Perceptual Learning Specificity to the Trained Context of Stimulus Display Durations in Difficult Visual Discriminations

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ABSTRACT

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Stimulus Display Durations in Difficult Visual Discriminations

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Compelling evidence stemming from past research suggests that a wide variety of visual search tasks can undergo perceptual learning. Such learning is typically characterized by a marked improvement in the speed and accuracy of target detection or identification by observers, as a result of repeated practice with the visual search task at hand. For difficult visual discriminations, the improvement in visual search performance associated with perceptual learning has been shown to be specific to the training context. Such contexts include, but are not limited to, the trained target stimuli and their trained retinal positions within the visual field.

The current compilation of psychophysical experiments aimed to investigate an aspect of perceptual learning specificity in difficult visual discriminations previously unreported in the relevant literature. These experiments assessed whether perceptual learning for difficult visual discriminations is specific to the trained context of stimulus display durations in which such discriminations are embedded.

With training, a significant improvement in performance for trials with a 50-millisecond stimulus display duration (difficult discriminations) resulted when such trials were embedded within sessions containing a variety of longer stimulus display durations (easier discriminations). However, this improvement was lost when difficult trials were no longer embedded within the context of easier trials. These findings may supplement our current knowledge regarding the perceptual plasticity of the visual system.

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I would like to thank my supervisor, Dr. Michael von Grünau, for his guidance and support throughout the course of this research project. I sincerely appreciated his flexibility in allowing me to explore my own ideas and to exercise my own judgment in the design and execution of my experiments. I would also like to thank Dr. Rick Gurnsey for his valuable feedback in regards to my statistical analyses and Dr. Norman Segalowitz for his comments and suggestions. Last, but not least, I would like to express gratitude to my participants, who endured the somewhat lengthy and demanding experimental procedure.

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Introduction

The visual search task

Vision scientists have utilized visual search paradigms extensively in order to investigate perceptual processes within the visual system (e.g., Green and Anderson, 1956; Neisser, 1964, Woodman and Chun, 2006). During a typical visual search task, participants are asked to detect or identify predefined target stimuli among distractor stimuli within a given visual scene. They are asked to do so by pressing pre-assigned keys on a computer keyboard.

Visual search tasks have been shown to differ from one another in terms of numerous fundamental characteristics. These characteristics determine the ease with which the target stimulus can be discriminated from the distractor stimuli. Such characteristics include parameters such as the relative difference in orientation, colour, contrast, shape, and spatial distribution between target and distractors (e.g. Duncan & Humphreys, 1989) as well as the stimulus onset asynchrony (SOA) between the stimulus display and a subsequent mask (e.g. Ahissar, 2000).

For instance, it is deemed easier to perceive a vertical line target among horizontal line distractors than to perceive this same vertical line target among distractor lines only slightly deviating from a vertical orientation. It is also easier to perceive a target stimulus within a stimulus display when that stimulus display is presented for a longer period of time (long SOA between the onset of the stimulus display and the onset of the mask) than when that stimulus display is presented for a short period of time (short SOA between the onset of stimulus display and the onset of the mask).

Perceptual plasticity

In our lifetime, our sensory receptors are incessantly activated by environmental stimuli. Such activation within the visual system may instigate conscious perception, resulting from a catalyst of neural processing. This processing, however, affects more than immediate perception alone. It also shapes subsequent perception by modifying our representation mechanisms (e.g. Ahissar and Hochstein, 2004).

Childhood is typically conceptualized as the period of neuronal plasticity. Nonetheless, evidence accumulated during the past several decades, shows that a large degree of perceptual plasticity is retained in adulthood (e.g., Buonomano and Merzenich, 1998). Consequently, visual experiences continuously modify our perception of the world. Long-term manifestations of such plasticity include phenomena such as adaptation, priming and perceptual learning.

Adaptation. Perceptual adaptation is a basic mechanism characteristic of all biological systems and is induced by exposure to stimuli. It essentially consists of a bottom-up process in which internal representations are modified in response to given external stimuli (Barlow, 1990; Dodwell and Humphrey, 1990). Responses to those unvarying stimuli are reduced through repeated exposure. This induces increased sensitivity to changes, or novelty detection. Since perceptual training involves exposure to stimuli, it also may involve adaptation. However, it is very difficult to explicitly discern the relative contribution of adaptation processes in perceptual learning (Ahissar and Ahissar, 1994; Kapadia et al., 1994). Nonetheless, when studying perceptual learning, the involvement of adaptation processes must be acknowledged.

Priming. Plasticity processes that dominate the first few exposures to a given visual scene are referred to as priming. When governed by top-down control, priming can induce strong and long-lasting changes to our perception of the visual scene. This suggests that priming may be the initial process of perceptual learning (Ahissar and Hochstein, 2004).

A dramatic example of this phenomenon is known as the Eureka Effect. According to this effect, an ambiguous visual object that is without initial obvious meaning can be disambiguated immediately following a single exposure to a clue as to its meaning. The effect is long lasting and does not require further practice. Another similar example is provided by a study conducted by Ahissar and Hochstein (1997). They found that a single long exposure to an easy 'pop-out' stimulus enabled learning of a very difficult detection task. This difficult task was almost never learned without the Eureka enabling experience.

Perceptual learning. The focus of the current study was on the phenomenon known as perceptual learning. Unlike adaptation and priming, perceptual learning is induced by task-specific practice. In 1955, Eleanor and James Gibson defined perceptual learning as "an increase in the ability of an organism to get information from its environment, as a result of practice with the array of information provided by the environment". Since then, a number of psychophysical studies have demonstrated that visual functions can undergo perceptual learning. Following intensive practice with a limited set of stimuli, the neuronal representations of these stimuli are gradually modified (e.g., Recanzone, Merzenich, Jenkins, Grajski and Dinse, 1992). But the nature of the changes that are induced by practice and the degree of modifiability of different sensory sites are still not well understood.

Perceptual learning and task difficulty

Practice on visual search tasks leads to an improvement in performing them. This improvement, however, can either be specific or general (Ahissar and Hochstein, 2000). The degree of specificity in perceptual learning varies according to the difficulty of the visual search task. For easy visual discriminations, generalized improvements in performance result. Thus, perceptual learning in such tasks is not specific to the trained target orientations and retinal positions. For difficult visual discriminations, specific improvements in performance result. Thus, perceptual learning in such tasks is specific to the trained target orientations and retinal positions.

A learning cascade has also been proposed (Ahissar and Hochstein, 1997). According to the notion of a learning cascade, improvement in performance on visual discrimination search tasks proceeds from easy to difficult conditions (e.g., long to short processing times). According to the Reverse Hierarchy Theory of perceptual learning (Ahissar and Hochstein, 1994), this cascade proceeds counter-current along the cortical hierarchy. It proceeds form higher (more generalizing) to lower (more discriminating) visual areas, as needed. Improvement can reportedly occur with only difficult conditions as long as there is a prolonged presentation to initiate learning (Eureka Effect).

A study by Ahissar and Hochstein (2000) provides an ideal example of the interaction between visual search task difficulty and perceptual learning specificity. Their study comprised a training phase and a testing phase. In the training phase, different groups of participants learned to anticipate the appearance of a target stimulus in either two horizontal, two vertical, 20 central (experimental conditions) or all possible (control condition) locations within a stimulus array. In the testing phase, the target stimulus was equally likely to appear in all possible locations in the visual field for all participants. By investigating stimulus location distribution, the researchers discovered that practice leads to a substantial overall improvement in target detection performance (i.e., speed and accuracy) over successive trials.

Ahissar and Hochstein (2000) also found that the available processing time, the individual skill of each participant, and the orientation gradient (i.e., the relative difference in orientation between target and distractors), were all difficulty factors that modulated the specificity of perceptual learning. Results from the testing phase in the easy visual search tasks indicated that learning spread to all display locations (i.e., not specific to trained locations). Results from the testing phase in the difficult visual search tasks indicated that learning was confined to the target locations. More specifically, an easy visual search task, characterized by a long stimulus onset asynchrony (SOA), high subject skill and large orientation gradient, was shown to lead to generalized learning. In other words, improvements in processing speed and accuracy during the training phase for this group of participants generalized to the testing phase, regardless of which training condition they were submitted to. Whether or not the target in the testing phase appeared within previously trained locations was not a factor for these participants. In contrast, a difficult visual search task, characterized by a short SOA, low subject skill and small orientation gradient, was shown to result in specific learning during testing for participants trained in the experimental condition. In other words, improvements in processing speed and accuracy during the training phase for this group was restricted to trained target locations. The researchers concluded that when visual search task difficulty increases, learning becomes more localized.

In a modified version of the above-mentioned visual search paradigm (Vavassis & von Grünau, 2005), similar results were found. This paradigm encompassed 4 simultaneously task-relevant regions in the visual field and 2 independent target stimuli, each associated with either 2 regions (experimental condition) or all 4 regions (control condition) of the visual scene during training. The training phase was followed by an assessment phase in which all participants were submitted to the control condition. This paradigm rendered participants unable to predict neither which target nor which location would be task-relevant on any given trial, thus allowing any apparent learning specificity to be attributed to active target-location pairing.

