Is Operant Behavior Facilitating Classical Conditioning at the Flight Simulator?

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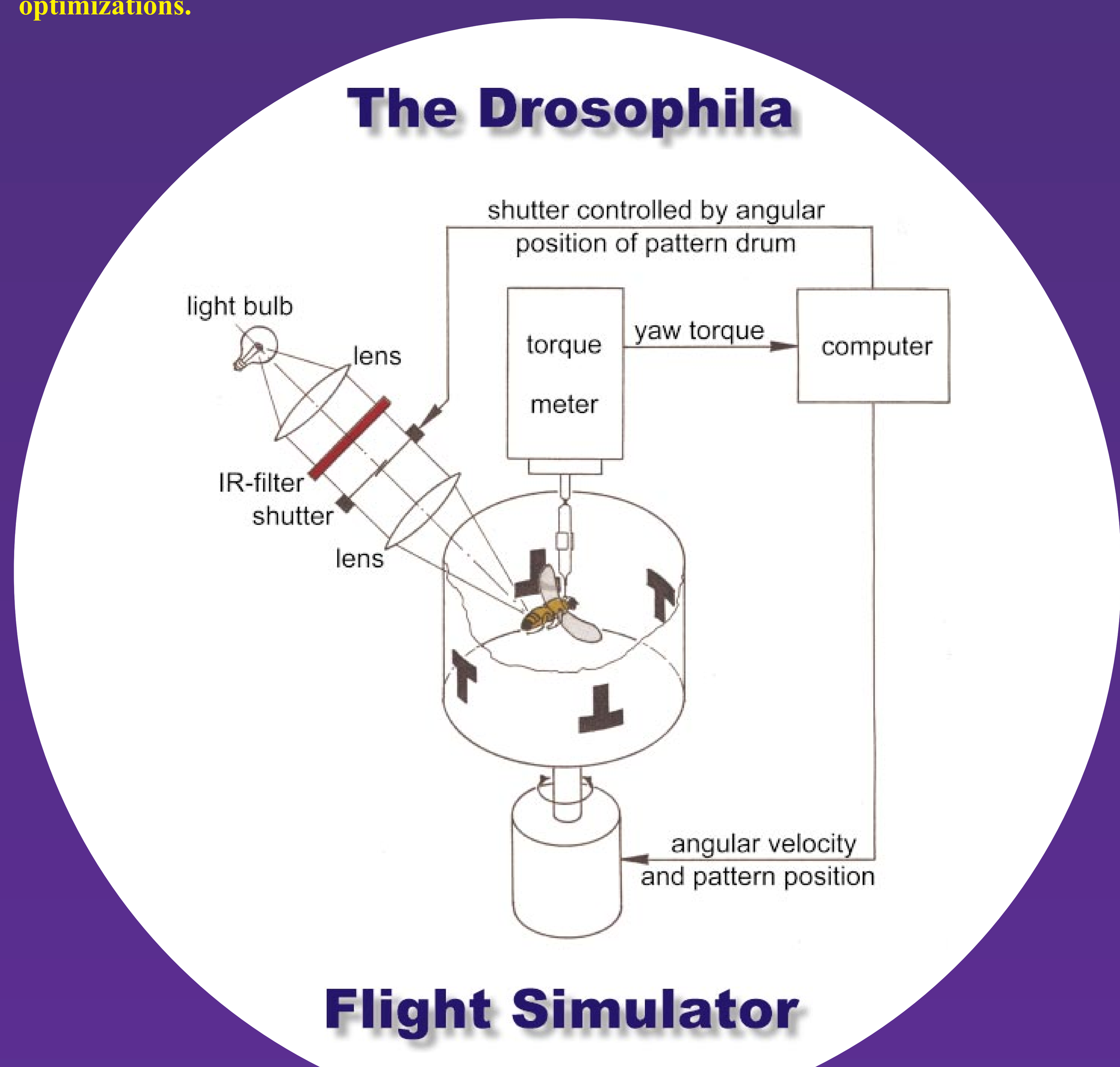
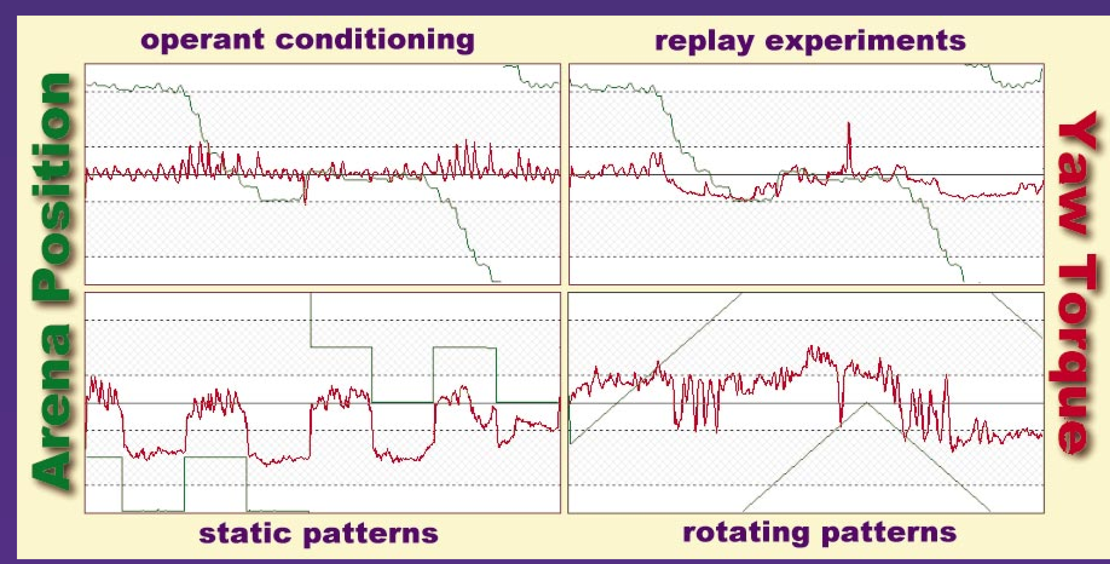
1. Introduction

