5. General Discussion

The suite of studies described in this dissertation was specifically designed to explore the parameters involved in vigilance decrement in the dolphin through the visual and auditory domain. Both dolphins readily learned their respective visual and auditory vigilance tasks. Monitoring as many as five critical stimuli simultaneously in up to 60 stimuli per trial, Elele and Hiapo demonstrated near ceiling levels of performance throughout the experiments.

However, unlike human subjects, who demonstrate vigilance decrement under prolonged periods of testing (Parasuraman, 1998), the dolphins showed no comparable decrements in performance within the limits explored. Overall, there was no decrement in performance accuracy either within trials or within sessions. Although some changes in reaction time were detected, none were comparable to the results found in experiment with humans. Indeed both dolphins continued to perform their vigilance task at or near ceiling levels despite changes in signal exposure time, inter stimulus interval, number of stimuli presented, probability or number of critical stimuli tested parallel.

Several factor were most likely responsible for the absence of vigilance decrement in the present studies. In human studies, vigilance decrement normally occurs at about 15-25 minutes into the task. A key element is that the subject keeps its attention focused on the task. Because the dolphins typically surfaced for a breath after about 2 minutes, the length of time where attention could be tested was limited to this time period. Furthermore, trials had to be kept short in order to the keep the dolphins interested in the task: it was found that with longer trials (more than 60 stimuli per trial) the reward given after the completion of a trial was not enough to keep the animals motivated to participate.

Experiment 1

In the visual experiment Elele showed no correlation of the change in parameters (SET, ISI) and her performance accuracy or reaction time in the task. In the auditory experiment however, Hiapo showed a significant increase in misses over trials, which is similar to the results obtained with humans. Overall sessions there was no significant change in reaction time; so the only indication of vigilance decrement was the increase in misses.

Experiment 2

In the second experiment both dolphins showed near or ceiling levels of performance regardless of the change in signal probability. Average reaction times though, were lower with higher probabilities and these findings are in line with those of human subjects where reaction time is found to be lower with higher probabilities. Nevertheless, no decrement in vigilance (higher reaction times within a trial or a session) could be shown for either of the dolphins.

Experiment 3

Here, no vigilance decrement (through performance accuracy or reaction time) within sessions or within trials by either of the subjects was observed. Average reaction time increased in the visual experiment with more than two criticals present but did not change significantly in the auditory experiment. If a vigilance decrement effect would have been observed average reaction time would have increased *over time* but this could not be shown even with the increased difficulty of monitoring several critical stimuli simultaneously. Rather, the observed effect (higher reaction times) was caused by the increased processing demand when the dolphin had to compare presented stimuli to more than two critical stimuli in memory. This increase was not linear and no further change in reaction time was observed with more critical stimuli being tested (e.g. with five criticals). With more criticals, possibly a further increase in reaction time might be detectable. Hiapo, on the other hand, did not show a significant increase in reaction time with more critical stimuli presented and his average reaction times were higher than Elele’s. This was caused by the fact that the auditory stimuli changed over time and were not necessarily recognizable with the onset of the sound as the pictures were in the visual experiment. Hiapo probably used different features in the sounds to recognize criticals. Furthermore, the underlying process that filters incoming stimuli might be different for the visual and the auditory sense. If the procedure was sequential then an increased number of test items should cause longer reaction times for items that are stored towards the end of the list. This might have been the case in visual experiment where an increase in reaction time between combinations of two and combinations of three critical stimuli was observed. The results of the auditory experiment though, suggest that here presented stimuli were processed parallel.

The drop in performance accuracy in the visual experiment was clearly linked to one particular critical stimulus (dragon fly) and might have been caused by a less salient representation of that item in memory, and once Elele was experienced in seeing this stimulus within combinations of two or three criticals her performance accuracy recovered.

In summary, despite the changes in parameters and settings neither of the dolphins displayed a vigilance decrement within the limitations of these studies as shown in human experiments. Nevertheless, the experiments clearly demonstrated that dolphins are capable of attending to particular events and monitoring these visual and auditory events over long periods of time. The dolphins' performance in the visual and the auditory vigilance task adds to the growing body of knowledge of dolphins' sensory perception and cognition. Performance levels across the auditory and visual vigilance task were remarkably equivalent, a finding consistent with other studies showing equivalent performance in cognitive tasks through visual and the auditory modalities (e.g. memory for visual and auditory stimuli, (Herman and Gordon 1974); visual and auditory matching to sample, (Herman, Hovancik et al. 1989); language comprehension, (Herman, Richards et al. 1984); and imitation, (Xitco 1988), (Herman 2002)).

Through the vigilance task it was also shown that dolphins are readily able to process 2-dimensional images displayed on a monitor. Previous research (Herman, Morrel-Samuels et al. 1990; Herman, Pack et al. 1998) had only used a "video trainer" or 3-dimensional objects raised by a person into the viewing area of a camera, but not static images that immediately appeared on the screen. In this experiment the dolphin was quickly able to adapt to the new method of presentation, despite previous difficulties in distinguishing an image from a standard background (see Experiment 1, training) and showed no problems in performing this task.

