



# Location and direction specificity in motion direction learning associated with a single-level method of constant stimuli



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## ABSTRACT

Recent studies reported significantly less location specificity in motion direction learning than in previous classical studies. The latter performed training with the method of constant stimuli containing a single level of direction difference. In contrast the former used staircase methods that varied the direction difference trial by trial. We suspect that extensive practice with a single direction difference could allow an observer to use some subtle local cues for direction discrimination. Such local cues may be unavailable at a new stimulus location, leading to higher location specificity. To test this hypothesis, we jittered slightly the directions of a stimulus pair by the same amount while keeping the direction difference constant, so as to disturb the potential local cues. We observed significantly more transfer of learning to untrained locations. The local cue effects may also explain the recent controversies regarding the finding that foveal motion direction learning becomes significantly more transferrable to a new direction with TPE (training-plus-exposure) training. One specific study by Zili Liu and collaborators that challenges this finding also used a single-level direction difference for training. We first replicated their results. But we found that if the directions of the stimulus pair were again jittered while the direction difference was kept constant, motion direction learning transferred significantly more to an orthogonal direction with TPE training. Our results thus demonstrate the importance of using appropriate psychophysical methods in training to reduce local-cue related specificity in perceptual learning.

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## 1. Introduction

Visual perceptual learning improves a person's sensitivity to fine differences of basic visual features, such as spatial frequency, orientation, contrast, and motion direction (Ahissar & Hochstein, 1997; Ball & Sekuler, 1982, 1987; Doshier & Lu, 1998; Fiorentini & Berardi, 1980; Schoups, Vogels, & Orban, 1995; Shiu & Pashler, 1992; Yu, Klein, & Levi, 2004). Like various VPL tasks, motion direction learning is found to be specific to the trained retinal location and feature dimension (i.e., a specific direction), which has led to the assumption that motion direction learning may suggest training-altered response properties of direction-selective visual neurons (Ball & Sekuler, 1982, 1987). However, neurophysiologically motion direction learning is more likely tied to changes in non-sensory cortical areas like LIP, and in contrast no significant changes of response properties of MT neurons are recorded (Law & Gold, 2008). Hence it is inferred that motion direction learning

may more likely depend on a reweighting mechanism, in that training improves the readout of sensory inputs from direction selective neurons at a decision level (Law & Gold, 2009).

The understanding of the mechanisms underlying motion direction learning is further advanced by two recent developments. The first development is that, in contrast to the strong location specificity first reported in the classical studies of Ball and Sekuler (1982, 1987), more significant learning transfer to untrained quadrant/hemisphere locations is observed (Wang, Zhang, Klein, Levi, & Yu, 2014; Zhang & Li, 2010). When gauged with a transfer index (TI) as the ratio of transfer/learning, TI is about 0.2 in Ball and Sekuler (1982, 1987), but it is significantly higher at 0.65 in Zhang and Li (2010) and 0.77 in Wang et al. (2014). This learning transfer, especially across brain hemispheres, is consistent with the neurophysiological data that motion direction learning may primarily occur in high-level non-sensory brain areas. A second development is that the direction specificity in motion direction learning, first reported by Ball and Sekuler (1982, 1987), can be minimized with a new training-plus-exposure (TPE) experimental design (Zhang & Yang, 2014). Specifically, motion direction learning transfers significantly to an opposite direction if the observers

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are additionally exposed to the untrained opposite direction through an irrelevant dot-number discrimination task (Zhang & Yang, 2014). These observations of learning transfer to untrained quadrants or hemisphere and directions suggest that motion direction learning is not just a reweighting process in which the brain learns to better read out the direction inputs from specific neurons activated by the trained stimuli. Rather motion direction learning is a smarter process in which the brain learns the rules of reweighting, so that these rules can be applied to new direction signals from untrained locations and directions to improve motion direction discrimination.

We conducted the current study to address two issues arising from the above developments. First, we wanted to find out why motion direction learning is less location specific in recent studies as compared to Ball and Sekuler's classical work. Second, the TPE-enabled transfer of motion direction learning to untrained directions is challenged in two papers by Zili Liu and collaborators (Liang, Zhou, Fahle, and Liu (2015a, 2015b)). In this study we mainly address one paper (Liang et al., 2015a) and lightly touch the other one (Liang et al., 2015b) that we will fully address in a separate article. Liang et al. (2015a) reported no significant learning transfer with TPE training, in which the observers first practiced motion direction discrimination for 23 days, and then they were exposed to an orthogonal direction via practicing a contrast discrimination task at the orthogonal direction for another 23 days. Although Liang et al. (2015a) concluded that long-term multiple-week training may fail the TPE effects, our experiments actually replicated their data with short-term 5-day TPE training (see Section 3). However, we noticed that both Ball and Sekuler (1982, 1987) and Liang et al. (2015a) used a special format of the method of constant stimuli in their training. Specifically, only one level of direction difference, which was defined by a pair of fixed motion stimuli, was used to train the observers, and the amount of learning and transfer was indexed by the  $d'$  changes (from now on we call this the single-interval MCS method). In contrast, the recent studies (Wang et al., 2014; Zhang & Li, 2010; Zhang & Yang, 2014) used staircase methods to train the observers.

