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Limited transfer of visual skill in orientation discrimination to locations treated by pre-testing and subliminal exposure

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ABSTRACT

Substantial transfer of perceptual skill learning can be achieved across large distances in the visual field by a brief pre-test, training-plus-exposure, or a double-training paradigm (Xiao et al., 2008; Zhang, Xiao, et al., 2010; Zhang, Zhang, et al., 2010). Additionally, subliminal exposure has been shown to be beneficial for subsequent perceptual learning. Here, we tested the generalization of orientation discrimination learning from a fully trained location towards four other test locations, either in the same or opposite hemifield as the training location, which each were subjected to a different type of pre-conditioning. In one test location, there was brief pre-testing in the first session. Two other locations were stimulated by masked stimuli similar or identical to concurrently presented stimuli in the training location. In the fourth test location, no stimuli were presented during training. Generalization of training to test locations was measured in the session immediately following the completion of training in the training location. Moreover, to test the robustness of transfer, training was continued in all four test locations. The experiment as a whole consisted of 15 sessions of orientation discrimination learning at the training location, followed by 15 sessions of training in the test locations. We found only limited generalization from the trained to the test locations. Performance in pre-tested and stimulated test locations showed a small advantage compared to the unstimulated test location. However, this advantage disappeared within a few sessions of further training in the test locations.

1. Introduction

Perceptual learning is defined as the acquisition of a perceptual skill over time. This learning process is characterized by fast improvements during early training and subsequent learning that gradually slows down until reaching asymptotic performance levels (Karni, 1996; Karni & Bertini, 1997; Karni & Sagi, 1993; Karni et al., 1998). Once a skill is learned, performance is retained for extended periods without further training (De Weerd, Pinaud, & Bertini, 2006). Especially during this asymptotic learning phase, learning has been reported to become specific to stimulus characteristics (Fahle, 1997; Karni & Bertini, 1997; Karni & Sagi, 1991; Schoups, Vogels, & Orban, 1995; Schwartz, Maquet, & Frith, 2002).

Recently, a series of experiments has cast doubt upon the idea that specificity is a defining characteristic of perceptual learning (Wang, Zhang, Klein, Levi, & Yu, 2012; Wang, Zhang, Klein, Levi, & Yu, 2014; Xiao et al., 2008; Zhang et al., 2010; Zhang, Xiao, Klein, Levi, & Yu, 2010). Xiao et al. (2008) showed that a double-training procedure consisting of feature and location training resulted in near-complete transfer of learning across far-removed retinal locations. Subsequently, a training-plus-exposure procedure was introduced (Zhang et al., 2010). Here, training was performed on a feature of interest in a training location. In the test location, initial training on the relevant feature was followed by a task on an irrelevant stimulus feature, while the stimulus feature of interest was simply exposed (assumedly unattended). Again, this experimental procedure resulted in substantial transfer.

Wang et al. (2012) extended these findings by showing that task relevance and task demand modulate the amount of transfer obtained in a double-training procedure using a Vernier task. They reported that passive exposure alone was insufficient to elicit transfer in a Vernier acuity task (Wang et al., 2012). More recent studies provide mixed results regarding the effect of passive exposure on location transfer. While Xiong, Zhang, and Yu (2016) reported that location transfer in a Vernier task requires either bottom-up stimulation or top-down transfer, Mastropasqua, Galliussi, Pascucci, and Turatto (2015) reported no transfer for passive stimulation with task-irrelevant stimuli. This latter finding might be seen as support for an effect of attention in generalization. In line with this, a brief pre-test, involving greater

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attentional allocation, led to substantial periphery-to-periphery transfer in an orientation discrimination task (Zhang et al., 2010). The data can also be seen as support for the idea that location specificity is strongly task-dependent. Some tasks such as orientation discrimination were demonstrated to work as actuators in double-training paradigms, enabling transfer of Vernier learning, whereas other tasks including contrast discrimination tasks failed to induce complete transfer (Wang et al., 2014).

A further modulator of transfer is the amount of training at threshold. Using the double-training procedure of Zhang, Wang, Klein, Levi, and Yu (2011), Hung and Seitz (2014) showed that increasing the number of trials at threshold for the Vernier task at the trained location (where there was also orientation discrimination training) eliminated transfer towards the test location. Despite the limited length of learning curves used in Hung and Seitz (2014) (7 sessions), they also demonstrated that increasing the number of trials at threshold increased specificity in orientation discrimination, even in the absence of a double training or a training-plus-exposure procedure. These findings are in line with older studies in which experience with 'difficult' discriminations or asymptotic learning is proposed as a precondition for specificity (Ahissar & Hochstein, 1997; Jeter, Dosher, Petrov, & Lu, 2009).

Although Wang et al. (2012) have shown that passive exposure alone was insufficient to elicit transfer in a Vernier acuity task, there is strong evidence that stimulus repetition leads to adaptation (for a review, see Grill-Spector, Henson, & Martin, 2006), which for some stimulus features has been associated with increased discrimination capabilities. For example, Regan and Beverley (1985) have shown a link between adaptation and improved orientation discrimination. Other studies also found enhanced discrimination of contrast, speed, and direction of motion following adaptation (Abbonizio, Langley, & Clifford, 2002; Clifford & Wenderoth, 1999; Phinney, Bowd, & Patterson, 1997).

