

Secondly, Hiapo appeared to change his response criterion in Session 15: In the previous three sessions, his errors had been only false alarms (i.e., striking the paddle on a non-critical). However, in Session 15, he started to miss presentations of critical stimuli and make less false alarms, thus reversing the previous performance ratios of critical and non-critical stimuli (previously performance on critical was 100% correct and on non-criticals was 98.15, 95.37 and 91.67% correct. In sessions 15 and 16 performance on critical was 85.42 and 81.94% correct, whereas performance on non-criticals increased to 97.92% correct in both sessions. Signal Detection Theory (SDT, see Figure 3) as described by Green and Sweets (1974) predicts that if the response criterion (k) is shifted to increase the performance in one stimulus class (in this case correct rejections) the performance in the other stimulus class will decrease (here: less correct detections). To avoid a further deterioration of his performance on critical sounds a new feature was implemented in the software that controlled the presentation of stimuli: A new sound ("NO-Sound") was automatically played immediately after a miss and Hiapo was called back to station by his tankside trainer. After a short period of waiting Hiapo was sent back to continue the trial. Hiapo very quickly changed his strategy to make fewer misses but now more false alarms (see Figure 28). His overall performance slowly recovered to his previous level over the next two sessions and the "No-Response" feature was switched of to avoid any further bias in the opposite direction towards more misses. An unbiased response criterion provides the opportunity to analyze both misses and false alarms, whereas a biased criterion might only provide one type of results: either *only* false alarms or *only* misses. Therefore it was important to try to adjust his performance to and unbiased response.

The minimum reaction time of 0.05 sec in session 47 (see Figure 24) was caused by a late reaction to a critical stimulus (a miss), but because a second critical followed right after the first, the computer counted the paddle press for the second stimulus and

measured therefore a reaction time of 0.05 sec. This data point was therefore excluded from the analysis.

Reaction time:

Of the 62 sessions the dolphin was tested, only 23 showed a significant change in average reaction time across positions, 19 of which had a decrease in reaction time and 4 had an increase in reaction time. Over trials, 20 of 62 sessions had a significant change in reaction time (17 had an increase and 3 had a decrease).

Proportions of misses and false alarms were calculated as number of misses or false alarms divided by the total number of possible misses or false alarm: here Hiapo showed a significant *increase* in misses over trials ($F=4.168$ at $p=0.05$) but no significant change in the proportions of false alarms ($F=3.463$ at $p=0.05$, see Figure 26.). Over positions Hiapo showed no significant change in misses but a significant *decrease* in false alarms ($F=56.349$ at $p=0.01$, see Figure 27).

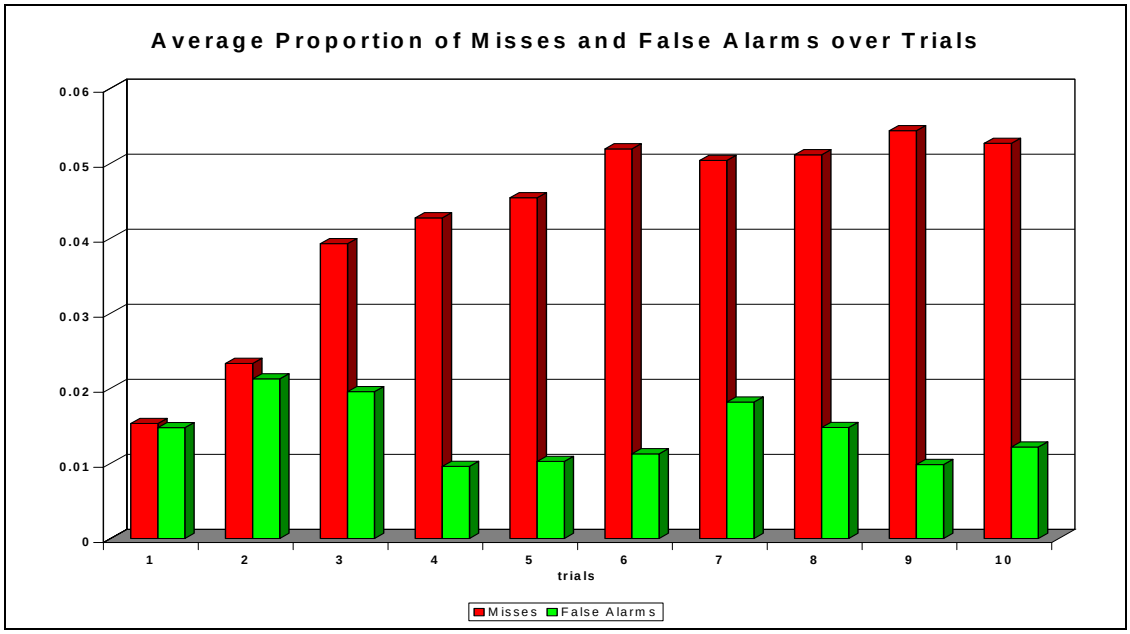


Figure 26: Average Proportion of misses and false alarms over trials.