Psycho-anatomy logic and the site of plasticity

According to psycho-anatomy logic (Julesz, 1971), by studying the characteristics of behavioural phenomena, we are able to draw certain inferences as to their respective neural underpinnings. As far as the visual modality is concerned, we have very broad knowledge of basic representations within the cortex. This knowledge is primarily based on single unit receptive field and fMRI studies. For instance, in the primary visual cortex, single neurons are selective for orientation and retinal position with relatively narrow tuning curves in these domains (Hubel and Wiesel, 1959). However, both the spatial and orientation tuning curves are broader for neurons at higher visual areas along the visual hierarchy. This basic observation can be used to deduce the site of neuronal modifications from learning generalization.

For example, if participants were trained on a visual task in which the stimulus orientations and spatial locations were fixed, the effect of changing the position or orientation of the stimuli would depend on the level of cortical processing. Thus, if the majority of plasticity underlying behavioral improvement occurred at low-levels (where there is a non-overlapping population of neuronal receptive fields), improvement would not transfer to these new stimulus conditions and participant performance would deteriorate towards initial levels, requiring a process of re-learning. On the other hand, if learning resulted from high-level modifications (where there is more overlap between neuronal receptive fields), it would largely transfer to novel positions and orientations.

Present study

The present compilation of psychophysical experiments was generally designed in an attempt to assess perceptual learning specificity in difficult visual discrimination search tasks. More specifically, the goal of the experiments was do explore a previously unreported form of perceptual learning specificity in such tasks. Difficult target discrimination in all 3 experiments was established using two methods, based on the existing perceptual learning literature. The visual search task as a whole was designed with a small orientation gradient between the target and distractor stimuli, as well as with a large variability among distractor orientations. The difficult trials of interest were also characterized by a very brief stimulus display duration (50 milliseconds). Easier trials were characterized by longer stimulus display durations (100 to 500 milliseconds).

Experiment 1 assessed whether the acquired improvement in target identification accuracy following perceptual learning for trials with a 50-millisecond stimulus display duration (difficult discriminations) is specific to the context of stimulus display durations in which they are embedded during training. In order to address this research question, trials with a 50-millisecond stimulus display duration were embedded within sessions containing trials with stimulus display durations ranging from 100 to 500 milliseconds.

Trials with a 50-millisecond stimulus display duration were then presented without the context of longer trials. If perceptual learning was duration context specific, then it was hypothesized that performance would deteriorate in sessions consisting of trials with 50-millisecond stimulus displays alone. Experiments 2 and 3 were designed to disambiguate some questions that arose from the results in Experiment 1.

Experiment 1

Purpose

The general purpose of Experiment 1 was to investigate perceptual learning specificity in visual search tasks consisting of difficult visual discriminations. The experiment specifically assessed whether the acquired improvement in target identification accuracy following perceptual learning for trials with a 50-millisecond stimulus display duration (difficult discriminations) is specific to the context of stimulus display durations in which they are embedded during training.

In order to address this research question, trials with a 50-millisecond stimulus display duration were embedded within sessions containing trials with stimulus display durations ranging from 100 to 500 milliseconds. Trials with a 50-millisecond stimulus display duration were then presented without the context of longer trials. If perceptual learning was duration context specific, then it was hypothesized that performance would deteriorate in sessions consisting of trials with 50-millisecond stimulus displays alone.

In addition, target location specificity was assessed. This was done in order to confirm that the difficulty of the visual discrimination used in this experiment corresponded to the difficulty of visual discriminations used in past experiments, which have reported perceptual learning specificity. If perceptual learning was location context specific, then it was hypothesized that target identification accuracy would be superior in trials with trained target locations than in trials with novel target locations.

In line with existing findings in the perceptual learning literature, it was additionally hypothesized that performance for all stimulus display durations would improve with training. Moreover, it was hypothesized that that longer stimulus display durations would lead to higher accuracy for target identification than briefer stimulus display durations.

Method

Participant sample. Four Concordia University psychology students (3 females and 1 male between the ages of 19 and 27) participated in this experiment. All observers had normal (20/20) or corrected-to-normal vision, based on self-report. Participants were recruited from the Concordia Visual Perception Laboratory, and from the undergraduate and graduate psychology population at the university. The 2 lab members volunteered their time, whereas the 2 non-lab members received $35.00 compensation. All participants were naïve as to the experimental hypotheses. Prior to being subjected to the testing protocol, they were asked to sign an informed consent form describing the purpose of the study, the methodological proceedings that were to transpire and their rights and responsibilities as subjects in psychophysical research (see Appendix A1 for a copy of the informed consent form). All participants were formally debriefed as to the underlying rationale of the study following complete data collection (See Appendix B for a copy of the participant debriefing sheet).

Stimuli, apparatus and laboratory space. The visual stimuli consisted of black bars ($x = 0.316$, $y = 0.341$) of equal size (0.5 x 2.0 degrees of visual angle) and luminance ($Y = 0.91$ cd/m^2) oriented vertically, horizontally and diagonally. The stimuli were situated within a white circular region ($x = 0.317$; $y = 0.334$; $Y = 14.8$ cd/m^2) occupying a task-relevant area with a radius of 11 degrees of visual angle on a black background ($x = 0.316$, $y = 0.341$; $Y = 0.91$ cd/m2). All stimuli were approximately 1.5 degrees of visual angle apart. At the center of the task-relevant region, a vertical and horizontal red line (x

= 0.611, y = 0.355; Y = 8.68 cd/m^2; 0.2 x 22 degrees of visual angle) intersected, thus simultaneously serving as a fixation cross and creating placeholders that subdivided the task-relevant region into 4 equally-sized adjacent quadrants (see Figure 1).

During the presentation of the stimulus display on any given trial, the task-relevant region contained 28 stimuli (7 per quadrant). Of these stimuli, 27 were distractors and 1 was a target. Distractor stimuli consisted of 30°, 45°, 60°, 120°, 135° and 150° oriented bars (see Figure 2a). Each distractor was assigned a single randomly chosen position within the task-relevant region, which remained constant across all trials in the experiment. The target item was either a vertically (0°) or horizontally (90°) oriented bar (see Figure 2b). The target replaced one of the 28 distractors on each trial. Figure 3 depicts two sample stimulus displays in which a vertical target replaced one of the distractors. Figure 4 depicts two sample stimulus displays in which a horizontal target replaced one of the distractors.

The dynamic black-and-white mask used in this experiment occupied an area spatially identical to that of the task-relevant region. The mask had an average luminance of 8.05 cd/m^2 based on 10 randomly selected 1 degree samplings of visual angle. It had a temporal frequency of 1 Hz.

All stimuli were presented to participants with the use of VPixx software (April, 2003) running on a G4 Power Macintosh computer with a 17-inch Apple LCD colour monitor. The resolution of the screen was set at 1024 x 768 pixels, with a refresh rate of 99 Hz. The seating arrangement involved the use of a chin-rest, which kept the observer's head in a stable position during the series of self-initiated trials. Throughout the course of the experiment, the distance between the participant's eyes and the screen was

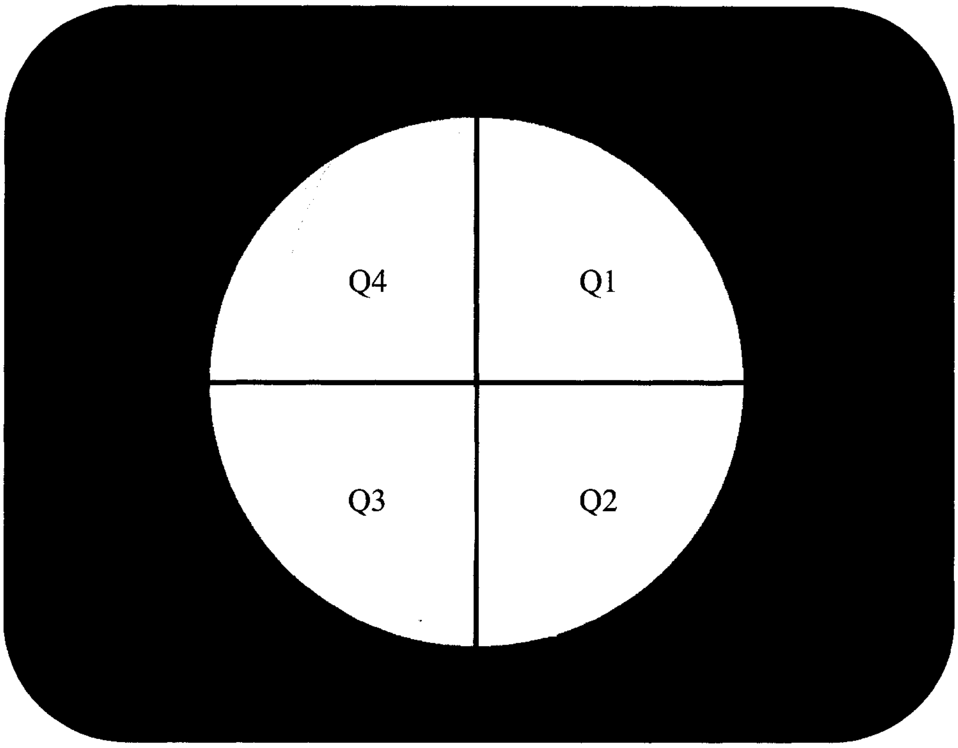

Figure 1. A representation of quadrant 1 (Q1), quadrant 2 (Q2), quadrant 3 (Q3) and quadrant 4 (Q4) within the task-relevant region used in Experiment 1, Experiment 2 and Experiment 3.

