Learning to drive with delayed visual feedback

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1 Introduction

Delaying the presentation of information to one sensory modality relative to another drastically impairs performance. Can humans learn to perform complex, real world tasks under such conditions?

Prism goggles (which produce a disagreement between the seen and felt **position** of an object) impair performance on most spatial tasks. A few minutes of the proper experience, however, allows the sensorimotor system to adapt to the new relationship.

Similarly, delayed visual feedback (which produces a disagreement between the seen and felt **time of occurance** of an event) drastically impairs performance on many tasks. Delays of 100 ms can render rapid and accurate behaviorial reactions impossible and delays greater than 1 second essentially eliminate the visual control of behavior (1,2,3). Only recently (4) has it been shown that, contrary to established belief (e.g., 1), a few moments of the proper experience can improve performance considerably. This improvement was obtained using abstract stimuli and a task with which subjects had little prior experience. Here, we extend this work to driving using a high−fidelity virtual environment.

2 General Methodology

2a Apparatus

Stimuli: A virtual world was generated on a Silicon Graphics Onyx 2 Reality Engine. Eighty arc deg of the virtual world were projected onto the center 45 arc deg of a half−cylindrical screen (7m diameter, 3.15m height).

Input: Subjects maneuvered a virtual car via a custom−designed, forced−feedback steering wheel.

2b Design Philosphy

Constant Velocity: Previous research on practice with delayed feedback found little or no improvement (1,2). Notably, the subjects in those experiments tended to slow down when exposed to delayed feedback (3) −− a strategy that negates the effects of the delay. For example, a driver traveling 36 km/h in a car with a 1s delay must turn the steering wheel 10 meters prior to reaching an intersection. Traveling at 3.6 km/h, however, they need to turn only 1 meter early −− they can act as if there were no delay and turn once in the intersection.

Following Cunningham et al.(4), we ensured that subjects were exposed to the delay, and thus had the chance to acclimate to it, by allowing them to control only the direction of travel. The speed was constant for the duration of each trial, with each subject being exposed to several different speeds.

Adaptation paradigm: Exp 1 was explicitly designed following the early work on prism adaptation: the task and stimuli were kept constant throughout the exp (e.g., the same street was used, see Fig 1). Exp. 2, following later prism adaptation work, examined the generalization of training to novel streets.

Task: The task was to maneuver the virtual car so that it stayed on the road.

3 Experiment 1 (Negative Aftereffect): Methodology

Pre−Test: For each subject, the 7 speeds were presented 5 times each in random order with immediate visual feedback.

Training: Visual feedback was delayed by 280ms. The slowest speed was repeatedly presented until one of 3 criteria was met. If the success criterion was met, the next faster speed was presented. If either of the other 2 criteria were met, then training ended.

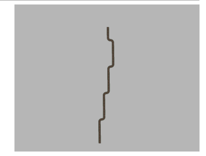

Figure 1: Street used in Exp 1

(a) *Success*: They reached the street's end on 8 of 10 sequential trials;
(b) *Failure*: They left the street 10 times in a row;
(c) *Stalemate*: Neither of the first two criteria was met within 40 trials.

Post−Test: Performance with immediate feedback was remeasured. To avoid re−adaptation to immediate feedback, only 10 trials were presented. For each subject, all 10 trials were at the fastest speed that they successfully completed on at least 4 of the 5 pre−test attempts.

4 Experiment 1 (Negative Aftereffect): Results

- During training, performance with delayed feedback improved.
- Each subject exhibited a strong negative aftereffect (after training with a delay, performance with immediate feedback decreased by approx. 80%, on average).

These results are consistent with those of Cunningham et al.(4), and demonstrate the robust nature of acclimation to large feedback delays.

5 Experiment 2 (Generalization): Methodology

Pre−Test: Baseline performance with delayed feedback was measured, using 5 paths each presented at 4 speeds. Half of the subjects saw Street Set A for the pre−test, and half saw Set B (see Figs 2,3). Driving skills vary widely, so speeds were chosen to match the widest range of skill levels possible, while keeping the speeds reasonably similar to each other. Nonetheless, these 4 speeds will be too slow for some (ceiling effect), and too fast for others (floor effect).