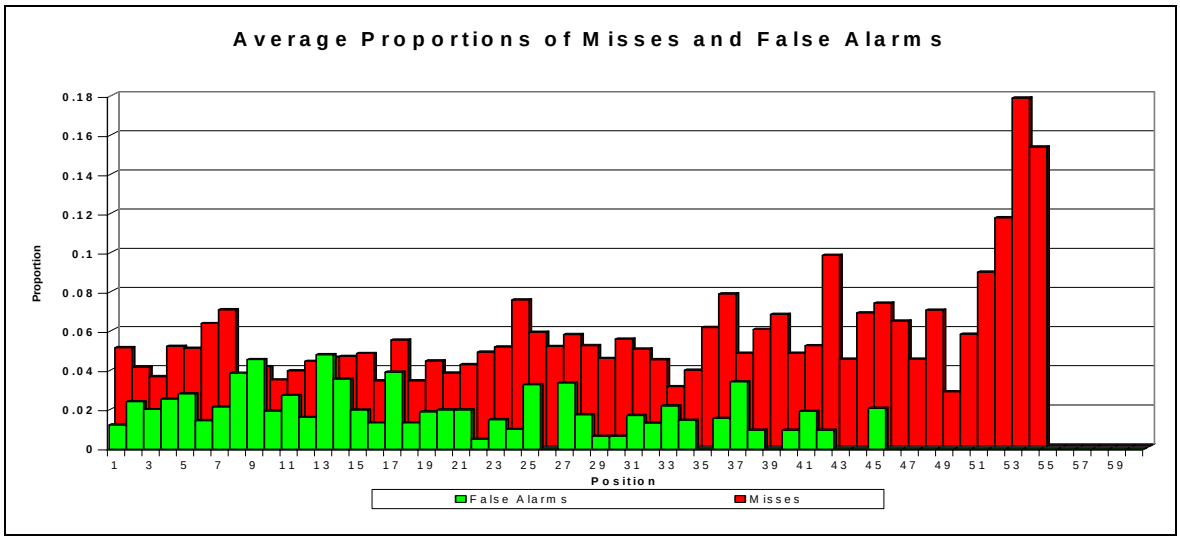


Figure 27: Average proportion of misses and false alarms over positions for all 62 test sessions.

Overall, Hiapo showed that he was able to adjust his performance to both the increased number of stimuli per trial as well as to the decreased pause time between stimuli. Average performance remained above 85 % throughout the experiment. No apparent correlation of vigilance decrement and the parameters varied throughout the experiment was detected. In comparison to the visual experiment, the decline in reaction time that was observed with the decreasing inter stimulus interval was not as distinct. This effect might have been caused by the fact that the visual stimuli appeared immediately and did not change over the time of the exposure, thus allowing for immediate recognition by the dolphin. Auditory stimuli, on the other hand, *did* change over time and Hiapo might have needed a larger section of the stimulus exposure time to recognize it. Thus, the time available to Hiapo to make his decision would have been actually less than for Elele within the same ISI settings. The question whether Hiapo needed more time to recognize the sounds or whether he simply used a later part of a stimulus for recognition remains unclear. In the setup used in this experiment he had to respond only to *one* stimulus – and omit response to all other stimuli, thus any recognition of other stimuli was not revealed. A different setup – e.g. where he would have to press *one* response paddle to indicate detection of a critical stimulus and *another* paddle for detection of a non-critical stimulus might have shown different reaction times for all the different non-critical stimuli. This way, an analysis of the features used to judge any auditory stimulus might have been possible.

4.6. Experiment 2: Probability Variation

This experiment investigated the effects of changes in the probability of occurrence of a critical *auditory* stimulus in any given position of a trial on performance accuracy and reaction time. It was designed to mirror the visual vigilance experiment as described in Experiment 2: Probability Variation as well as to test for differences in performance between the visual and the auditory sense. In comparison, humans auditory vigilance studies are normally linked to increased accuracy and speed and seem to show a less vigilance decrement (Warm & Jerison 1984, Davis & Parasuraman,1982).

4.6.1. Methods

The same procedures as described in Visual Vigilance Experiment 2 were applied here using auditory stimuli. A total of 20 test sessions were conducted. Table 9 shows the order in which the test sessions were run.

Table 9: Order of sessions in the auditory probability variation experiment.

Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Probability	30	30	30	30	10	10	30	30	50	50	30	30	20	20	30	30	40	40	30	30

Sessions consisted of 10 trials with 60 stimuli each. The inter-stimulus-interval was set at 1.25 seconds. Five different probability values, 50%, 40%, 30%, 20% and 10% were tested. Each probability was tested for two consecutive sessions. The trial-by-trial procedure used in this experiment was identical to that described in the previous auditory vigilance study.

4.6.2. Results and Discussion

Hiapo's performance remained at or near ceiling levels across the 20 test sessions. Figure 28 shows his performance in percent correct detection of critical and correct rejection of non-critical stimuli and his average reaction times combined over the tested probabilities decreasing from 50% to 10%. His performance accuracy was 96.3, 95.6, 96.8, 97.0 and 100% for 50, 40, 30, 20, and 10 % probability respectively. No significant

difference was detected between these performances. His accuracy on correct rejections never dropped below 99.3%.

Hiapo's average reaction times for the five different probabilities tested were 0.715s, 0.850s, 0.764s, 0.770s and 0.832s for 50, 40, 30, 20 and 10% probability respectively.

An analysis of variance showed that there was a significant difference in Hiapo's reaction times between different probabilities ($F=17.0689$ at $p=0.05$). A subsequent Scheffé test on all 2-way comparisons to determine where the exact differences occurred showed that there was no difference between 40% and 10% (group 1), and 30% and 20% (group 2). In comparison, with data obtained from human subjects one would expect higher reaction times with lower probabilities showing a *linear* increase of reaction time with decreasing probability of appearance of a critical stimulus. This could not be shown for the auditory experiment with Hiapo within the limits tested. The high reaction times for the 40% sessions do not fit a linear model although overall higher reaction times were observed with lower probability settings. These results are similar to the data obtained in the visual vigilance experiment with Elele (see Visual Vigilance, Experiment 2) where average reaction time also increased with lower probability.

Three different trend analyses (linear regression) were applied to the complete set of data. In the first analysis the change of reaction time from position 1 to position 60 in a trial was examined. For that purpose the average values for all reaction times in a given position in all trials of sessions of the same probability were calculated. Subsequently, a linear regression for these values was tested for significance. Of the 5 groups tested, three (50%, 40% and 30%,), showed a significant trend towards faster reaction time at the end of a trial ($F = 17.1$, $F =20.1$ and $F= 17.1$ at $p = 0.01$, respectively, see Figure 30). No significant trend was observed for the 20% and the 10% group ($F= 3.2$ at $p=0.01$ and $F=1.1$ at $p=0.01$).