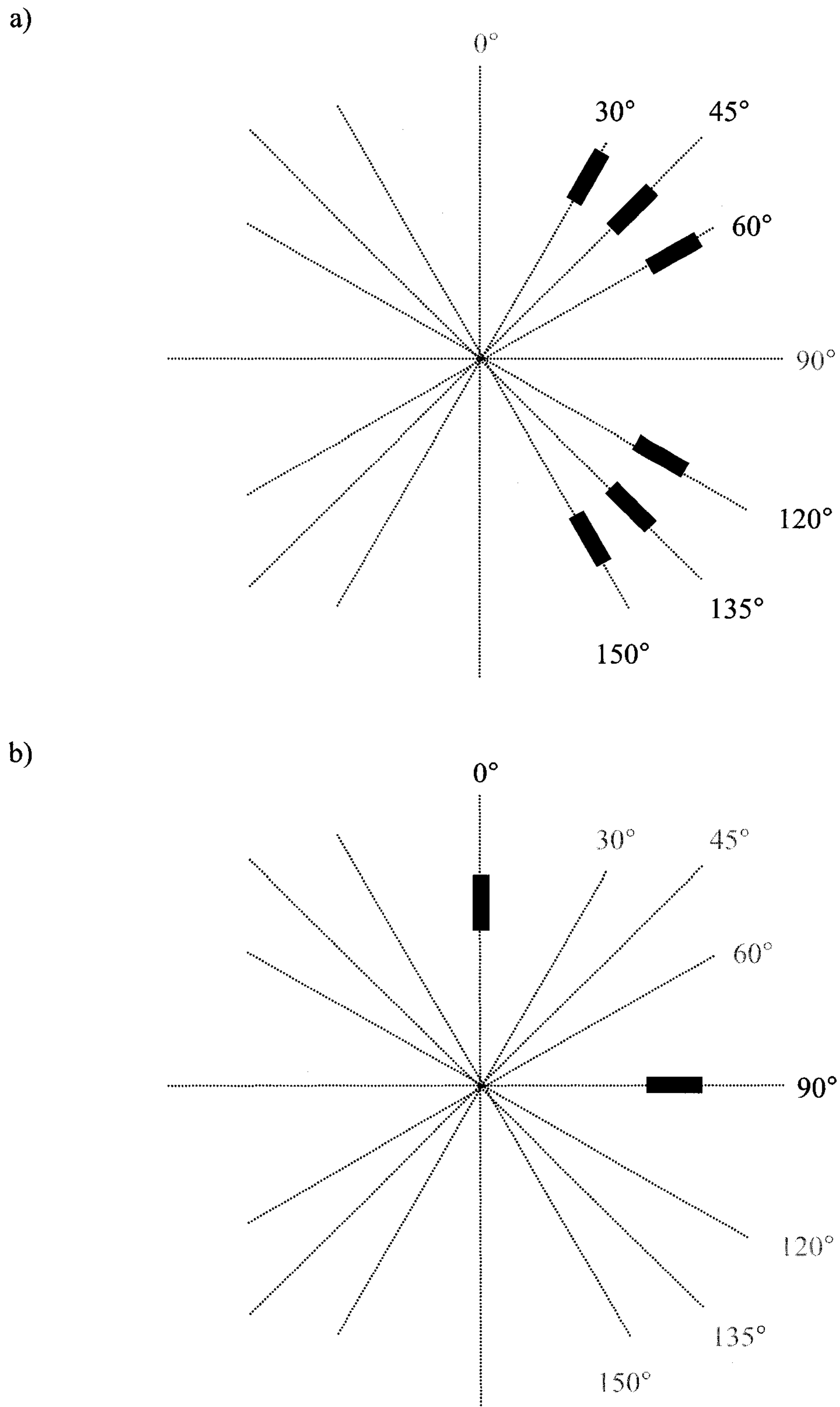

Figure 2. a) Distractor stimulus orientations and b) target stimulus orientations used in Experiment 1, Experiment 2 and Experiment 3.

a)

b)

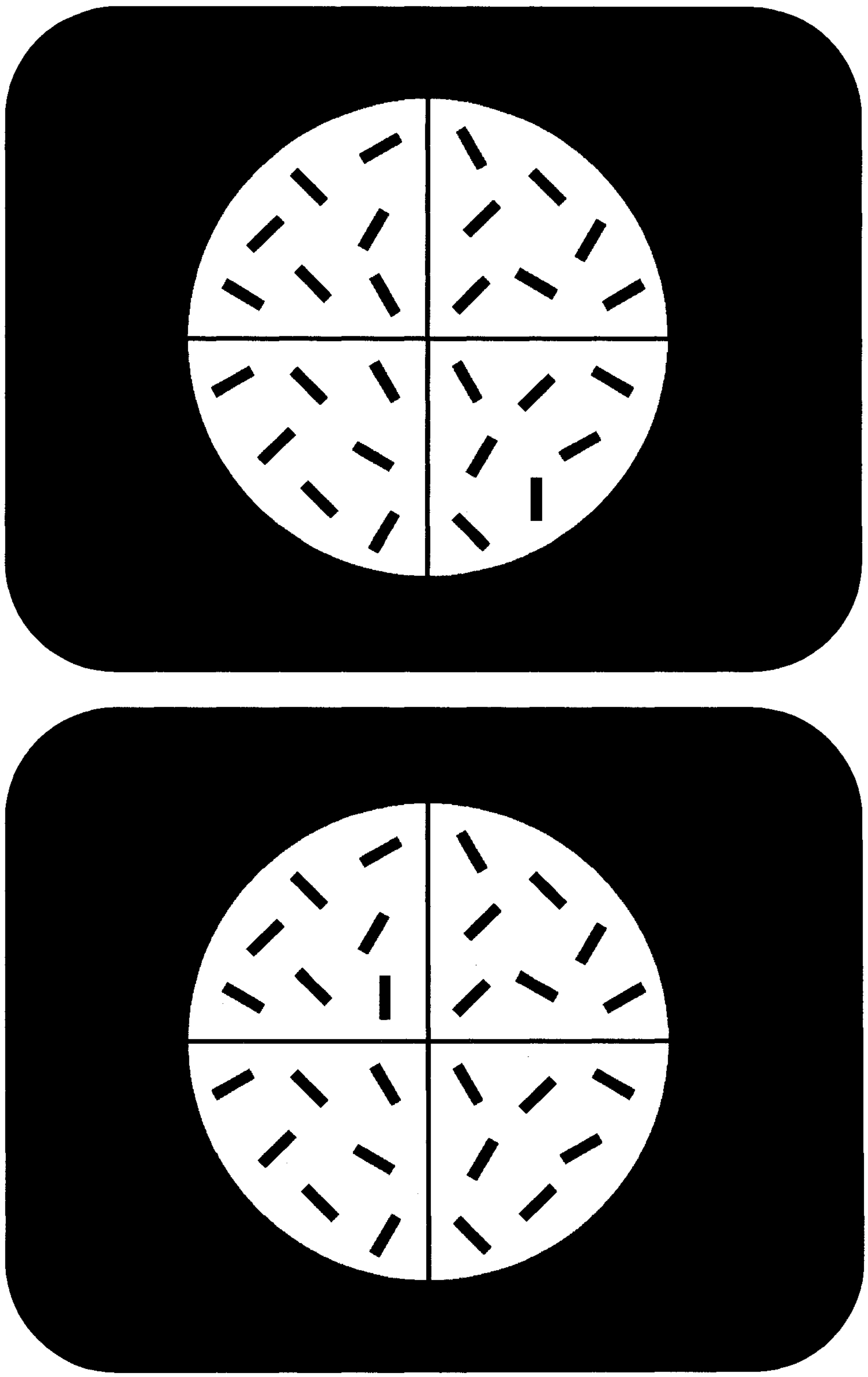

Figure 3. Sample stimulus displays used in Experiment 1, Experiment 2 and Experiment 3 with a vertical target replacing one of the distractors in a) quadrant 2 and b) quadrant 4.

a)

b)

