

# Eliminating Direction Specificity in Visuomotor Learning

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The generalization of learning offers a unique window for investigating the nature of motor learning. Error-based motor learning reportedly cannot generalize to distant directions because the aftereffects are direction specific. This direction specificity is regarded as evidence that motor adaptation is model-based learning, and is constrained by neuronal tuning characteristics in the motor cortices and the cerebellum. However, recent evidence indicates that motor adaptation also involves model-free learning and explicit strategy learning. Using rotation paradigms, here we demonstrate that savings (faster relearning), which is closely related to model-free learning and explicit strategy learning, is also direction specific. However, this new direction specificity can be abolished if the participants receive exposure to the generalization directions via an irrelevant visuomotor gain-learning task. Control experiments indicate that this exposure effect is weakened when direction error signals are absent during gain learning. Therefore, the direction specificity in visuomotor learning is not solely related to model-based learning; it may also result from the impeded expression of model-free learning and explicit strategy learning with untrained directions. Our findings provide new insights into the mechanisms underlying motor learning, and may have important implications for practical applications such as motor rehabilitation.

**Key words:** learning specificity; motor adaptation; motor generalization; motor learning

## Significance Statement

Motor learning is more useful if it generalizes to untrained scenarios when needed, especially for sports training and motor rehabilitation. However, as a form of motor learning, motor adaptation is typically direction specific. Here we first show that savings with motor adaptation, an index for model-free learning and explicit strategy learning in motor learning, is also direction specific. However, the participants' additional exposure to untrained directions via an irrelevant gain-learning task can enable complete generalization of learning. Our findings challenge existing models of motor generalization and may have important implications for practical applications.

## Introduction

Motor learning is a fundamental process that enables us to acquire new skills and adapt to changing environments. It is essential for many aspects of our daily lives, from simple tasks like walking to complex activities like playing sports. Understanding the mechanisms of motor learning can help us improve our performance and develop effective rehabilitation strategies for individuals with motor impairments.

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### Experimental design

Experiment 1 (generalization without exposure). **Figure 1**

Figure 1 shows the experimental design for Experiment 1. The design is divided into two parts: A and B. Part A consists of 10 trials, and Part B consists of 10 trials. The trials are arranged in a sequence, with trials 1-5 in Part A and trials 6-10 in Part B. The trials are labeled as follows: Trial 1, Trial 2, Trial 3, Trial 4, Trial 5, Trial 6, Trial 7, Trial 8, Trial 9, and Trial 10.

Experiment 2 (generalization enabled by visuomotor gain learning). **Figure 2**

Figure 2 shows the experimental design for Experiment 2. The design is divided into three parts: A, B, and C. Part A consists of 10 trials, Part B consists of 10 trials, and Part C consists of 10 trials. The trials are arranged in a sequence, with trials 1-10 in Part A, trials 11-20 in Part B, and trials 21-30 in Part C. The trials are labeled as follows: Trial 1, Trial 2, Trial 3, Trial 4, Trial 5, Trial 6, Trial 7, Trial 8, Trial 9, Trial 10, Trial 11, Trial 12, Trial 13, Trial 14, Trial 15, Trial 16, Trial 17, Trial 18, Trial 19, Trial 20, Trial 21, Trial 22, Trial 23, Trial 24, Trial 25, Trial 26, Trial 27, Trial 28, Trial 29, and Trial 30.

Washout controls (savings after washout). **Figure 3**

Figure 3 shows the washout controls for Experiment 2. The design is divided into two parts: A and B. Part A consists of 10 trials, and Part B consists of 10 trials. The trials are arranged in a sequence, with trials 1-10 in Part A and trials 11-20 in Part B. The trials are labeled as follows: Trial 1, Trial 2, Trial 3, Trial 4, Trial 5, Trial 6, Trial 7, Trial 8, Trial 9, Trial 10, Trial 11, Trial 12, Trial 13, Trial 14, Trial 15, Trial 16, Trial 17, Trial 18, Trial 19, and Trial 20.

Experiment 3 (relevant factors in the exposure task). **Figure 4**

Figure 4 shows the experimental design for Experiment 3. The design is divided into two parts: A and B. Part A consists of 10 trials, and Part B consists of 10 trials. The trials are arranged in a sequence, with trials 1-10 in Part A and trials 11-20 in Part B. The trials are labeled as follows: Trial 1, Trial 2, Trial 3, Trial 4, Trial 5, Trial 6, Trial 7, Trial 8, Trial 9, Trial 10, Trial 11, Trial 12, Trial 13, Trial 14, Trial 15, Trial 16, Trial 17, Trial 18, Trial 19, and Trial 20.