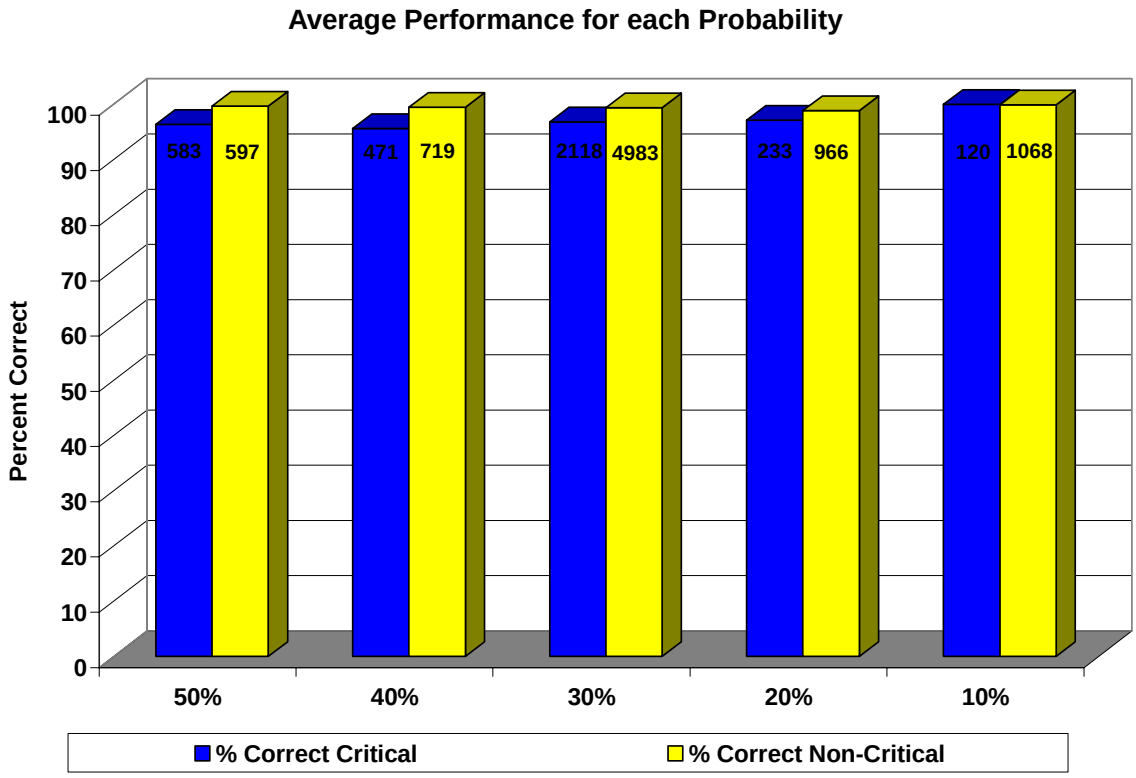


Figure 28: Hiapo's performance for critical and non-critical stimuli in the five different probabilities used. The numbers on each bar represent the samples collected.

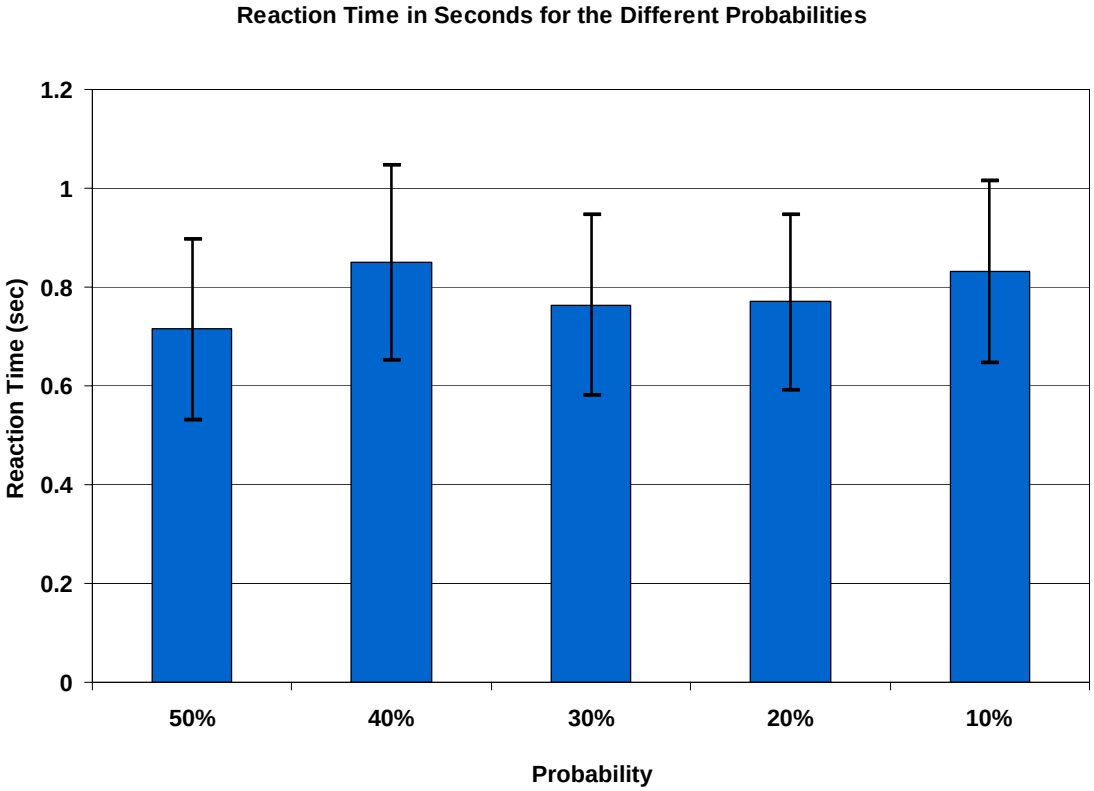


Figure 29: Hiapo's reaction times for the different probabilities and the standard deviation