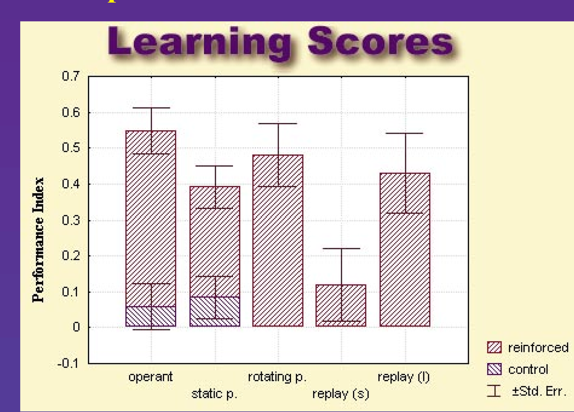
While in recent years classical conditioning has been established as an information transfer from the unconditioned to the conditioned stimulus, the processes underlying operant conditioning are still poorly understood. Modification of motor-programs in response to reinforcement accounts for some but possibly not all cases.
The study of pattern learning in the *Drosophila* flight simulator seems well suited to compare the two types of learning: The same behavioral test - the choice between two patterns - can be used to assess learning success in differently trained animals. During training, the sequence of conditioned and unconditioned stimuli can either be controlled by the fly itself (closed-loop, operant training) or by the experimenter, the fly having no possibility to interfere (open-loop, classical conditioning). In the flight simulator, the experimenter has exquisite control over the various contingencies that one might establish among behavioral output, visual input and the reinforcer.
The different processes assumed to underlie the different training procedures might lead to different behavioral strategies to avoid the pattern orientation associated with heat. For instance, if the classically trained fly learned that one of the pattern orientations was associated with heat, it might use the same behavioral repertoire to avoid this flight direction as it employs to express a spontaneous pattern preference.
Conversely, during operant training flies may acquire a more effective (or at least different) way to avoid the heat, selecting one of several behavioral strategies. In this case, the motor-output should be different from that of the naive and the classically conditioned flies.
The flight simulator provides the means for a detailed comparison of the relationship between behavioral output, visual input and the reinforcer, necessary to find behavioral optimizations.



