# Unexpected Events, Predictive Eye Movements & Imitation Learning


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## Background and Aims

It has been proposed that **unexpected events** are advantageous for learning (e.g. Schultz, 2006; Wills et al, 2007). To investigate this possibility, we intentionally disrupted subjects' expectations about the sequence of visual motions that they were trying to imitate.

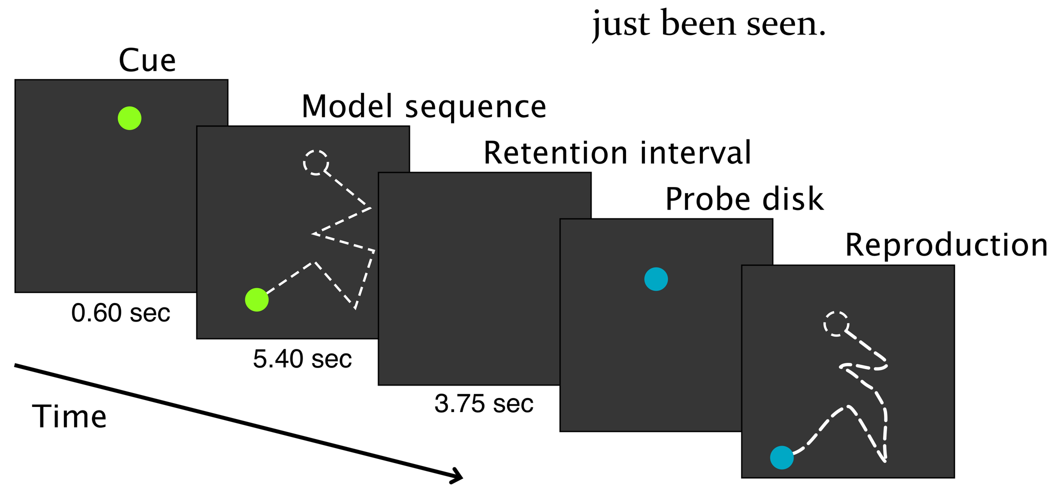
Subjects learned to reproduce sequences of movements (Agam et al, 2010). We occasionally injected a novel direction of motion into a well-learned sequence, disrupting subjects' expectations of what motion would be seen.

To gauge the impact of disrupted expectations, we measured (i) eye movements made while subjects observed each motion sequence, and (ii) the fidelity with which each sequence, with or without a disruption, was subsequently reproduced.

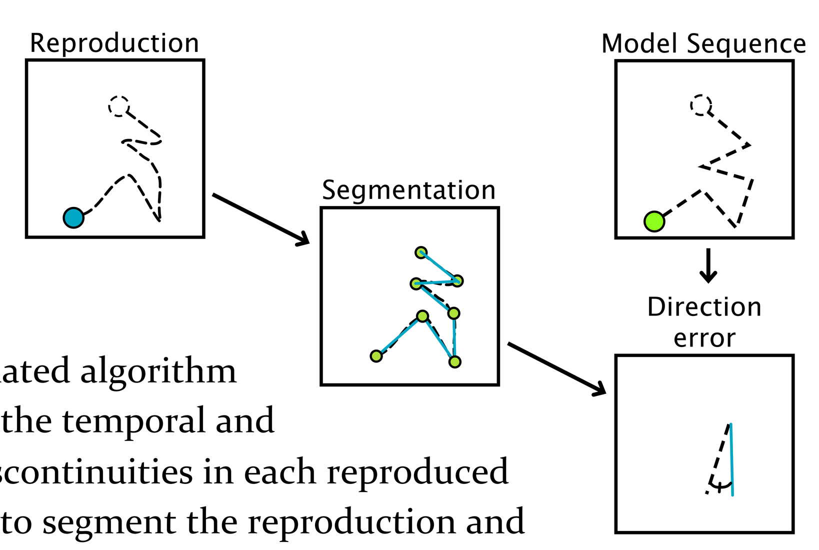
## Imitating a sequence of movements

Subjects watched a small disk traverse a quasi-random path made up of six linear, directed component motions.

After a retention interval, subjects used a stylus and graphics tablet to reproduce from memory the path that had just been seen.