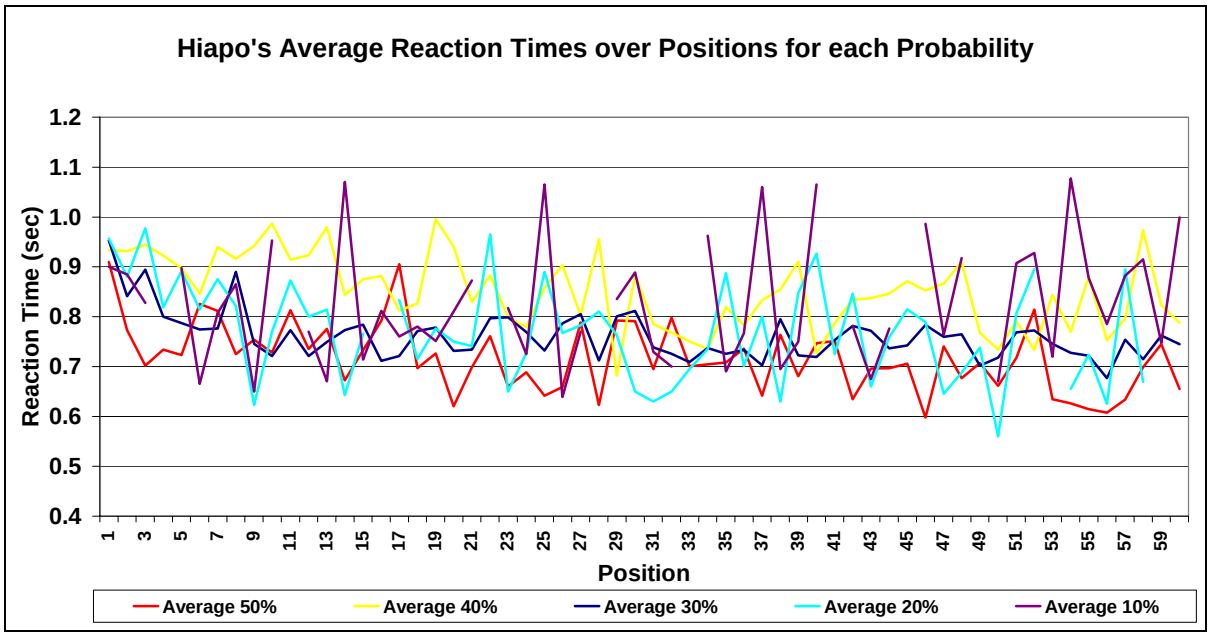


Figure 30: Average reaction times for the five different probabilities used over positions in a trial. Interrupted lines represent positions that did not have any data points due to the low probability of the critical stimulus.

Similar to the visual experiment, these data are not consistent with human data where reaction time increases with the time spent on the task. But the major difference between reaction times in human data and this experiment is the duration of a trial. In human experiments trial durations are normally in the range of more than 30 minutes whereas in this experiment duration of trials never exceeded two minutes. Thus, the effect shown here (*decrease* of reaction time) might just be an initial adjustment appearing in the first couple of minutes. As longer trials were not feasible with the dolphin an increase in reaction time as seen in human experiments could not be shown.

Errors were again pooled over all sessions and average proportions were calculated for each position. Errors declined over positions on average from the beginning to the end of a trial ($F=28.1$ $p=0.01$ for false alarms, $F=15.9$ $p=0.01$ for misses, see Figure 31).

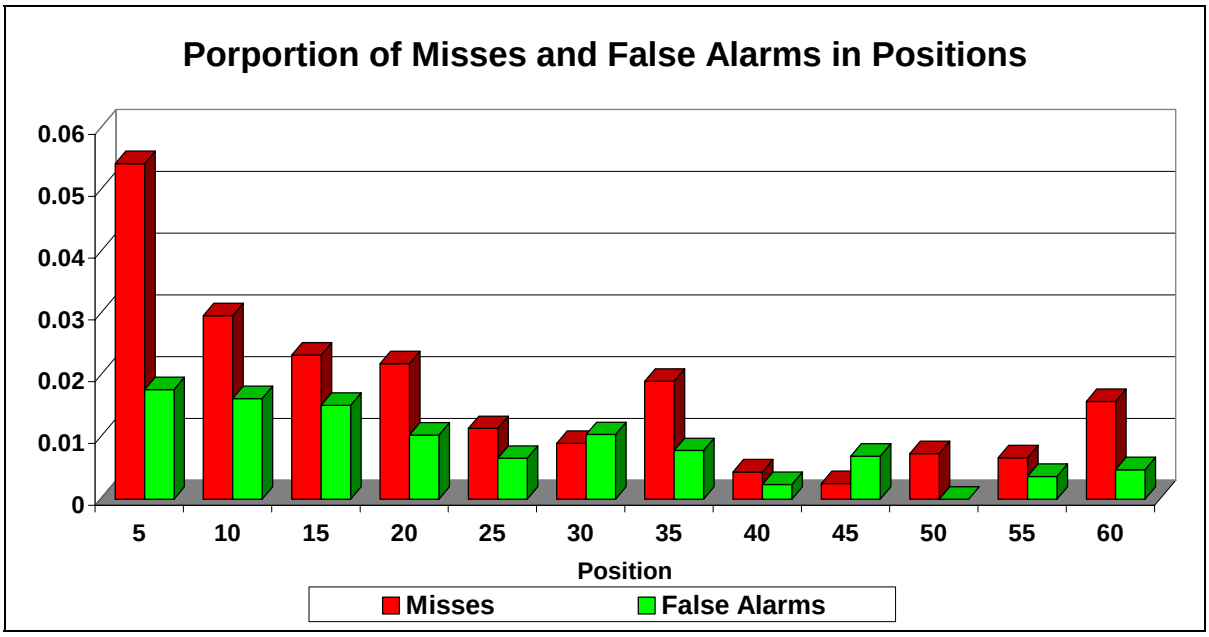


Figure 31: Hiapo's proportion of errors over positions. The values of 5 positions are grouped together to avoid local fluctuations