This vigilance task involves memory decision making for stimuli in particular modalities and could also be used to gain further insight in the cognitive abilities of dolphins as a distraction task within a cross-modal matching experiment. In this setup

(Herman, Pack et al. 1998; Pack, Herman et al. 2002) three-dimensional sample objects are presented to either the echoic sense or the visual sense. The animal then has to find the matching alternative in the other sense. Bottlenose dolphins have shown immediate recognition across the senses and no prior exposure to the test objects is necessary. This indicates that dolphins are able to form a mental representation of the sample that is accessible through both senses. The underlying mental process is not yet understood and here a vigilance task would shed light on how the animal stores information of a sample object. Human research (Wickens 1984, Pashler 1993) has shown that stimuli presented to the same modality interfere more than stimuli presented to different modalities. The explanation offered by researchers for this phenomenon defines limited "processing resources" necessary to perform the task and tasks that utilize the same resources yield lower performance than if they use independent resources (Norman and Bobrow 1975). In case of the dolphin, one could indirectly determine how the received information is coded: If the sample is presented to the echoic sense and the received information is stored in an auditory representation, then an auditory vigilance trial run between the presentation of a sample and the presentation of the alternatives should interfere with the ability to retain the sample in memory. On the other hand, if the representation is coded in visual memory, then an auditory vigilance trial should not cause a deterioration of the encoded sample. In this case a visual vigilance task should interfere. It is of course possible that the construct in memory is based on a more amodal representation that might contain information form both senses and is accessible to both senses. Here, either vigilance task should cause some decrement in performance but not a complete loss of the representation.

As no vigilance decrement could be observed in the present studies, future changes might reveal possible effects: the length of trials could be increased by training the dolphins to hold their breath for an extended period of time. The question remains whether it would be possible to keep the dolphin interested in a longer trial. Already, one of the subjects had lost interest in the multiple-critical experiment and the length of trials had to be reduced. The length of trials was approximately 2 min. In human experiments the onset of a decrement was at approximately 15-20 minutes into the task and it is unlikely that the dolphins would participate in trials of that length without receiving reinforcement during the trial. One possible solution would be to perform the experiment near the surface where the dolphin could breathe and reinforce the animal continuously throughout the experiment. Furthermore, the number of critical stimuli used could be increased to 10 or more to increase the difficulty of the task and thus lead to an earlier onset of vigilance decrement. A higher number of critical stimuli would also shed more light on the question whether stimuli are processed sequentially or parallel. If the animal was processing the presented stimuli parallel then there should be a limit up to which parallel processing is possible (Miller 1956). A further increase in the number of items should either lead to a drop in performance: either only a subset of the presented stimuli might be recognized and certain stimuli are not detected at all or performance on all presented stimuli decreases.

Prior work on judgments of similarity of dolphin whistles has relied on human subjects or complex algorithms based on various dimensions (McCowan 1995; Janik 1999). These experiments tried to investigate differences in individual whistles and how the dolphins might use these differences to recognize individuals within a group and communicate with them. Nevertheless, the algorithms and dimensions used to classify these vocalizations are arbitrary and artificial and might not represent a natural classification system as used by the dolphin. Here, a vigilance task could investigate how dolphins form a natural classification system: the animal would be trained to report the presence of a certain type of whistle or burst-pulse sound. Within a trial, variations of these sounds would be embedded in the regular train of stimuli presented. If the dolphin then would repeatedly indicate a hit upon the presentation of a *specific* variation of one of these whistles, this would indicate that the dolphin classified this particular variation as part of a certain whistle category. Thus it would be possible to gain insight into how dolphins naturally classify vocalizations and how they might utilize the large repertoire of whistles and burst-pulse sounds for communication within their social group. Furthermore, this could also be used to investigate classification of natural objects that the dolphin perceives through its visual sense: how the animal distinguishes food resources visually or how it might recognize features in its environment. On a more theoretical approach the classification of novel and artificial objects could also be explored for both the visual and the auditory sense and might give insight into the cognitive processes that occur when an animal is exposed to novel stimuli or a unfamiliar environment.

How are the findings in the current vigilance task related to vigilance behavior in its natural environment? Studies of animals in the wild, including a wide range of species such as baboons (Alberts 1994), several bird species (Yasukawa, Whittenberger et al. 1992; Desportes, Cezilly et al. 1994), squirrels, monkeys (Baldellou and Henzi 1992), ungulates (Illius and Fitzgibbon 1994) an others, have investigated attentive behavior and its relationship with group size, gender, foraging behavior and predation. As mentioned earlier, each animal has to balance the cost of monitoring its environment for predation with the need to feed, and dolphins are no exemption. Spinner dolphins for example are nocturnal feeders (Norris, Wuersig et al. 1994) and during that time an individual dolphin has to monitor for potential predation from sharks, search for food resources and be aware or the behaviors and interactions of its group mates. The costs of these factors have to be weighed against each other to optimize the dolphin's interaction with its environment and to insure survival. Therefore the ability to monitor various important events through different sensory channels over *extended* periods of time is paramount and essential.

Living in a complex social hierarchy provides more protection as the risk of predation decreases with the group size and each individual spends less time monitoring for possible dangers. Although with a larger group size more animals might compete for the same food resources, better utilization of these resources is possible through cooperative feeding behavior. A complex social hierarchy thus forces the animal to recognize and react to changing social situations quickly. Thus attention plays an integral part in the daily life of dolphins and provides parts of the framework for a functioning interaction with the environment.

Finally, studies of vigilance including vigilance decrement have been instrumental in the development of models of attention in humans (Niebur & Koch, 1998). These models include data obtained in pharmacological experiments with a variety of animals including rats and monkeys, as well as data from brain injury cases (Swick and Knight 1998) and non-invasive brain research on humans (Computer Tomography, Corbetta 1998; Magnetic Resonance Imaging, Haxby et al. 1998; etc.). Overall, a comparative and converging approach to the study of attention seems to add further pieces of a complex puzzle. The studies described in this dissertation as well as further studies might lead to a more detailed understanding of the mechanisms and limitations of attention in humans and animals. On a more general level, this will lead to deeper insight into how a biological information system functions, how it is able to process the information that is presented through various sensory channels and successfully interact with and ever-changing and challenging environment.