Adaptation has also been linked to generalization of skill learning. It has been shown that by removing adaptation, complete generalization can be achieved in a texture discrimination task (Harris, Gliksberg, & Sagi, 2012). Moreover, repeated exposure to unattended stimuli can result in perceptual learning (Gutnisky, Hansen, Iliescu, & Dragoi, 2009; Watanabe, Náñez, & Sasaki, 2001). In addition, a study by Tsushima, Seitz, and Watanabe (2008) showed that the beneficial effect of exposure disappeared when the stimuli could be attended. They suggested that passively exposed stimuli of which the observer is aware during performance of another task may be suppressed by attention, so that an unconscious form of exposure might provide a more effective tool to test a potential contribution to learning (Seitz & Watanabe, 2003) and generalization.

In the light of the conflicting literature, we wished to test generalization in an orientation discrimination task designed to achieve strong perceptual learning. To that aim, we presented sufficiently clear examples of large orientation differences (Ahissar & Hochstein, 2004) especially at the beginning of learning (see Section 2). At the same time we maximized numbers of trials performed near threshold, by starting measurements from the second session onward not too far away from threshold, and by extensive asymptotic training (15-session learning curves) (Ahissar & Hochstein, 1997; Hung & Seitz, 2014; Jeter et al., 2009; Karni & Sagi, 1991). These conditions favoring perceptual learning were combined with testing conditions that have been shown to induce transfer. The first transfer condition consisted of a test location pre-tested with a single orientation discrimination training session (similar to Zhang et al., 2010). Second, we used two transfer conditions in which a test location was passively exposed to Gabor stimuli, which were ignored and masked with the aim of pre-conditioning these locations for subsequent generalization from the trained location. The idea of using exposure was inspired by Xiao et al. (2008), although our procedure was more similar to the approach of Watanabe et al. (2001). We used two slightly different passive exposure conditions to which transfer was tested: In one condition, participants were exposed to masked, unattended stimuli that were identical to those used in the actively trained task, such that visual feedback on correctness in that task in the trained location applied correctly to the unseen stimuli in the exposure location. In the other exposure condition, the unseen oriented stimuli were randomized in orientation (for details see Section 2) so that the feedback signal became irrelevant and any passive learning would only reflect the effects of exposure. We anticipated that these procedures might lead to significant transfer from a trained location to one or possibly both of the masked exposure test locations. Third, for all the different test locations, we wished to verify how robust the advantage would be after pre-testing or after masked exposure compared to a location where no stimuli had been shown. Whereas in all prior studies generalization testing was limited to a single session, in the present study additional prolonged training was performed in all test locations to verify the robustness of any advantages afforded by masked exposure and pretesting.

2. Methods

2.1. Participants

Eight participants (mean age 22.27 years, *sd* 1.41, 7 female), naïve to the purpose of the study participated in the experiment and the control condition. All participants had normal or corrected-to-normal visual acuity. Informed, written and verbal consent was obtained according to the Helsinki Declaration, after full information about all procedures and about the right to withdraw participation at any time. Participants agreed to the full length of the experiment, to be tested at least three times a week at approximately the same time of day, and to show up well-rested at each session. Prior to the first session, the task and required responses were explained to the participants with the help of instructions and illustrations on paper. All procedures were approved by the local Ethical Committee of the Faculty of Psychology and Neuroscience (ECP). For their participation in the study participants received either monetary reward or credits to fulfill course requirements.

2.2. Task, stimuli, and apparatus

Participants performed a forced-choice orientation discrimination task with two response options in which participants had to compare a single stimulus to an implicit oblique reference orientation. They indicated the direction of the orientation offset of a Gabor stimulus from the oblique reference by pressing either the left or right arrow key for counterclockwise and clockwise rotations respectively (Fig. 1A). Each trial started with a 950 ms window in which participants had the opportunity to initiate fixation. Without fixation, this waiting period was restarted. Successful initiation of fixation was followed by a 300 ms period in which steady fixation was required (within 1.5° from the fixation point) to trigger stimulus presentation. Stimulus presentation lasted 33 ms and was followed immediately in some conditions by a mask of 49 ms. Fixation errors during pre-stimulus period and stimulus presentation led to abortion of the trial. The response window started from the beginning of stimulus onset and was 1500 ms long. Upon response, feedback was provided by a color change of the fixation spot to either green or red, for correct and incorrect responses respectively. The color change remained visible for 250 ms after which the trial was terminated and the next trial started. The inter-trial-interval depended on the speediness of responses and on how quickly participants regained fixation.

The Gabor stimuli used (2.37 cycles/degree spatial frequency, 50% Michelson contrast, 3° diameter, 8° eccentricity, average luminance 56 cd/m^2) showed small clockwise or counterclockwise deviations from 135°. Note that we chose relatively high eccentricities to increase the separation in the visual field between the five locations used in our study. The fixation spot was a small white dot of 0.2° diameter. The mask was of the same size as the Gabor stimuli. It was equiluminant