The second analysis investigated the change of reaction times over consecutive trials regardless of the position. For that purpose the average of all reaction times in a given trial was calculated. Reaction time values from sessions with the same probability were again pooled together. Of all linear regressions only one (30%) showed a negative slope (decrease in reaction times over trials), but this was not significant. The remaining four groups showed an increase in reaction times over trials but only the 50 and 20 % groups had a significant increase ($F=10.44$ and $F=14.4$, respectively).

Misses and false alarms were again pooled over all sessions. To adjust for the difference in probabilities proportions of misses and false alarms (number of misses or false alarms divided by the number of presentations of critical or non-critical stimuli per trial respectively) were calculated. Figure 32 shows the average proportion of errors over trials. No significant difference was detected ($F=0.8044$ for misses and $F=0.00436$ for false alarms).

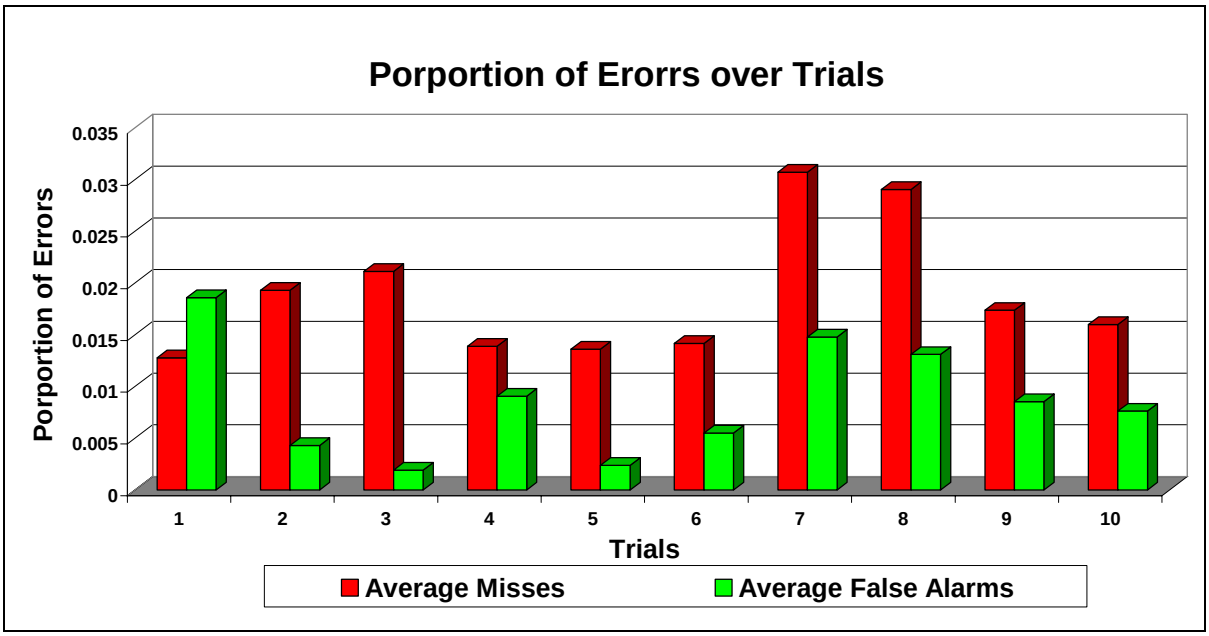


Figure 32: Average proportion of errors of Hiapo's performance over trials.

A third regression analysis was performed on all presentations as they occurred in a session. In this case consecutive trials were linked together. Data from sessions with the same probability were pooled. Two groups (40 and 30%) showed a decrease in reaction times over all 600 positions ($F=0.04$ and $F=5.53$ $p=0.05$, respectively). The three other groups (50,20 and 10%) showed a significant increase in reaction times over all presentations ($F=12.35$, $F=6.89$ and $F=5.73$, respectively).

Figure 33 shows the distribution of reaction times for all probabilities combined. In contrast to the visual experiment it does not represent a normal distribution rather than a two tailed distribution with a second peak a 1.1 seconds. This seems to indicate that Hiapo had two different decision criteria that he applied throughout the experiment. As auditory stimuli change over the time of their exposure he might have used two different features of the critical stimulus for recognition. If those features appeared at different times in the presentation of the stimulus it could result in two distinctly different peaks in reaction times.