The single-level MCS method and the staircase method differ in an important way that could potentially alter the transfer effects. The single-level MCS method presents the stimuli at a single direction difference that is defined by a pair of fixed stimuli. However, the staircase method is a self-adaptive procedure in which the direction difference keeps changing, and so do the stimuli defining the direction differences. We suspect that when the single-level MCS method is used, the observers may learn to use some subtle local cues that are specific to the fixed stimuli to help the motion direction judgments. Mollon and Danilova (1996) interpreted these local cues as "the local idiosyncracies of his retinal image, of his receptor mosaic". One potential local cue may be related to the observers' less uncertainty with the fixed stimuli than with the ever-changing stimuli. The brain thus can learn to pay more precise attention to the fixed stimuli. However, such precise attention is disturbed when the stimuli are switched to a new location or direction, which causes learning to be specific to the trained condition to some degree. Another potential local cue may be related to the brain's stronger adaptation to the fixed stimuli than to ever-changing ones. There is evidence that adaptation may be at least partially responsible for the learning specificity (Harris, Glikberg, & Sagi, 2012). The adaptation status is changed when the stimuli are switched to a new location or direction, which can also produce location and/or direction specificity. In addition, some irrelevant cues from experimental settings, such as the monitor edge, can also be picked up by the observers. Again the same cues may not be available or useful at a new stimulus location or direction. In contrast, all these local cues are much less a concern in staircase training because they are disturbed by the changing stimuli.

Therefore, we hypothesize that local-cue learning may be at least partly responsible for the discrepancies in the transfer effects of motion direction learning. Specifically, for location specificity, learning of some local cues with the single-level MCS method may not be transferrable to a new retinal location, which may have led to stronger location specificity in Ball and Sekuler (1982, 1987). Meanwhile for direction specificity, single-level MCS training may also lead to learning of local cues that are not transferrable to an untrained direction even with a TPE method. However, with staircase training observers may have to learn the real motion direction task, and this learning, as we suggested earlier, is transferrable to untrained directions with TPE training.

A simple way to test our hypothesis is to disturb the local cues during single-level MCS training even if we do not know exactly what these local cues are. To do so, in the current study we jittered slightly the directions of the stimulus pair that define the direction difference by the same amount while keeping the direction difference unchanged in single-level MCS training. This measure allowed the stimulus directions to vary trial by trial, as in staircase training, to disturb the local cues that the observers could normally use in single-level MCS training. Our results did show that the direction jitter enabled significantly more transfer of motion direction learning to untrained quadrants or hemisphere, and to untrained directions with TPE training. These results thus help explain the discrepancies among various studies regarding location and direction specificity and transfer in motion direction learning.

## 2. Methods

### 2.1. Observers and apparatus

Forty-three observers in their early 20s participated in this study. All had normal or corrected-to-normal vision, and were new to visual psychophysical experiments and naive to the research purpose. Informed consent was obtained from each of them before data collection. The study has been carried out in accordance with the Declaration of Helsinki for experiments involving humans.

The stimuli were generated with a Psychtoolbox-3 (Pelli, 1997) and were presented on a 21-inch Sony G520 color monitor. The monitor specifications were 1024 pixel  $\times$  768 pixel resolution, 0.39 mm  $\times$  0.39 mm pixel size, 120 Hz frame rate, and 58.2 cd/m<sup>2</sup> mean luminance for presenting peripheral motion stimuli; and 1600 pixel  $\times$  1200 pixel resolution, 0.24 mm  $\times$  0.24 mm pixel size, 100 Hz frame rate, and 42.2 cd/m<sup>2</sup> mean luminance for presenting foveal motion stimuli. The luminance of the monitor was linearized by an 8-bit looking-up table. A chin-and-head rest was used to stabilize the head of the observer. Experiments were run in a dimly lit room. An Eyelink 1000 (SR Research, Kanata, Ontario, Canada) was used to monitor eye movements in half the observers in peripheral learning tasks. Trials were excluded from data analysis if eye positions deviated from the fixation point more than 2° before the stimulus onset.

### 2.2. Stimuli

The peripheral motion stimuli were identical to those used in a previous study (Wang et al., 2014). Each stimulus consisted of 25 black random dots (4  $\times$  4 pixels each), which was regenerated for every presentation. The stimulus appeared in an invisible (mean luminance) 2°-diameter circular window that was centered in a visual quadrant at 5° retinal eccentricity (Fig. 1a). When a dot reached its lifetime (250 ms) or traveled out of the stimulus window, a new dot emerged from the other side of the window at a random position. All dots moved in the same direction at a speed of 7°/s.

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