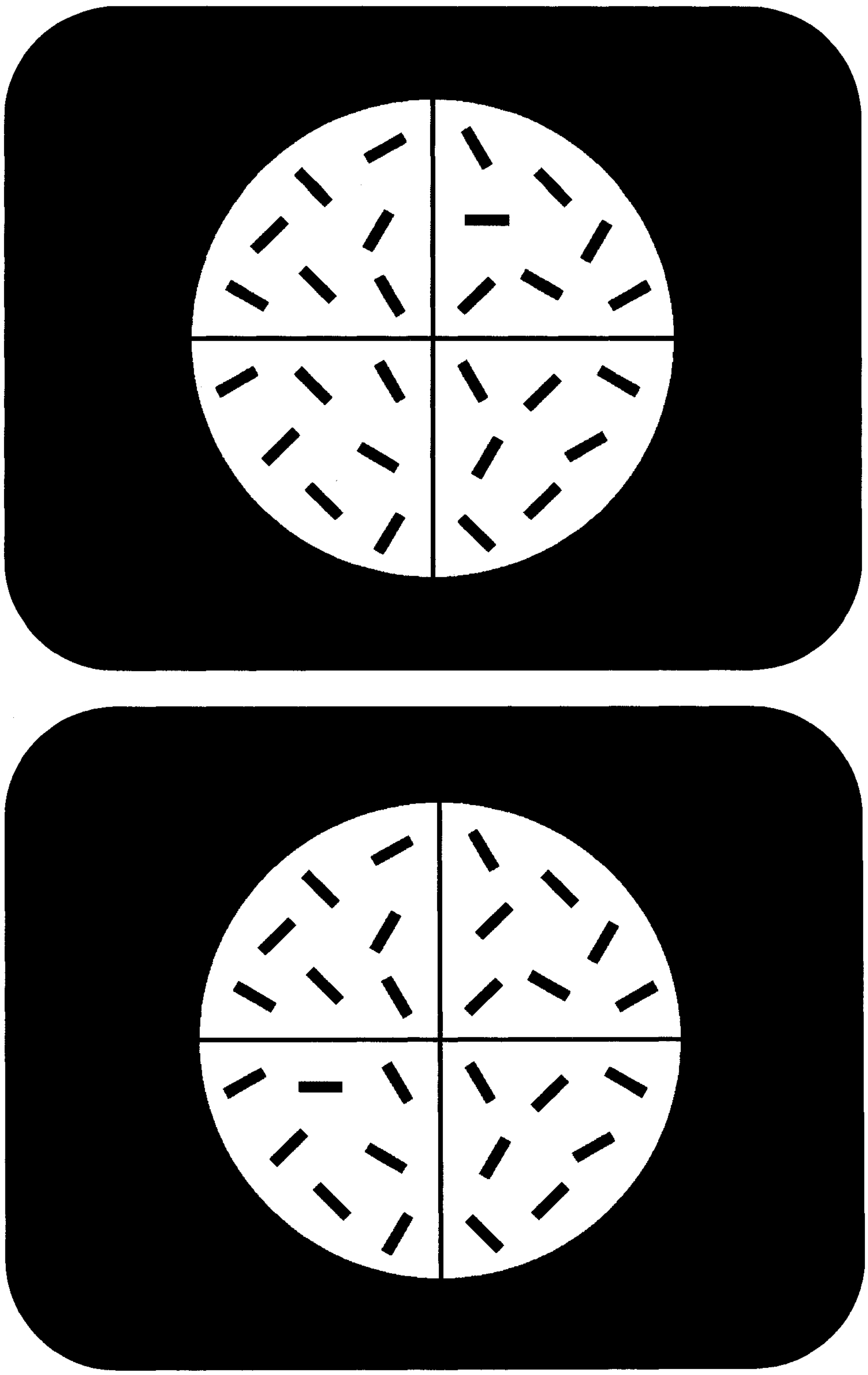

Figure 4. Sample stimulus displays used in Experiment 1, Experiment 2 and Experiment 3 with a horizontal target replacing one of the distractors in a) quadrant 1 and b) quadrant 3.

consequently maintained at 57 centimeters. The experiment took place in a dimly lit and quiet room.

Design and procedure. A 9 x 10 within-subjects factorial design was used in this investigation. The two independent variables were the session and the stimulus display duration. In total, the experiment encompassed 9 sessions and 10 stimulus display durations. The stimulus display durations ranged from 50 to 500 milliseconds. The dependent variable was the accuracy for target identification (% correct).

The study was divided into an uninterrupted series of three 280-trial sessions per day for a period of 3 consecutive days. Testing for each participant was scheduled to occur at approximately the same time of day on all 3 days. It is meaningful to note that the experiment was subdivided into a 3-day sequence partly in an attempt to avoid postural and optical fatigue, which may arise as a result of the mandatory fixation and seating arrangement. Furthermore, the experiment was subdivided in such a fashion to allow for the consolidation of perceptual training, which is reportedly facilitated by episodes of REM sleep (Karni & Sagi, 1993).

The experiment consisted of 2 successive phases. The first was operationally defined as the perceptual training phase. This phase was primarily designed in an attempt to train participants on a context of stimulus display durations. However, it was also designed to train participants on a context of target stimulus locations, thus attempting to replicate past research findings.

The perceptual training phase encompassed the 3 sessions on Day 1 of the experiment (session 1.1, session 1.2 and session 1.3) and the 3 sessions on Day 2 of the experiment (session 2.1, session 2.2 and session 2.3). On each trial within each training session, either the vertical target replaced one of the 7 distractors in quadrant 2 (50% of vertical target trials) or quadrant 4 (50% of vertical target trials), or the horizontal target replaced one of the 7 distractors in quadrant 1 (50% of horizontal target trials) or quadrant 3 (50% of horizontal target trials). Each session within the training phase incorporated a single fully randomized replication of each of the 14 vertical target locations and of each of the 14 horizontal target locations for the complete range of stimulus display durations (50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 milliseconds).

The perceptual training phase was followed by the perceptual learning specificity assessment phase. This phase encompassed the 3 sessions on Day 3 of the experiment (session 3.1, session 3.2 and session 3.3). In this phase of the experiment, only trials with 50-millisecond stimulus display durations (difficult visual discriminations) were presented. The perceptual learning specificity assessment phase was itself subdivided into 2 components (duration context specificity and location context specificity), differing in terms of possible target locations.

Component 1 of the perceptual learning specificity assessment phase was designed to assess the duration context specificity of 50-millisecond stimulus displays. The goal was to determine whether the acquired improvements in accuracy for target identification in such displays following training are specific to the context of stimulus display durations in which they were embedded during training (i.e. 50-millisecond stimulus displays presented in a context of stimulus displays ranging from 100 to 500 milliseconds). It was comprised of the first 2 sessions on Day 3 of the experiment (session 3.1 and session 3.2). Within these sessions, only the trained target locations were maintained (i.e. target locations were the same as in the perceptual training phase). Each session within this component of the perceptual learning specificity assessment phase consisted of 10 fully randomized replications for each of the target locations.

Component 2 of the perceptual learning specificity assessment phase was designed to assess the location context specificity of 50-millisecond stimulus displays. The goal was to determine whether acquired improvements in accuracy for target identification in such displays following training are specific to the context of trained target locations. It was comprised of the third session on Day 3 of the experiment (session 3.3). This session included both trained target locations (i.e. vertical target in quadrants 2 and 4 and horizontal target in quadrants 1 and 3) and novel target locations (i.e. vertical target in quadrants 1 and 3 and horizontal target in quadrants 2 and 4). On each trial within the session, either the vertical target replaced one of the 7 distractors in quadrant 1 (25% of vertical target trials), quadrant 2 (25% of vertical target trials), quadrant 3 (25% of vertical target trials) or quadrant 4 (25% of vertical target trials), or the horizontal target replaced one of the 7 distractors in quadrant 1 (25% of horizontal target trials), quadrant 2 (25% of horizontal target trials), quadrant 3 (25% of horizontal target trials), or quadrant 4 (25% of horizontal target trials). The session within this component of the perceptual learning specificity assessment phase consisted of 5 fully randomized replications for each of the 28 vertical target locations and 28 horizontal target locations.