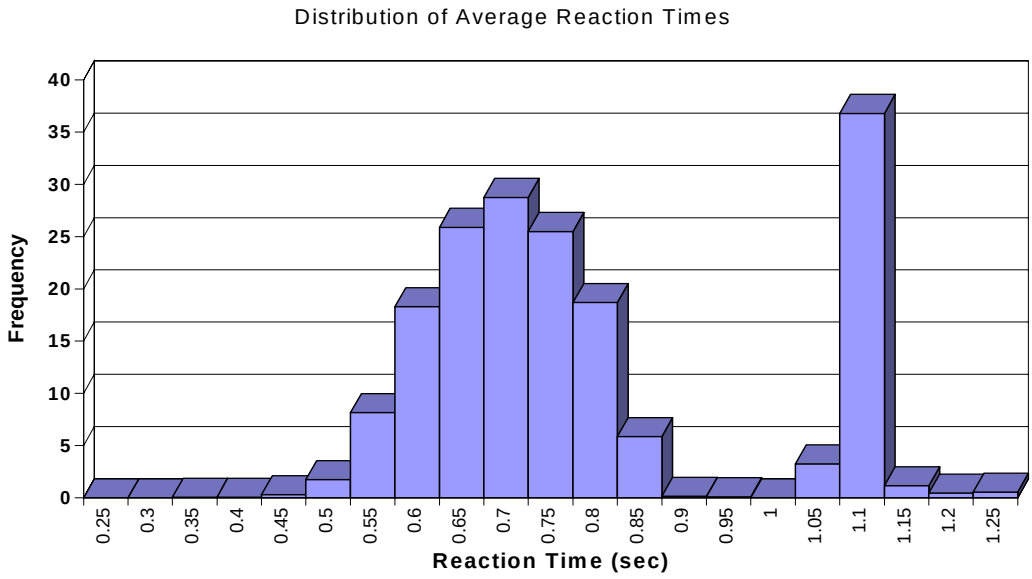


Figure 33: Distribution o Hiapo's reaction times averaged over all sessions.

4.7. Experiment 3: Multiple Criticals

4.7.1. Methods

In this experiment Hiapo's ability to detect several different target stimuli simultaneously in a session was examined. The procedure used to train four new critical sounds was the same as in the visual experiment. During the training phase responses to single sounds were reinforced. The new critical sounds were played through the transducer in front of the underwater window while Hiapo was simultaneously instructed by the "video trainer" in the remote room to press the response paddle. Over the course of four sessions the number of stimuli presented to the dolphin was increased. Once Hiapo's performance was better than 85% correct on the new stimuli over the course of two consecutive sessions, a new critical stimulus was introduced until all four new stimuli were trained. Finally the number of sounds played in a trial was increased until a trial consisted of 60 sounds. Each of the new critical sounds was never paired with any of the other critical stimuli during training sessions. The probability of the occurrence of a critical stimulus was set to 50 % for all sessions. The same five steps of increasing difficulty was in the visual experiment were used here. In Step 1, each of the five different criticals was used exclusively in one session and appeared 300 times over the course of the 10 trials. In Step 2 each possible combination of two critical stimuli was used (e.g. critical 5 and 2 or 1 and 3). As in the visual experiment, combinations were increased to three, four and all five critical stimuli with each new step.

In the 3rd and 4th session of Step 3 Hiapo no longer approached the window when signaled by the tankside trainer. Instead he remained at tankside at the surface. To remedy this, the trial length was reduced by half (30 stimuli per trial). The second half was tested in a separate session. Thus, overall the same number of stimuli was presented over all test sessions.

4.7.2. Results and Discussion

4.7.2.1. Step 1

In Step I Hiapo performed correctly at 99.0 % for Critical 1, 89.67 % for Critical 2, 93.0 % for Critical 3, 96.33 % for Critical 4 and 95.0 % on Critical 5 (see Figure 34). Performance on non-critical stimuli (correct rejections) was at 99.7%, 97.3 %, 98 %, 96.7 % and 95.3 %, respectively (see Figure 36).

The average reaction times for each critical were 0.612s, 1.138s, 1.126s, 1.365s and 1.163s respectively (see Figure 35). Thus Hiapo was responding fastest on critical 1 followed by critical 5, 3, 2 and 4. Reaction times did not decrease significantly on average from position 1 to position 60 for any of the criticals. Furthermore, average reaction times did not change significantly form trial 1 to trial 10 of each session.

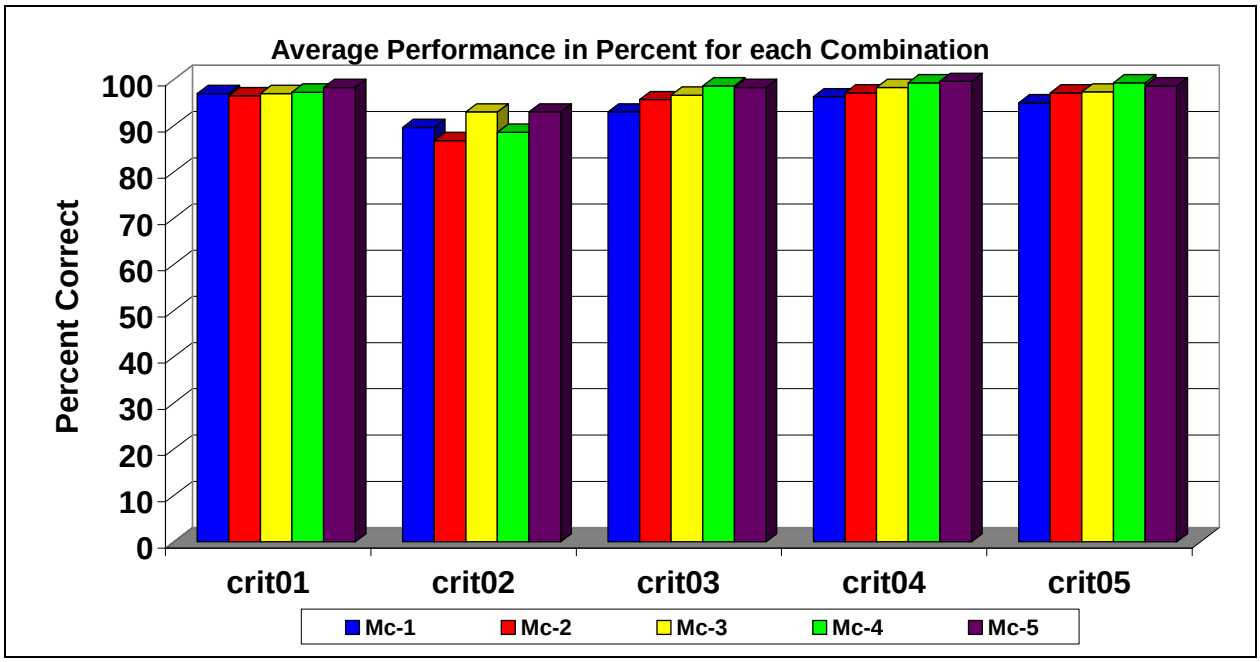


Figure 34: Hiapo's average performance for each critical stimulus during the five steps. Each of the bars for each critical represents performance for that particular stimulus alone (first bar) or in combination with 1, 2, 3 or 4 other criticals (2^{nd} to 5^{th} bar).