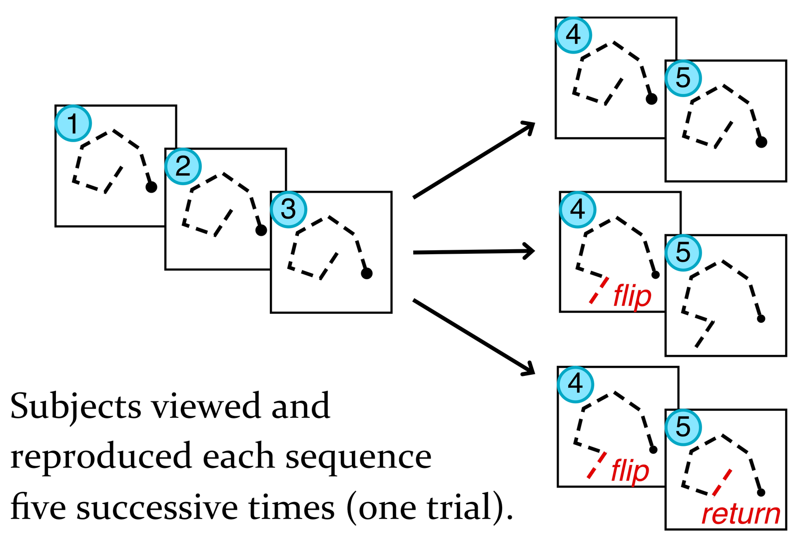

## Quantifying reproduction accuracy




An automated algorithm exploited the temporal and spatial discontinuities in each reproduced sequence to segment the reproduction and to identify each of its directions of motion.

The algorithm compared each component in the reproduced sequence to the comparable component in the model motion sequence. Imitation quality was measured by the absolute difference between comparable components.

## Inducing errors in prediction




**Congruent** trials (68 % of trials)

**Flip** trials (16 % of trials)

**Flip-return** trials (16 % of trials)

Subjects viewed and reproduced each sequence five successive times (one trial).

Occasional deviant component directions violated subjects' expectations. Each "flipped" component's direction of motion differed by 180° from the established component that it replaced.

### Experiment 1:

- 8 young adults, 112 trials each.
- "Flip" occurs on **fourth** presentation
- Eye movements recorded.

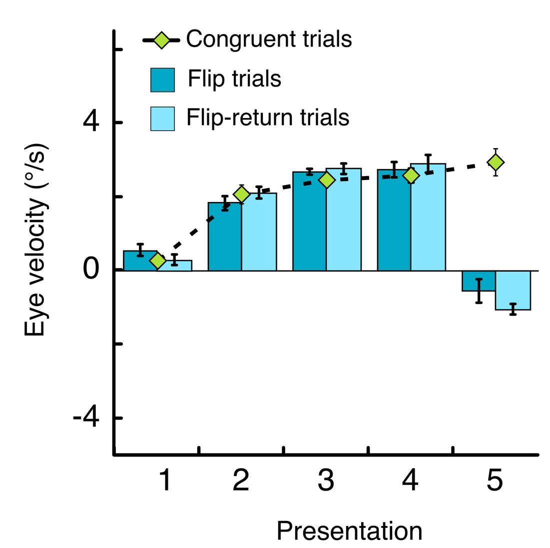
### Experiment 2:

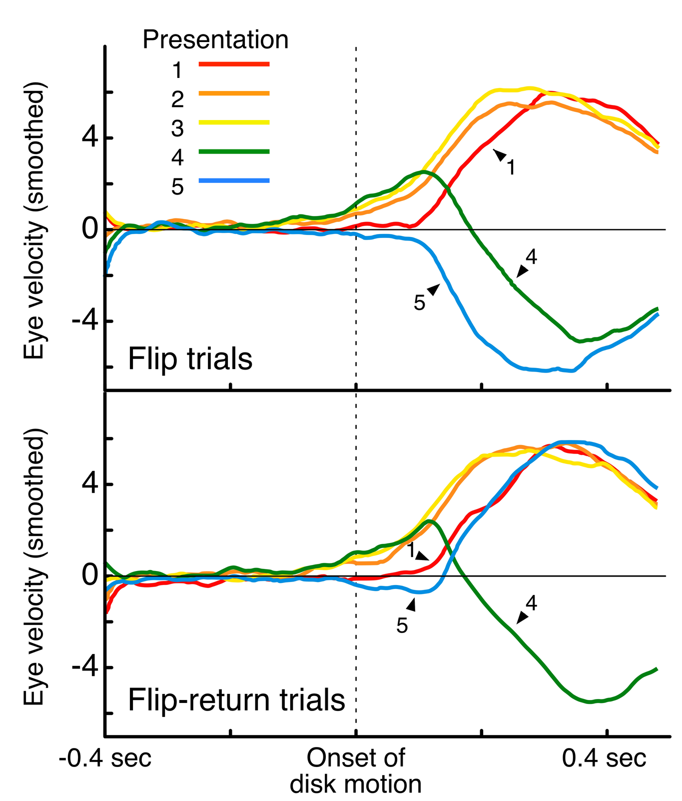
- 10 young adults, 112 trials each.
- "Flip" occurs on **third** presentation

## Flipped components are unexpected

Eye velocity at 80 ms after disk motion onset reflects anticipatory smooth pursuit for the final component.

