Introduction:

Honeybees in their natural environment experience many complex stimuli and in response to them they display a wide range of complex behaviors. Also, from the kind of tasks they perform in their society and their complex navigation skills, one can only wonder how all this is achieved. It is known since quite sometime that honeybees display behaviors which are very complex and many scientists believe that these are indeed cognitive in nature (Gould, 1990; Menzel et al., 2001 and 2006). Bees are known to show complex behaviors such as sensory preconditioning (Müller et al., 2000), context-dependent learning (Collett et al., 1997; Cheng, 2005; Zhang et al., 2006), second-order conditioning (Bitterman et al., 1983; Hussaini et al., 2007), blocking (Guez et al., 2007; Blaser et al., 2006; Guerrieri et al., 2005), reversal learning (Komischke et al., 2002) etc. All this requires a well organized and a highly specialized nervous system.

The honeybee has a well developed nervous system suited for sensing external stimuli. They have exceptionally good sense of smell. The hairs on their antennae allow them to smell or taste. The olfactory information from the antennae reach the first olfactory neuropil called antennal lobes where odors are coded. From here information is carried to higher brain centers such as mushroom bodies which are homologous to hippocampus in mammals. Much of the sensory information converges into these neuropils. Mushroom bodies are known to be involved in information processing and are the hot seat for learning and memory consolidation.

The purpose of this thesis was to understand two of the many complex behaviors displayed by honeybees and also to understand if sleep played any role in learning and memory consolidation.

For illustration sake imagine the following situation:

A forager bee flies out of its hive in search of food. Its surroundings are complex mixture of buildings, trees, animals etc. Bees use their visual and olfactory acuity to locate food and bring it back to the hive. Bees from its previous experience have to accurately fly to the same location several times in a day. Apart from other kinds of learning during such flights, bees also have to undergo second-order condition and context-dependent learning. For example second-order conditioning can occur when an

odor from a flower does not directly predict reward but leads to another flower containing reward. Similarly bees have to remember its surrounding environment by learning landmarks, time of day, temperature etc which serve as contexts and therefore are predictors of a biological relevant event such as food, predator etc. During night, bees have known to display decreased activity inside the hives (Kaiser, 1988) which strongly indicates sleep like behavior. Therefore, the questions we address in this thesis are very much relevant in the natural conditions of honeybees and its society.

The first chapter was a follow up of a previous study (Bitterman et al., 1983) on second-order conditioning (SOC). We previously knew that bees display SOC, but how is such a complex learning brought about and what factors control SOC was poorly understood.

Questions:

1) What percent of bees show SOC?
2) What are the conditions necessary for SOC?

In the second chapter we deal with another complex behavior called Context-dependent learning (CDL). This behavior has been shown previously in free flying bees (Collett et al., 1997, Cheng, 2005, Zhang et al., 2006), but we wanted to know if restrained bees could learn contexts too. Our main aim was to understand the neural mechanisms of context learning. To achieve this we extracellularly recorded from mushroom body neurons of freely behaving bees.

Question:

1) Do restrained bees show CDL?
2) Which contexts are best for learning?
3) Is the mechanism of context learning and acquisition learning same?

Sleep has been a subject of much debate recently and scientists have been probing to understand the functions of sleep. We like majority of the sleep scientists believe that sleep might be important for consolidation of memories. We knew from previous studies that honeybees also display sleep like most animals (Kaiser, 1988). In the third chapter of this thesis we studied antennal movements (sleep indicator) in honeybees to understand

how sleep interacts with learning and if it is really necessary for any form of learning to occur.

Questions:

1) Do bees sleep like other animals?
2) How does learning affect sleep?
3) How does sleep (or lack of it) affect learning?