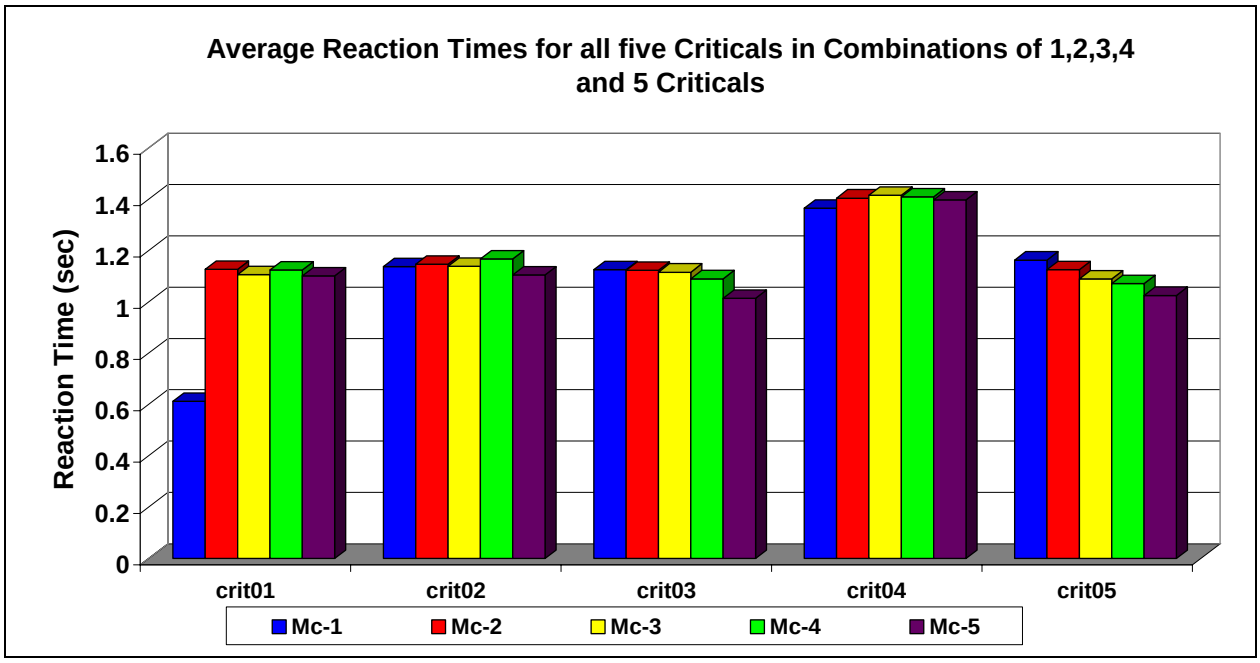


Figure 35: Hiapo's average reaction times for each critical during each step. Each of the bars for each critical represents reaction times for that particular stimulus alone (first bar) or in combination with 1, 2, 3 or 4 other criticals (2^{nd} to 5^{th} bar).

4.7.2.2. Step 2

In step 2 combinations of two criticals were used. Performance on criticals was combined across the sessions each critical was used (4 possible combinations with any of the other criticals). Hiapo performed again near or at ceiling levels for all criticals with average detection rates of 96.5 %, 86.83 %, 95.67 %, 97.17 % and 97.17 % respectively. The average reaction time for each critical was 1.12s, 1.15s, 1.12s, 1.40s and 1.13s respectively. Thus, only critical 1 showed a significant increase in reaction times (from 0.61 to 1.12 seconds) while reaction times for the other criticals did not change significantly from step one to step two.

Performance on non-criticals (correct rejections) was in all sessions above 96.2%.

4.7.2.3. Step 3

In Step 3 performance on each critical was averaged over the six sessions that used this stimulus. Hiapo was again performing near ceiling levels for all criticals with 97.0%, 93.0%, 96.67%, 98.33% and 97.33%, respectively.

Due to the change in presented number o stimuli per trial from 60 to 30 no trend analysis for changes of average reaction times over positions was calculated. Average reaction times over trials did not change significantly for any of the sessions except one where Hiapo's reaction times decreased significantly for critical 1. Performance on non-critical stimuli (correct rejections) was an average of 88.2% over all sessions of this step.

4.7.2.4. Step 4

Here combinations of four critical stimuli were tested. Hiapo's performance accuracy was at 97.32%, 88.65%, 98.68%, 98.33% and 99.31% for critical 1 – 5. Reaction times for these criticals were at 1.12s, 1.14s, 1.09s, 1.41s and 1.07s respectively. Performance on correct rejections was at an average of 92.4% over all sessions.

4.7.2.5. Step 5

Finally all five criticals were tested together over the course of five sessions. Performance accuracy was 98.3%, 93.0%, 98.33%, 99.67 and 98.67 % correct detection of critical 1 to 5. Reaction times for these hits were at 1.10s, 1.10s, 1.01s, 1.40s and 1.02s respectively. His performance on correct rejections was on average 93.9% over all sessions (see Figure 36).