Subjects do not anticipate the flip on presentation 4; on presentation 5 they expect the component to remain flipped.

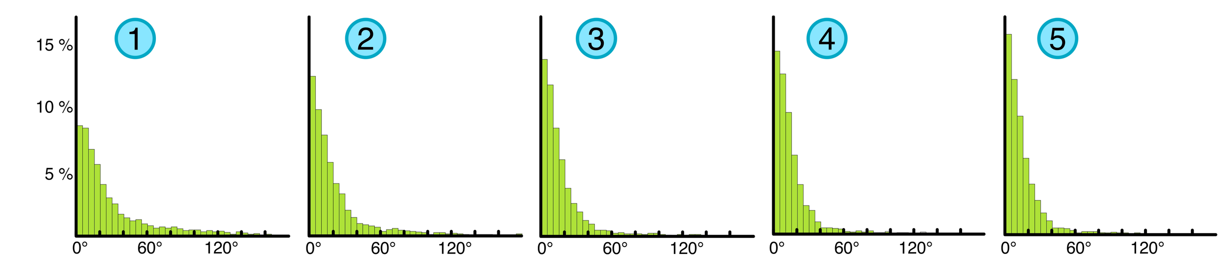


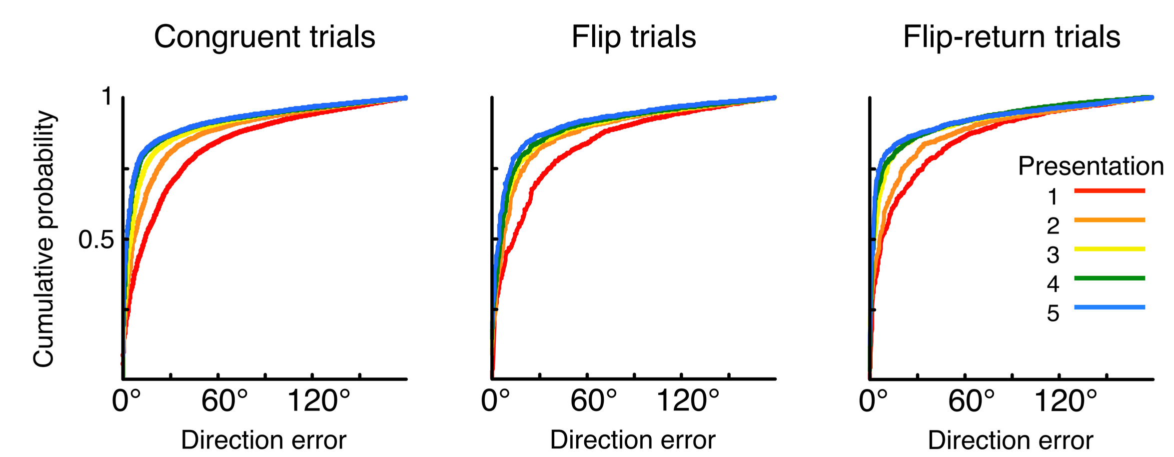

Eye velocity traces during component 6 show anticipation of the upcoming direction, and, when an error is made, correction of that error.

Eye movements suggest that subjects (i) do not expect the deviant component, and (ii) do not expect the original sequence to be reinstated.

## Memory for movement is preserved



Error distributions for **congruent** trials, experiment 1, ordered by presentation. Over successive presentations, distributions cluster more tightly around zero error.




Cumulative probability of degree of error, over presentations, by trial type (experiment 1). Data shown are for components 1-5.

This pattern of learning characterizes both experiments, and **congruent** trials as well as the non-flipped segments on **flip** and **flip-return** trials.

### Memories are degraded, but not lost

Analysis of error distributions suggest that subjects virtually never are guessing randomly. Rather, they successfully maintain at least some representation of each direction of movement that is to be imitated. Errors result from memory degradation, not complete loss. This contrasts to Zhang & Luck (2009)'s suggestion that short-term memory can undergo catastrophic "sudden death," which is accompanied by random guessing.