All participants were tested individually. In order to initiate each trial within each session, the participant pressed the key labeled "START TRIAL" key (space bar) on the computer keyboard. All trials were divided into 4 successive components, as illustrated by Figure 5. At the onset of a typical trial, the participant was presented with a dynamic

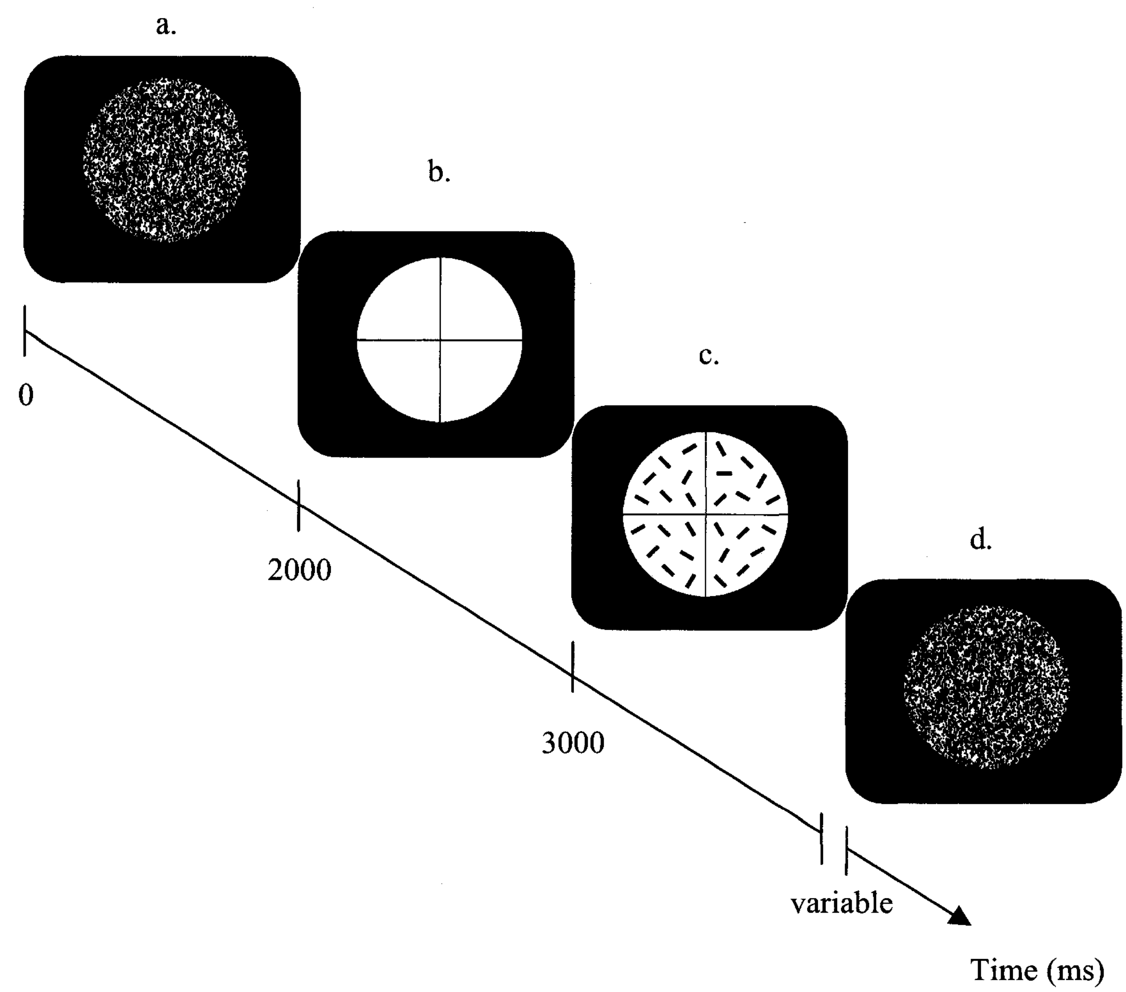

Figure 5. The 4-stage trial sequence used in Experiment 1, Experiment 2 and Experiment 3: a) 2000 ms dynamic mask; b) 1000 ms fixation cross; c) stimulus display of variable duration (50, 100, 150, 200, 250, 300, 350, 400, 450 or 500 milliseconds); d) dynamic mask.

mask, 2000 milliseconds in duration. The mask was succeeded by a 1000 millisecond fixation point, which then remained on the screen during the subsequent component of the trial, during which the stimulus display of variable duration appeared. Although observers were asked to keep fixation, both prior to and during the presentation of the stimulus display, eye movements were not recorded.

During the presentation of the stimulus display, the participant's task was to determine the identity of the target stimulus (vertical bar or horizontal bar) found therein, and to report that identity with the greatest accuracy possible using the designated keys on the computer keyboard. The participant's response was recorded during the final component of the trial, namely, during the presentation of the second dynamic mask. Seeing as distractor positions did not vary from trial to trial, the masks were used in order to minimize after images, which may inadvertently aid in the identification of the target.

If the vertical target was judged to be present, the participant was required to press the key labeled "V" (left arrow key). If the horizontal target was judged to be present, the participant was required to press the key labeled "H" (right arrow key). The participant was asked to guess when unsure as to the identity of the target. If a response had not been made after a 10-second delay had elapsed, the trial was scheduled to terminate. However, although participants were not informed of this methodological constraint, post hoc observations of the data revealed that none exceeded the imposed time limit.

At the end of the experiment, each participant answered a series of questions on a paper paper-based feedback questionnaire (see Appendix C1 for a copy of the feedback questionnaire). The questionnaire was designed as a tool to assess the subjective experience of participants during the course of the experiment. This information was meant to supplement the formal data collected during computerized testing. The questionnaire was in part structured (participants were required to give specific answers to specific questions) and in part open (participants could elaborate on their specific answers and/or make additional comments).

Results

Statistical analyses. For each participant, VPixx recorded the responses and saved the raw data in a Microsoft Excel (v11.3.5) worksheet. Within Excel, the averaged accuracy (% correct) data for every participant was individually tabulated for each possible combination of session and stimulus display duration permissible by the given experimental design, resulting in 63 averaged values. The averaged data was subsequently analyzed using SPSS (v11.0.4).

Within SPSS, 3 within-subjects analyses of variance (ANOVAs) were conducted. The first ANOVA assessed overall perceptual learning in the perceptual training phase, averaged over the full range of stimulus display durations. The second ANOVA assessed duration specific perceptual learning for 50-millisecond stimulus displays during the perceptual training phase and the duration and location specificity components of the perceptual learning specificity assessment phase. The third ANOVA assessed location specific perceptual learning for trained versus novel target locations during the location specificity component of the perceptual learning specificity assessment phase. All statistical tests were conducted using an alpha level of .05 (See Appendix D for complete proofs).

Overall perceptual learning. The interaction between session and stimulus display duration was not significant, $F(45, 135) = 1.580, p = 0.240, \eta^2 = 0.345$. A significant main effect of session was obtained, $F(5, 15) = 7.169, p = 0.001, \eta^2 = 0.705$ (see Figure 6). This effect demonstrated that a general improvement in accuracy for target identification throughout the perceptual training phase resulted. A significant main effect of stimulus display duration was also obtained, $F(9, 27) = 6.142, p < 0.001, \eta^2 = 0.672$ (see Figure 7). This effect demonstrated that the longer the available processing time, the higher the accuracy for target identification.

Duration context specific perceptual learning. For 50-millisecond stimulus display durations, a significant main effect of session was obtained, $F(8, 24) = 16.082, p < 0.001, \eta^2 = 0.843$ (see Figure 8). Bonferroni pairwise comparisons revealed that accuracy for target identification significantly improved between session 1.1 (M = 59.000, SE = 4.601) and session 2.3 (M = 89.500, SE = 3.524), $p = 0.026$. Therefore, accuracy was significantly higher on the last perceptual training session than on the first perceptual training session. Furthermore, the comparisons showed that accuracy deteriorated between session 2.3 (M = 89.500, SE = 3.524), and session 3.1 (M = 59.250, SE = 5.677), $p = 0.044$, session 3.2 (M = 60.250, SE = 5.391), $p = 0.022$ and session 3.3 (M = 57.750, SE = 3.816), $p = 0.002$. Therefore, accuracy was significantly higher on the last perceptual training session than on all perceptual learning specificity assessment sessions. Moreover, accuracy in session 1.1 (M = 59.000, SE = 4.601) did not differ from accuracy in session 3.1 (M = 59.250, SE = 5.677), session 3.2 (M = 60.250, SE = 5.391) and session 3.3 (M = 57.750, SE = 3.816), $p = 1.000$. Therefore, accuracy was