2. Four Learning Paradigms



Training:
operant conditioning: The fly is enabled to control the appearance of the reinforcer (i.e. the beam of infrared light) by its choice of flight direction with respect to the angular positions of visual patterns at the arena wall ('closed loop').
replay experiments: The movements of the arena (together with the heating schedule), recorded from a previously operantly trained fly, are played back to the fly ('open loop').
static patterns: In open loop, the panorama is kept stationary with one pattern orientation in front of the fly. After 3s the panorama is quickly rotated by 90°, thus bringing the other pattern orientation into the frontal position. One of the two orientations is made contiguous with the reinforcer.
rotating patterns: The panorama is rotated continuously at w=30°/s in open loop. As the heat is switched on/off every 90° (whenever the two pattern orientations are at a 45° angle with respect to the longitudinal axis of the fly) the same heating regime as during stationary pattern presentation is applied.
Test:
In all instances, the identical behavioral test is used to assess learning success: The fly's pattern preference is measured in closed loop without reinforcement.

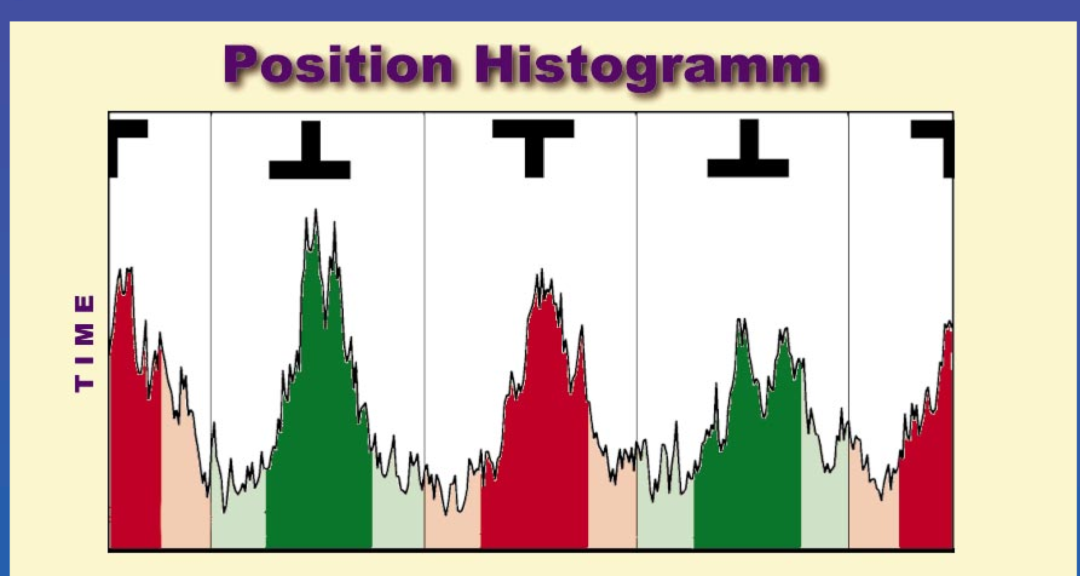


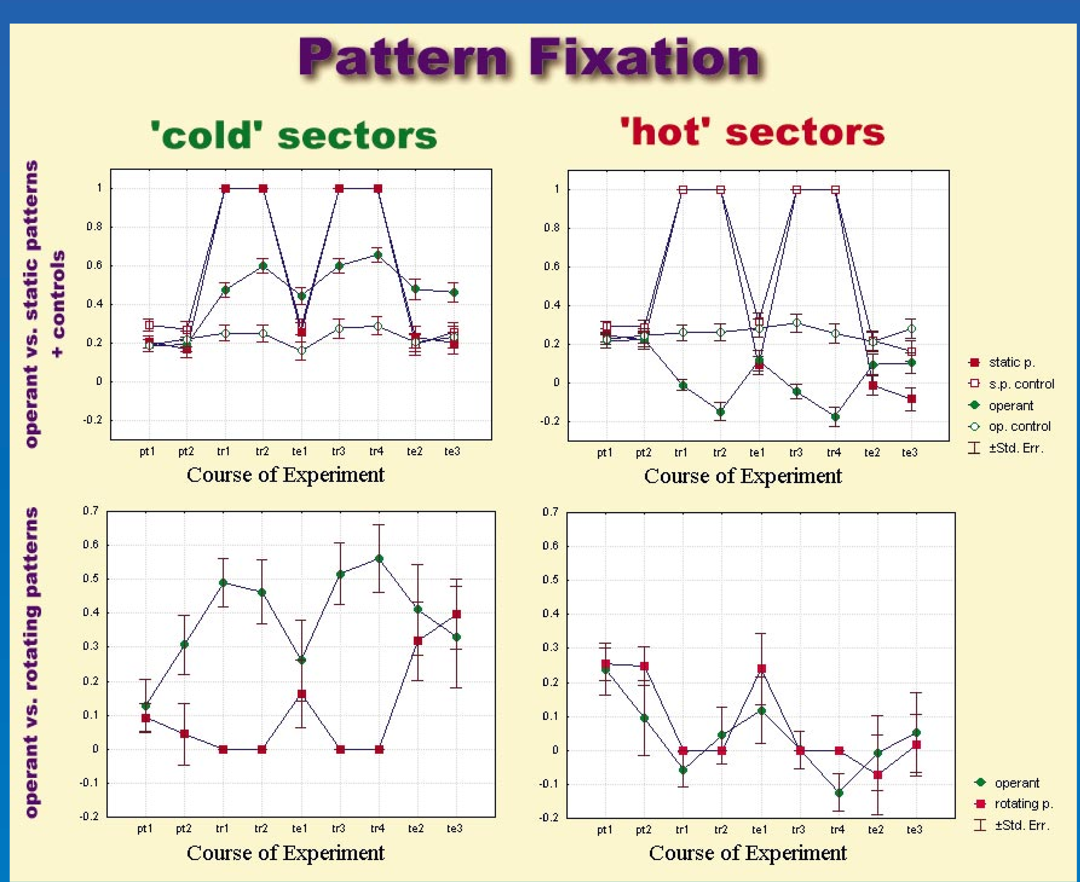
Average learning scores of the four learning paradigms. The preference index is calculated as (p2-pl)/(p2+pl), with p2 being the time during which the pattern orientation not associated with heat was kept in the frontal quadrant of the visual field and p1 denoting the remaining time.
replay (s) - 2x4min replay-training
replay (l) - 4x4min replay training