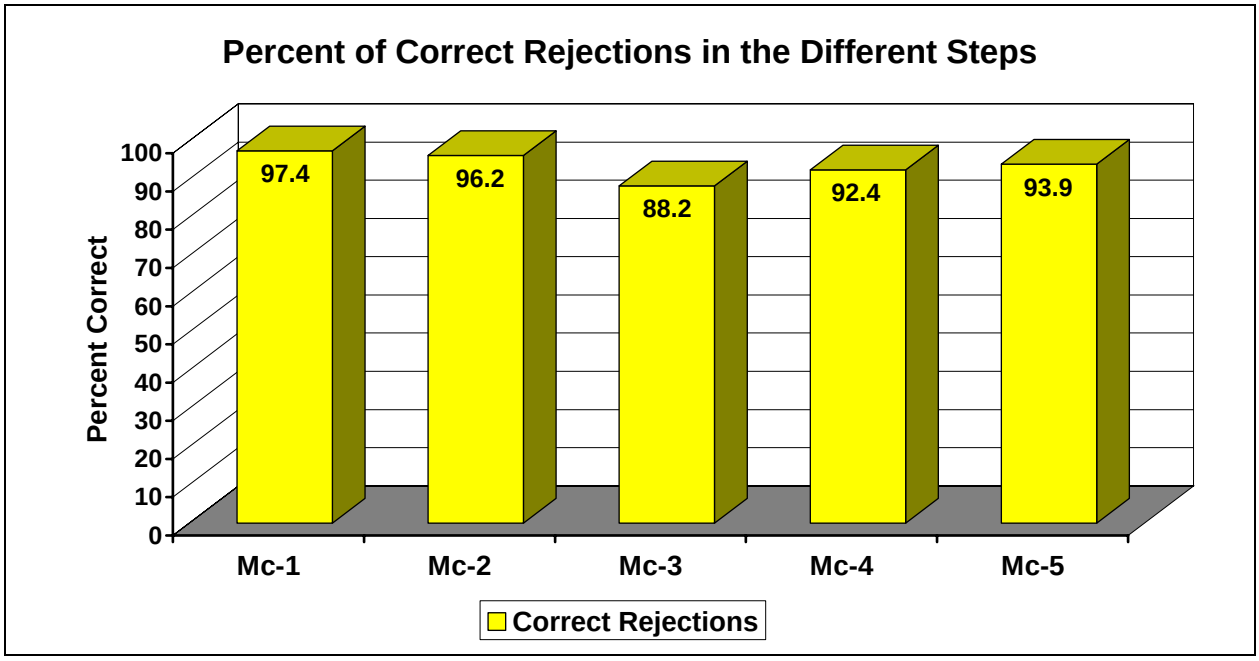


Figure 36: Hiapo's average performance on non-criticals for the five different steps.

4.7.3. Discussion

Over all five steps Hiapo's performance did not change with the increasing difficulty of the task. Critical 2 had the lowest performance of all five (90.23% correct detection average over all sessions) followed by Critical 3 (96.47% average), Critical 1 (97.23% average), Critical 5 (97.4% average) and Critical 4 (98.17% average). Interestingly, longest average reaction time was calculated for Critical 4, which had the best overall performance. To determine differences in reaction times for each critical cross the five steps an analysis of variance was calculated. The results show no differences between the steps for Critical 2 . Critical 1, when used separately, had the fastest reaction time (average 0.611s) but increased up to 1.13 seconds after that and stayed at this level in all following combinations. The significantly longer reaction time of Critical 4 can be explained by the fact that all the stimuli changed over the time of the presentation (1 sec). If Hiapo used a later portion of the sound to recognize it as a critical stimulus, then the reaction time for that stimulus would be higher than for a stimulus where recognition was based on a early feature of the sound. Unlike the reaction time

results in the visual multiple critical experiment, no significant increase in reaction time was detected with an increased number of critical stimuli present. Hiapo therefore might have been representing the learned critical stimuli differently than Elele, due to the fact that different in the sensory channel were used (auditory versus visual). If he was retaining the critical stimuli in a list and would sequentially compare each presented stimulus with that list then one would have expected longer reaction times as the number of critical stimuli presented simultaneously with a trial increased. This was not the case and a second hypothesis seems more plausible to explain the results: if Hiapo was comparing any presented stimulus parallel to the set of five critical stimuli then there should be no increase in reaction time with an increased number of criticals. A further increase in the number of critical stimuli used should reveal the limitations of a set of stimuli that could be retained parallel and would provide evidence of the correctness of this hypothesis.

4.7.4. Summary

In this part of the set of experiments a second dolphin was tested on its ability to perform an auditory vigilance task and sustain its attention over a prolonged period of time. As in the visual vigilance experiment the animal demonstrated that he was capable of monitoring and reporting a critical signal over 10 trials with up to 60 stimuli per trial without decrement in performance accuracy or an increase in reaction time.

Experiment 1: This experiments was designed to mirror the visual experiment 1 with the difference that the sample exposure time did not change in the auditory experiment. Hiapo showed no decrement in performance accuracy or reaction times that could have been linked to the changing parameters (inter-stimulus interval and number of stimuli per trial).

Experiment 2: In the probability experiment Hiapo did not show any decrement in performance accuracy. Comparable to the results in the visual experiment higher average reaction times for lower probabilities were measured, although no clear trend could be shown within the limitations of the settings. Within trials only higher probabilities showed a significant decrease in reaction times. Within a session and across trials no significant change in average reaction times was detected for the probabilities tested.

Experiment 3: This experiment examined the effect of the simultaneous display of up to five critical stimuli on the dolphin's performance accuracy and reaction time. Here, in contrast to the results obtained in the visual experiment, no significant increase in reaction time with the increasing number of critical stimuli was observed. His performance accuracy remained near ceiling levels throughout the whole experiment regardless of the varied parameter.