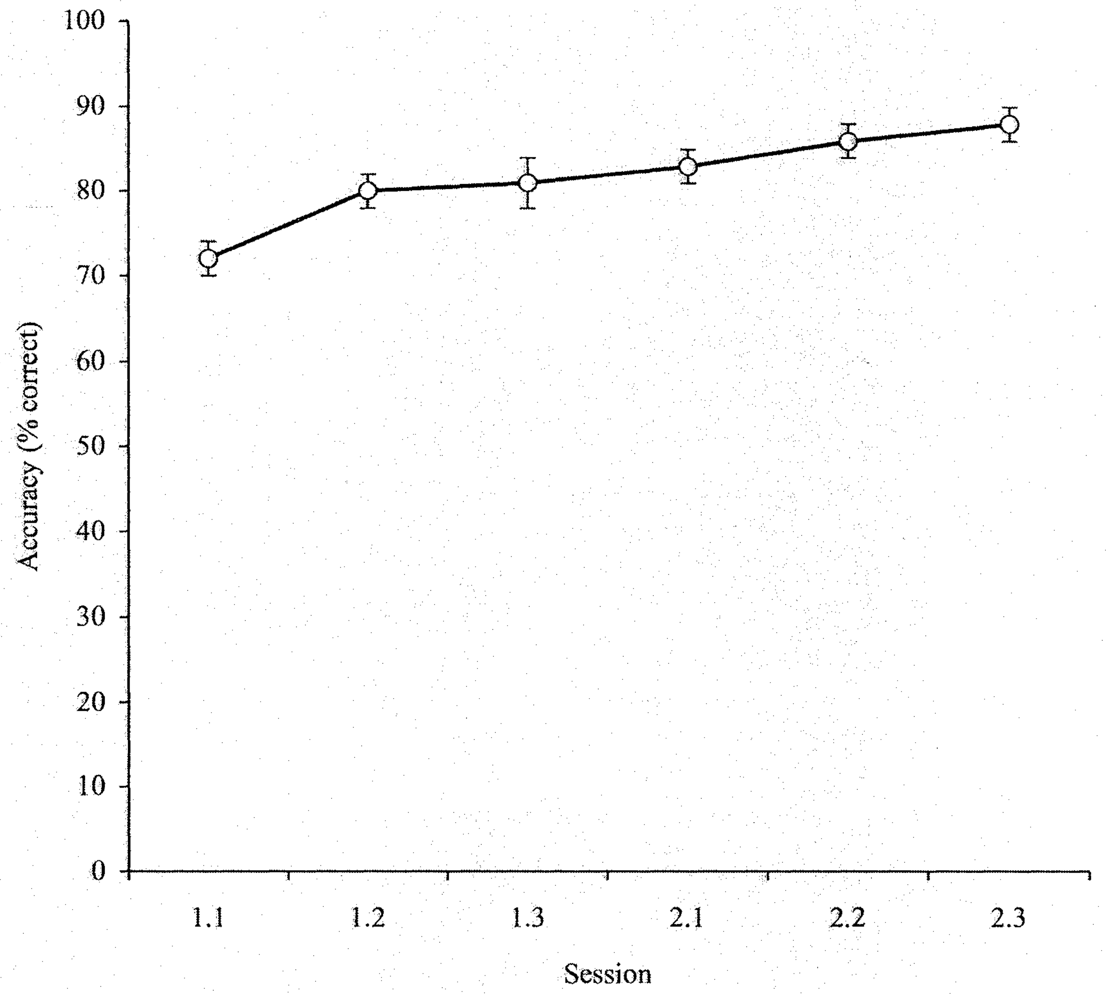

Figure 6. Target identification accuracy in the perceptual training phase in Experiment 1. The results are averaged over all stimulus display durations. The standard errors of the mean are represented by error bars.

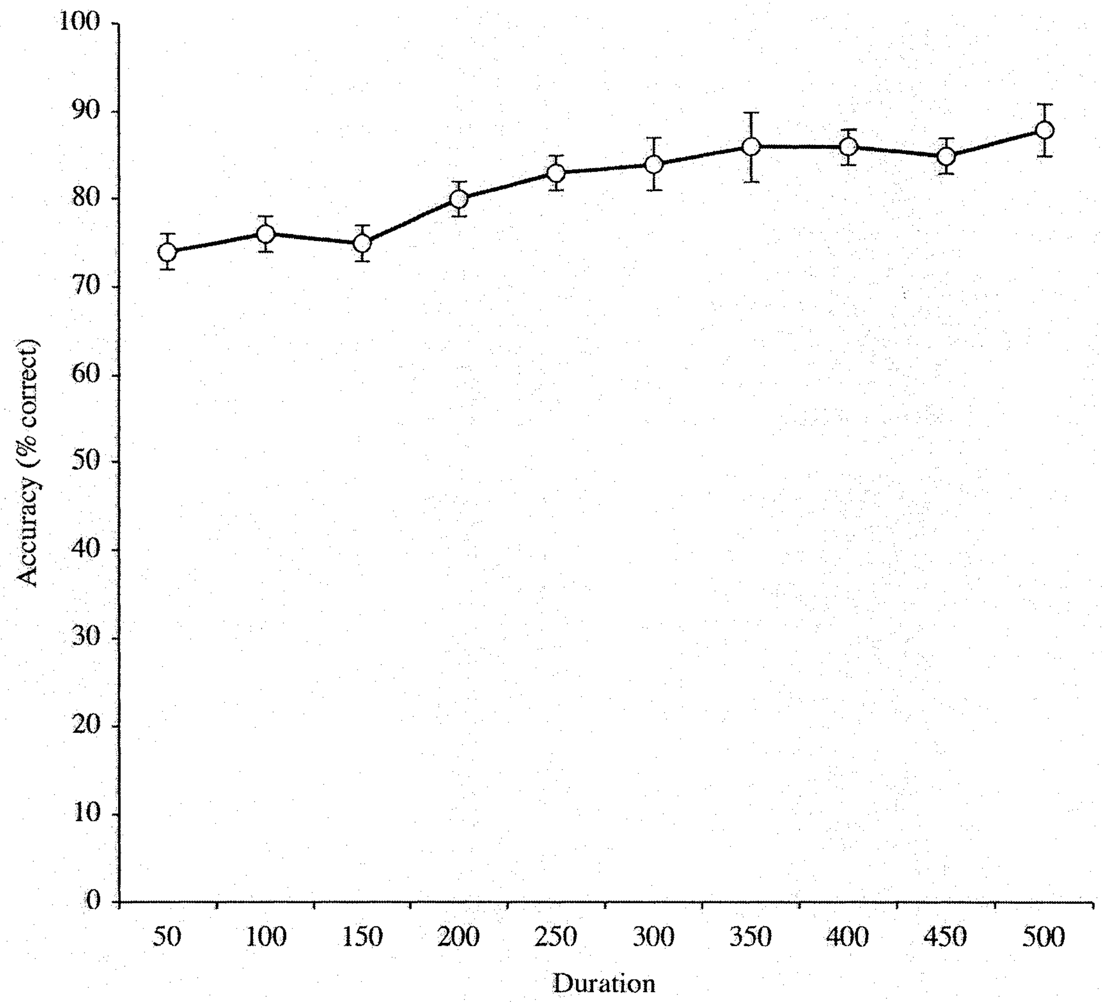

Figure 7. Target identification accuracy across all stimulus display durations in Experiment 1. The results are averaged over all sessions in the perceptual training phase. The standard errors of the mean are represented by error bars.

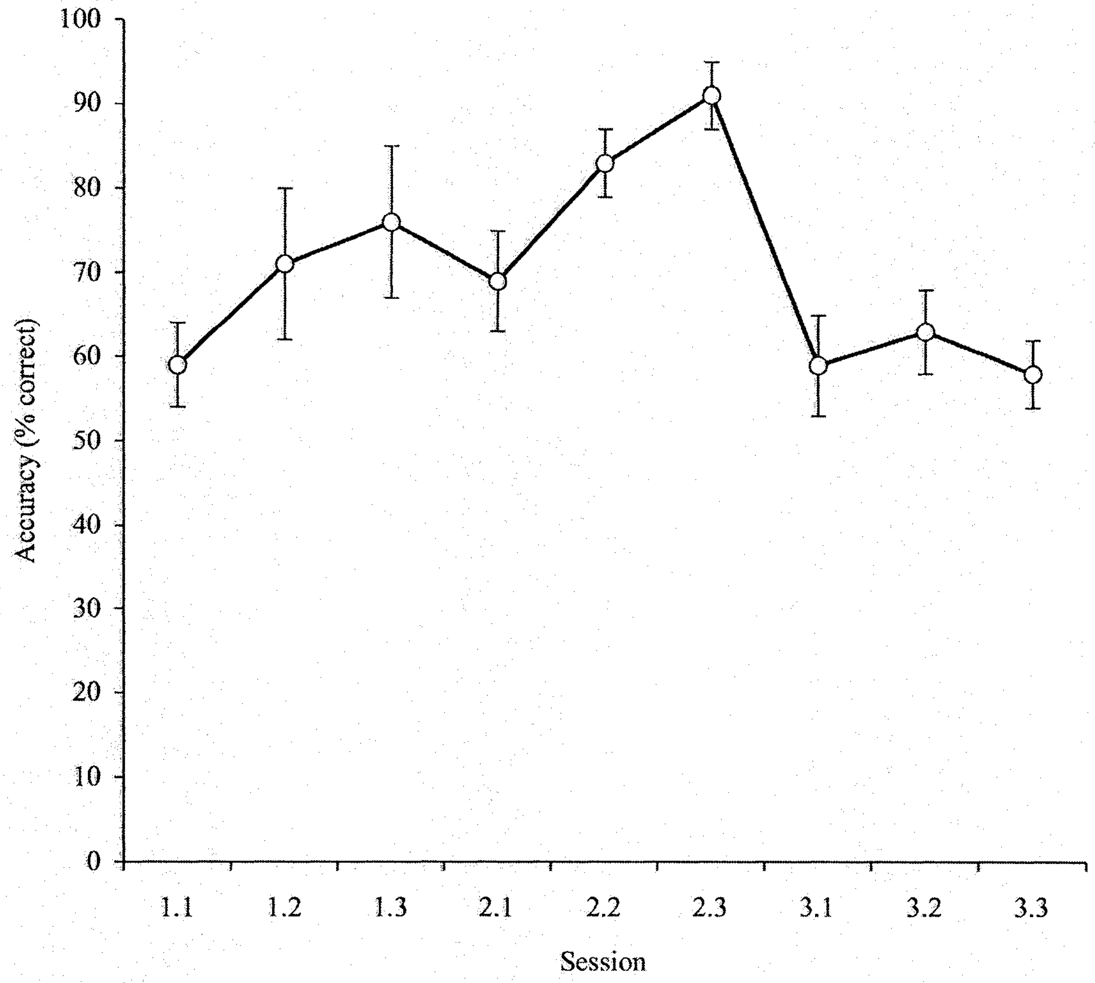

Figure 8. Target identification accuracy for 50-millisecond stimulus display durations in the perceptual training phase (sessions 1.1, 1.2, 1.3, 2.1, 2.2 and 2.3) and in the perceptual learning specificity assessment phase (sessions 3.1, 3.2 and 3.3) in Experiment 1. The standard errors of the mean are represented by error bars.

demonstrated not to differ between the first perceptual training session and all perceptual learning specificity assessment sessions.