Training: The training was identical to Experiment 1, including the fact that only one street (see Fig 4) was used.

Post−Test: The post−test was identical to the pre−test, with the single exception that 5 new paths were used: The subjects who saw Street Set A for the pre−test, saw Set B for the post−test, and vice versa (see Figs 2,3).

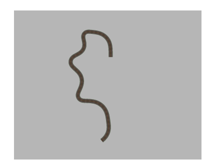

Figure 4: Training street

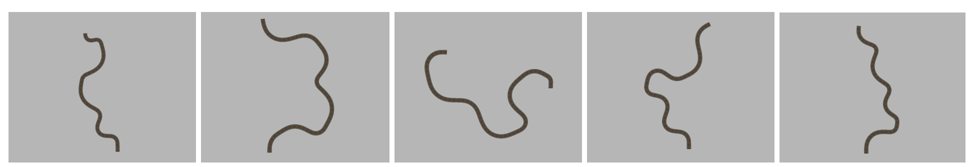

Figure 2: Street Set A

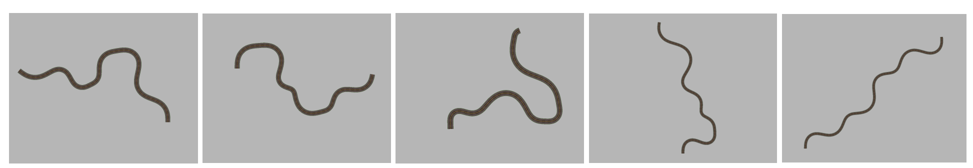

Figure 3: Street Set B

6 Experiment 2 (Generalization): Results

- On average, driving accuracy was 35% before training and 74.6% after training. In other words, subjects' ability to reach the end of a street they had never seen before increased by 39.6% as a result of training.
- Of the 11 subjects, one was at ceiling and one at floor (see Figs 5&6). Of the remaining 9 subjects, every one showed an increase in driving accuracy.
- Although the street sets were created randomly, street set B seems to be more difficult than set A. Despite this, both orders of presentation produced increases in driving accuracy.

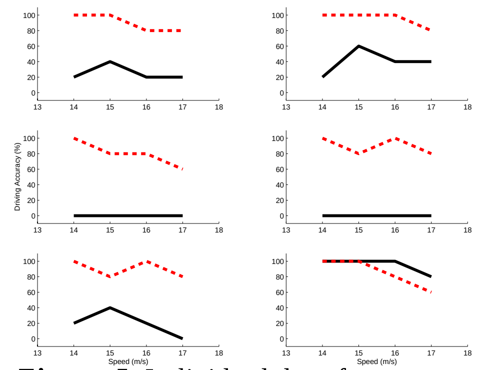

Figure 5: Individual data from subjects who saw Street Set A in the pre−test. The black line represents pre−test scores, and red the post−test scores.

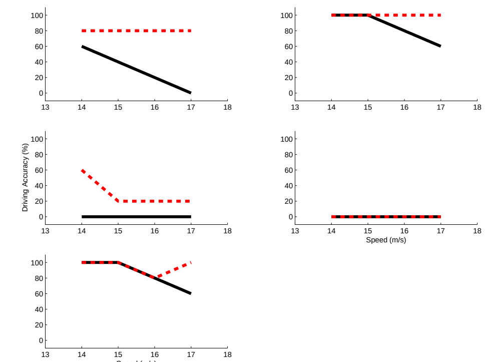

Figure 6: Individual data from subjects who saw Street Set B in the pre−test. The black line represents pre−test scores, and red the post−test scores.

7 Conclusions

- Humans can learn to drive a car with visual delayed feedback by ~300 ms.
- The improved performance produced by training generalizes to novel streets.
- Combined with Cunningham et al.'s (4) earlier work, this suggests a general ability to learn to perform complex tasks with delayed feedback.
- The results are suggestive of sensorimotor adaptation to intersensory temporal differences.
- The results are **not** consistent with over−training, cognitive or motoric memorization of the path, or simple behavioral strategies (e.g., attempting to turn earlier).

8 References

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