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$$RM = \sqrt{\left( \sum_{i=1}^n \Delta x^2 + \sum_{i=1}^n \Delta y^2 \right) / n}$$

$\Delta x$  and  $\Delta y$  are the horizontal and vertical displacement errors, respectively.

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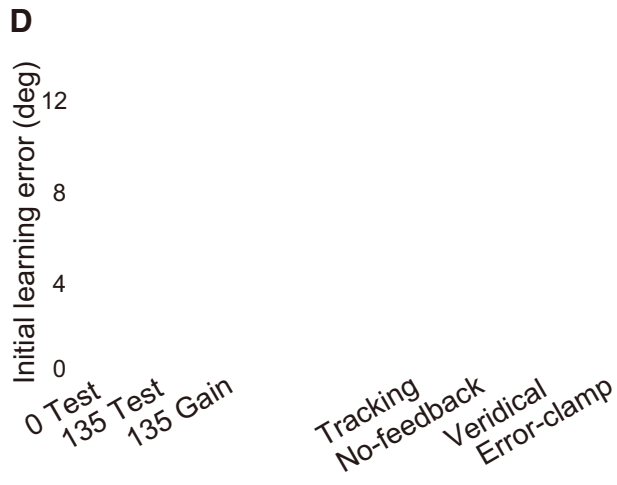
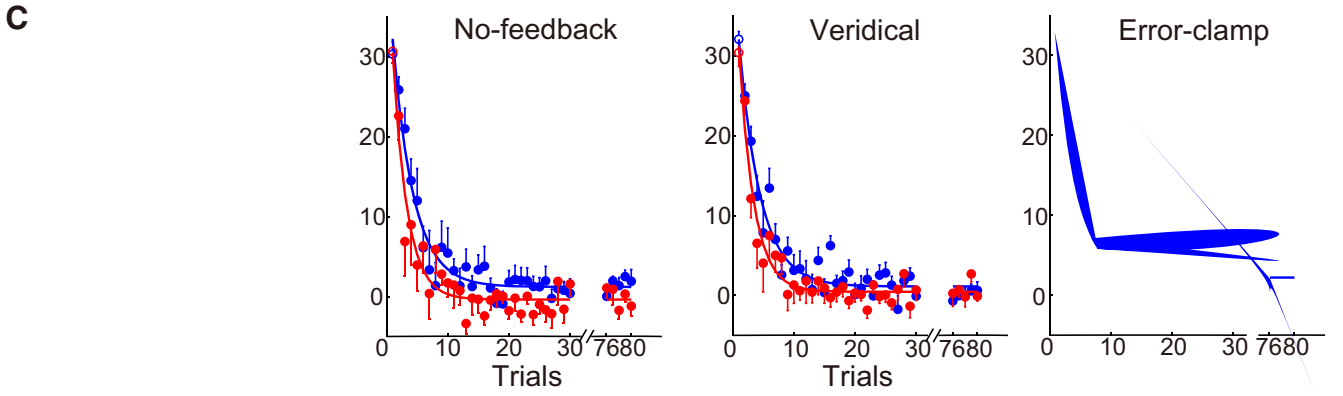
### Data analysis

Data analysis was performed using the root mean square (RMS) error metric. The RMS error was calculated for each trial in the experiment. The RMS error was then averaged across all trials to obtain the overall RMS error for the experiment.









0 Test    135 Test    135 Gain    Tracking  
 Savings (%)    Initial learning error (deg)

1. Introduction  
2. Literature Review  
3. Methodology  
4. Results  
5. Discussion  
6. Conclusion

The purpose of this study is to investigate the impact of social media on mental health. The research is based on a survey of 1,000 participants. The findings indicate a significant correlation between social media use and increased anxiety and depression. These results suggest that excessive social media use may be detrimental to mental well-being.

The study was conducted using a cross-sectional design. Data was collected through an online survey. The sample was diverse in age and gender. The results were analyzed using statistical software. The findings are consistent with previous research on the topic.

The implications of this study are significant. It highlights the need for further research into the psychological effects of digital technology. The findings also suggest that users should be encouraged to take breaks from social media to maintain their mental health. Future studies should explore the long-term effects of social media on mental health.

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