Location context specific perceptual learning. For 50-millisecond stimulus displays, accuracy for target detection was higher for trained target locations than for novel target locations, $F(1,3) = 50.342, p = 0.006, \eta^2 = 0.944$ (see Figure 9). Therefore, evidence was found for location specific learning.

Self-report data. It is important to note that no formal analyses were performed on the self-report data. When participants were asked about the difficulty rating they would give to the experiment they had just performed, they all rated it as difficult or very difficult. In addition, all participants reported that the experiment became easier through practice. Moreover, participants reported that the task became slightly more challenging on the perceptual learning specificity assessment sessions. However, they failed to report any conscious awareness of the target locations throughout the experiment. In their additional comments, some participants reported that the stimulus display durations in the perceptual learning specificity assessment phase were briefer than any stimulus display duration they had been exposed to during the perceptual training phase. They also reported noticing having committed errors.

Discussion

This experiment was primarily designed to assess whether perceptual learning for difficult visual discriminations is specific to the trained context of stimulus display durations in which such discriminations are embedded. With training, a significant improvement in performance for trials with a 50-millisecond stimulus display duration (difficult visual discriminations) resulted when such trials were embedded within sessions

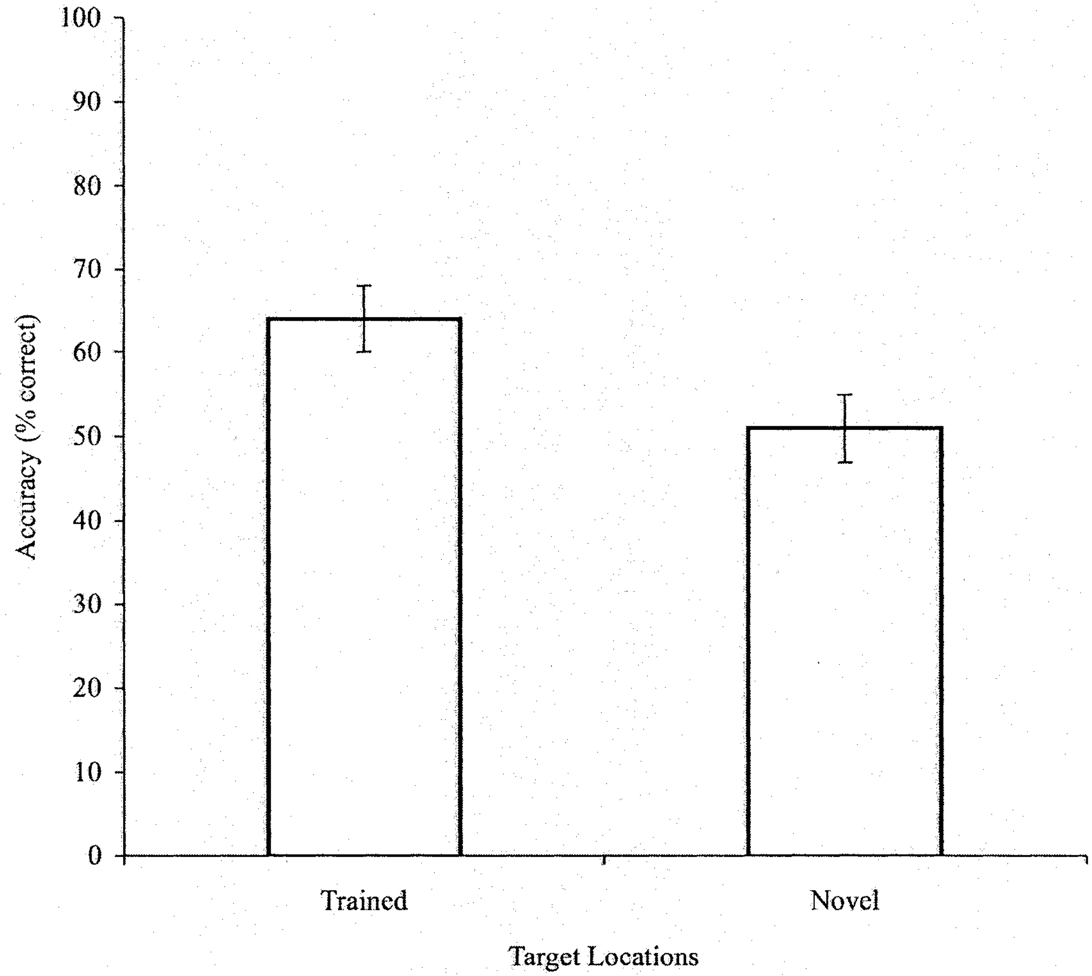

Figure 9. Target identification accuracy for trained and novel target locations for 50-millisecond stimulus displays in the location specificity component of the perceptual learning specificity assessment phase (session 3.3) in Experiment 1. The standard errors of the mean are represented by error bars.

containing a variety of longer stimulus display durations (easier discriminations). However, this improvement was lost when difficult trials were no longer embedded within the context of easier trials and, in fact, returned to pre-training accuracy.

This experiment was also designed to assess whether perceptual learning for the difficult visual discriminations chosen for this investigation is specific to the trained context of target stimulus locations. The findings indicate that location specific perceptual learning took place, thus confirming that the difficulty of the visual discrimination used in this experiment corresponds to the difficulty of visual discriminations used in past experiments, which have reported perceptual learning specificity.

Within the self-report data, participants' inability to correctly identify the vertical and horizontal target locations within each session and their post hoc awareness of errors committed suggests an element of implicit learning. Furthermore, their faulty perception that the 50-millisecond stimulus display durations in the perceptual learning specificity assessment phase were briefer than the 50-milliseccond stimulus display durations they had been exposed to during the perceptual training phase is a point of interest. It is an indication that subjective perception of difficulty may vary according to the context of stimulus display durations within a given time frame (in this case, each session was approximately 25 minutes long) and may consequently influence perception and action. Experiment 2 addresses this issue in greater depth.

Experiment 2

Purpose

Experiment 2 was designed with the goal to assess whether subjective perception of difficulty for 50-millisecond stimulus displays may vary according to the context of stimulus display durations within a given time frame and explain the dramatic decrease in target identification accuracy in the perceptual learning specificity assessment phase in Experiment 1.

In Experiment 1, all sessions were of equal length (280 trials). Therefore, during a given perceptual training session, in which 10 stimulus display durations were used, only 28 trials consisted of 50-millisecond stimulus display durations. However, during a given perceptual learning specificity assessment session, in which only 1 stimulus display duration was used, all 280 trials consisted of 50-millisecond stimulus display durations. Consequently, within a nearly identical and fairly lengthy time frame (each session was approximately 25 minutes long), there were 10 times more difficult visual discriminations in the perceptual learning specificity assessment sessions as compared to the perceptual training sessions.

In Experiment 2, the perceptual training phase was identical to the one used in Experiment 1. However, the perceptual learning specificity assessment phase consisted of an alternating sequence of three 2.5-minute long sessions containing 50-millisecond stimulus displays only and two 25-minute long sessions containing all stimulus display durations (the same as those used in the perceptual training phase). Thus, both the stimulus display duration context (50 versus 50, 100, 150, 200, 250, 300, 350, 400, 450, 500 millisecond stimulus displays) and the time frame (2.5 versus 25 minute sessions) varied between the 2 assessment-session-types in this experiment. However, both session types contained an equal number of trials with 50-millisecond stimulus displays (28).

If the performance drop in the perceptual learning specificity assessment phase in Experiment 1 was due to the fact that participants were unable to perform 50-millisecond visual discriminations outside of the context of easier visual discriminations and for a fairly lengthy period of time (25 minutes), then it was expected that performance in all sessions of the perceptual learning specificity assessment phase in Experiment 2 would not be subject to a similar drop. This prediction was made in Experiment 2 seeing as the long sessions (25 minutes) in that phase would retain their trained stimulus display duration context and the sessions containing 50-millisecond stimulus displays only would be very brief (2.5 minutes).

Method

Participant sample. Four Concordia University psychology students (2 females and 2 males between the ages of 20 and 25) participated in this experiment. All observers had normal (20/20) or corrected-to-normal vision, based on self-report. Participants were recruited from the Concordia Visual Perception Laboratory, and from the undergraduate and graduate psychology population at the university. The 3 lab members volunteered their time, whereas the 1 non-lab member received $35.00 compensation. All participants were naïve as to the experimental hypotheses and had not participated in Experiments 1 and 2. Prior to being subjected to the testing protocol, they were asked to sign an informed consent form describing the purpose of the study, the methodological proceedings that were to transpire and their rights and responsibilities as participants (see Appendix A2 for a copy of the informed consent form). All participants were formally debriefed as to the underlying rationale of the study following complete data collection (See Appendix B for a copy of the participant debriefing sheet).