3. Does the fly's behavior during test reveal different avoidance strategies after the various conditioning procedures ?

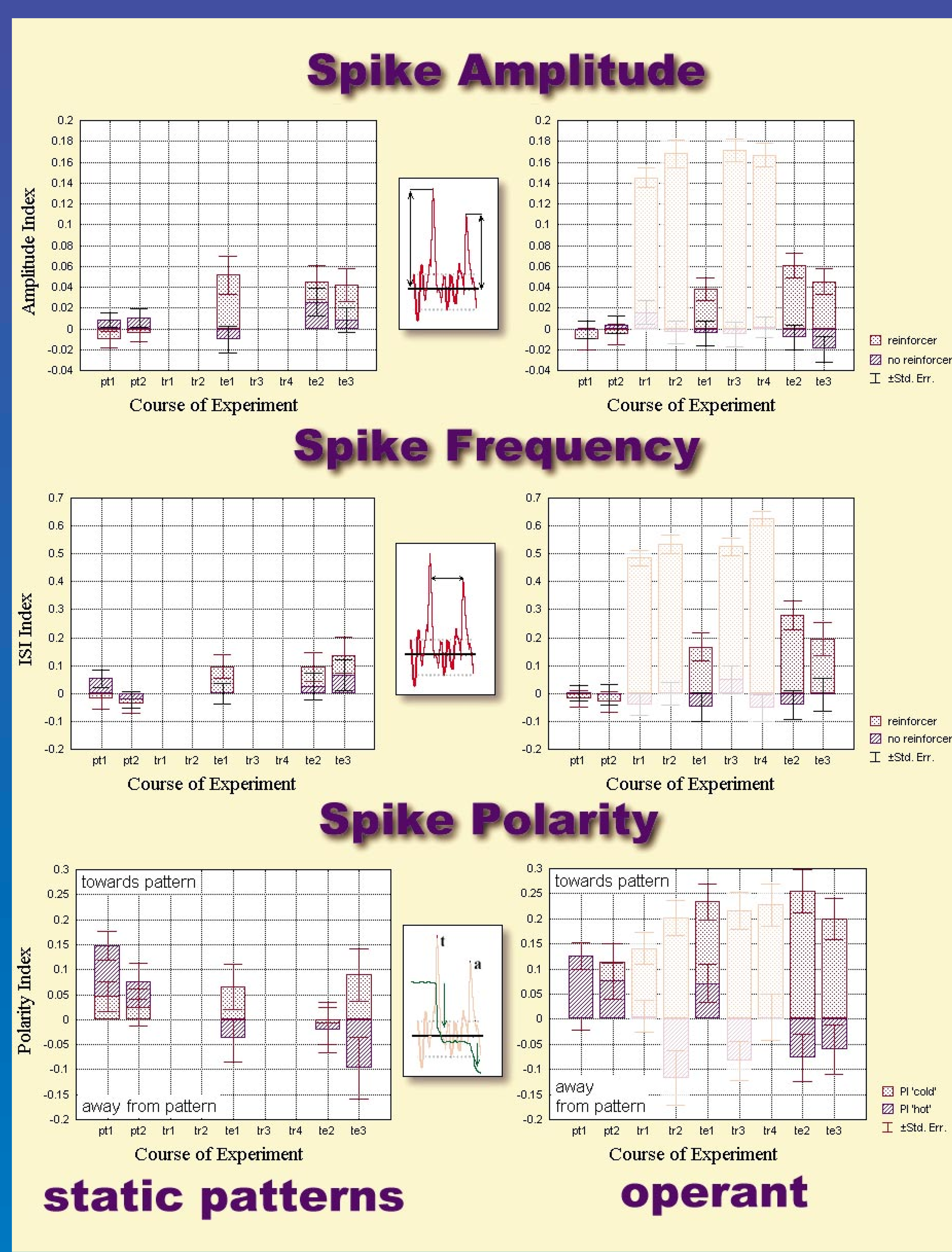
2. Arena Position: The time the fly keeps the preferred pattern in the frontal position is used to assess learning success. This information is stored in the position trace. In contrast to the torque trace which only displayes the motor-output of the fly, the position trace also contains information about the visual input of the fly. Since the conditioned stimulus in all paradigms is visual and in closed loop it is directly controlled by the fly, evaluation of the position trace can yield important clues about different behavioral strategies, aquired during training.
Since the only detectable difference in the torque trace was spike polarity towards (away from) the pattern, the amount of time spent in the vicinity of either patterns or sector borders was used to measure pattern fixation.

1. Yaw Torque: Upon observing a fly in the flight simulator, it is striking that the fly neither keeps the cylinder immobilized nor rotates it continuously: phases of fairly straight flight are interrupted by sudden turns at high angular velocity. The turns are due to short pulses of torque (torque spikes). Results from previous studies suggest that the spikes are the primary behavior by which the fly adjusts its orientation in the panorama. Therefore, spiking behavior (e.g. spike amplitude, frequency, polarity, etc.) seemes a suitable candidate to search for different behavioral strategies acquired during conditioning.





Comparing the test groups with the non-reinforced control-groups, it turned out that the flies in the operant group enhanced fixation in the 'cold' sectors during the course of the experiment, whereas the flies trained classically with static patterns decreased pattern fixation in the 'hot' quadrants. Using rotating patterns for classical conditioning abolishes the differences in pattern fixation completely.



Out of the measured parameters, only one was significantly different: Spike Polarity. In order to study this difference more closely, the arena position was used to assess pattern fixation.

4. Conclusion

"Under carefully controlled experimental circumstances, an animal will behave as it damned well pleases."
Harvard Law of Animal Behavior

Comparison of flight behavior after operant training and after classical conditioning with static patterns revealed only one parameter to be significantly different: operantly trained flies chose flight directions as far away from the heat-associated ones as possible (i.e. high pattern fixation). Rotating the patterns during classical training instead of presenting them stationarily abolished this difference. Apparently, the same avoidance strategies are used after operant and classical conditioning. If there are no differences, what is it that makes operant training more effective than classical training?
Recording the sequence of conditioned and unconditioned stimuli during 2x4min of operant training and subsequently playing them back to a naive fly, does not yield any significant learning scores. This shows that the learning in the original experiment is indeed operant. Increasing the amount of reinforcement by reiterating the replay training 4x4min, however, restores learning scores to near control levels (see learning scores for short and long replay-experiments). We thus propose that in the original experiment operant behavior facilitates the information transfer from the unconditioned to the conditioned stimulus, so that less reinforcement is required to perform the same task.

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