Our task differs from that of Zhang & Luck (2009) in that here (i) the items in memory are directions of motion, (ii) the items are presented sequentially, rather than simultaneously, and (iii) the items comprise an organized "chain.

Further investigation will be needed to determine whether any or all of these factors are responsible for difference between our results and those of Zhang & Luck.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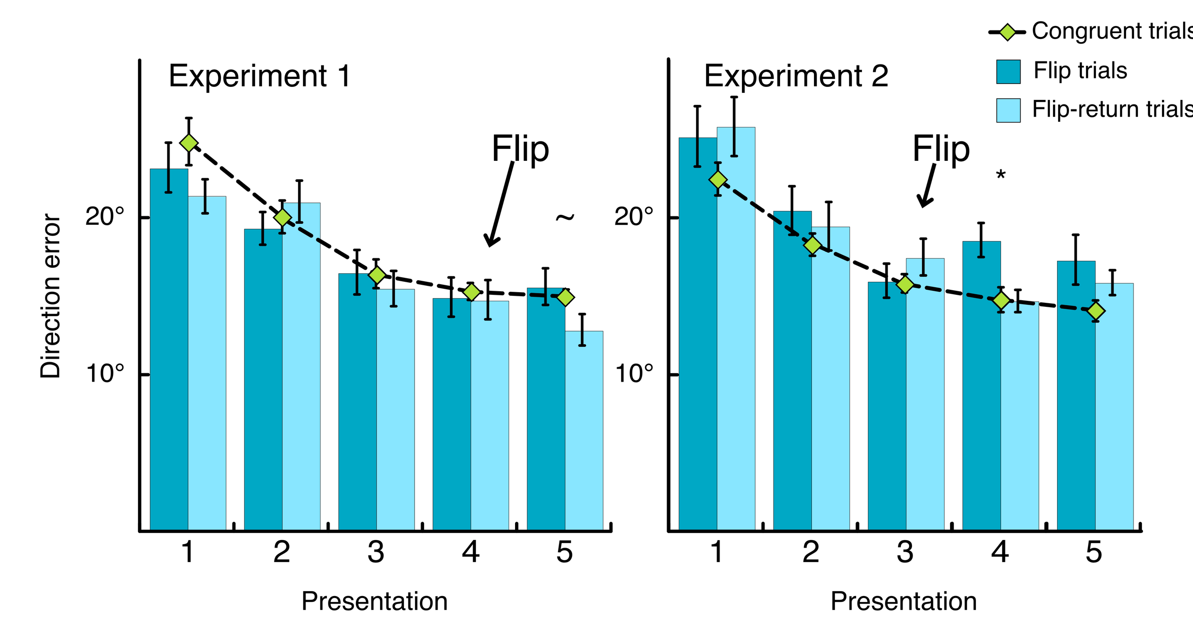
## Prediction errors facilitate learning

Despite their novelty and despite their having violated subjects' expectation, flipped components are reproduced with accuracy equal to that of equivalent congruent components. Also, on the presentation following the flip, accuracy is greater on **flip-return** than on **flip** trials.




Mean direction error on component six, by trial type.

The flipped component (on **flip** and **flip-return** trials), and the return to the original configuration (on **flip-return** trials) are unexpected. We believe that their unexpected character contributes to the accuracy with which they are remembered and imitated.

## Conclusions

Accurate reproduction of unexpected sequence events seems to be facilitated by a "novelty signal" that boosts attention and encoding (Kumaran & Maguire, 2008). This might explain the accuracy with which an unexpected, unfamiliar component is reproduced.

Errors in memory for a sequence of motions are approximately normally distributed around zero, with a variance that decreases as the sequence grows more familiar. The distributions of errors made by subjects shows that memory may be degraded to some degree, but does not suffer all-or-none "sudden death."


Agam, Y., Huang, J. & Sekuler, R. (2010). Neural correlates of sequence encoding in visuomotor learning. *Journal of Neurophysiology, 103*, 1418-1424.

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Schultz, W. (2006). Behavioral theories and the neuropsychology of reward. *Annual Review of Psychology, 57*, 87-115.

Wills, A. J., Lavric, A., Croft, G. S., & Hodgson, T. L. (2007). Predictive learning, prediction errors, and attention: evidence from event-related potentials and eye tracking. *Journal of Cognitive Neuroscience, 19*, 843-854.

Zhang, W. & Luck, S. J. (2009). Sudden death and gradual decay in visual working memory. *Psychological Science, 20*, 423-428.