Stimuli, apparatus and laboratory space. The same as in Experiment 1.

Design and procedure. A 11 x 10 within-subjects factorial design was used in this investigation. The two independent variables were the session and the stimulus display duration. In total, the experiment encompassed 11 sessions and 10 stimulus display durations. The stimulus display durations ranged from 50 to 500 milliseconds. The dependent variable was the accuracy for target identification (% correct).

The study was divided into an uninterrupted series of three 280-trial sessions per day for a period of 2 consecutive days and into an uninterrupted series of 5 sessions on a 3rd consecutive day (two 280-trial sessions and three 28-trial sessions). Testing for each participant was scheduled to occur at approximately the same time on all 3 days.

The experiment consisted of 2 successive phases. The first was operationally defined as the perceptual training phase. This phase was designed to train participants on a context of stimulus display durations. The training phase encompassed the 3 sessions on Day 1 of the experiment (session 1.1, session 1.2 and session 1.3) and the 3 sessions on Day 2 of the experiment (session 2.1, session 2.2 and session 2.3). On each trial within each training session, either the vertical target replaced one of the 7 distractors in quadrant 2 (50% of vertical target trials) or quadrant 4 (50% of vertical target trials), or the horizontal target replaced one of the 7 distractors in quadrant 1 (50% of horizontal target trials) or quadrant 3 (50% of horizontal target trials). Each session within the training phase incorporated a single fully randomized replication of each of the 14 vertical target locations and of each of the 14 horizontal target locations for the complete range of stimulus display durations (50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 milliseconds).

The perceptual training phase was followed by the perceptual learning specificity assessment phase. The specificity assessment phase encompassed the 5 sessions on Day 3 of the experiment (session 3.1, session 3.2 and session 3.3, session 3.4 and session 3.5) and contained two types of sessions. The first session-type was designed to assess the duration context specificity of 50-millisecond stimulus displays within a 2.5-minute time frame. It was comprised of 3 sessions on Day 3 of the experiment (session 3.1 and session 3.3 and session 3.5). Within these sessions, only the trained target locations were maintained (i.e. target locations were the same as in the perceptual training phase). Each session within this component of the specificity assessment phase consisted of a single fully randomized replication of each of the 14 vertical target locations and of each of the 14 horizontal target locations. The second session-type was identical to the ones used in the perceptual training phase and was integrated into the experiment as a point of comparison for the above-described assessment sessions. It was comprised of 2 sessions on Day 3 of the experiment (session 3.2 and session 3.4). This session included only trained target locations. The session within this component of the specificity assessment phase consisted a single fully randomized replication of each of the 14 vertical target locations and of each of the 14 horizontal target locations for the complete range of stimulus display durations (50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 milliseconds).

At the end of the experiment, each participant answered a series of questions on a paper paper-based feedback questionnaire (see Appendix C2 for a copy of the feedback questionnaire). The questionnaire was designed as a tool to assess the subjective experience of participants during the course of the experiment. This information was meant to supplement the formal data collected during computerized testing. The questionnaire was in part structured (participants were required to give specific answers to specific questions) and in part open (participants could elaborate on their specific answers and/or make additional comments).

All other aspects of the procedure were the same as in Experiment 1.

Results

Statistical analyses. For each participant, VPixx recorded the responses and saved the raw data in a Microsoft Excel (v11.3.5) worksheet. Within Excel, the averaged accuracy (% correct) data for every participant was individually tabulated for each possible combination of session and stimulus display duration permissible by the given experimental design, resulting in 83 averaged values. The averaged data was subsequently analyzed using SPSS (v11.0.4).

Within SPSS, an analysis of variance (ANOVAs) was conducted. The ANOVA assessed duration specific perceptual learning for 50-millisecond stimulus displays during the perceptual training phase and the perceptual learning specificity assessment phase. All statistical tests were conducted using an alpha level of .05. See Appendix D for complete proofs.

Duration context specific perceptual learning. For 50-millisecond stimulus display durations, a significant main effect of session was obtained, $F(10, 30) = 14.064$, $p < 0.001$, $\eta^2 = 0.824$ (See Figure 10). Bonferroni pairwise comparisons revealed that accuracy for target identification significantly improved between session 1.1 ($M =$

54.000, $SE = 1.780$) and session 2.3 ($M = 91.500$, $SE = 1.555$), $p = 0.046$. Thus, accuracy was significantly higher on the last perceptual training session than on the first perceptual training session. Furthermore, the comparisons showed that accuracy deteriorated between session 2.3 ($M = 91.500$, $SE = 1.555$), and session 3.1 ($M = 52.250$, $SE = 1.031$), $p = 0.024$. Therefore, accuracy was significantly higher on the last perceptual training session than on the first 2.5-minute perceptual learning specificity assessment session. Moreover, accuracy in session 1.1 ($M = 54.000$, $SE = 1.780$) did not differ from accuracy in session 3.1 ($M = 52.250$, $SE = 1.031$), $p = 1.000$. Therefore, accuracy was

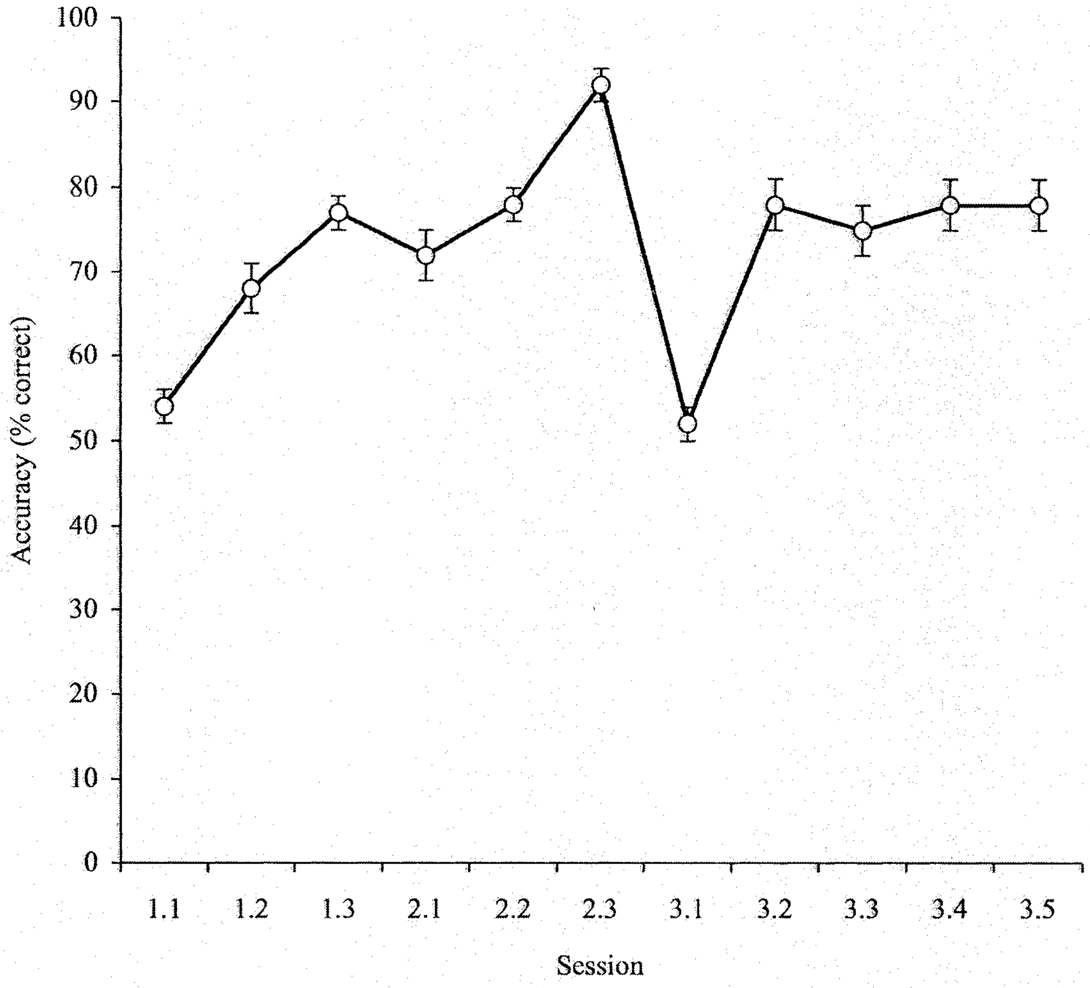

Figure 10. Target identification accuracy for 50-millisecond stimulus display durations in the perceptual training phase (sessions 1.1, 1.2, 1.3, 2.1, 2.2 and 2.3) and in the perceptual learning specificity assessment phase (sessions 3.1, 3.2, 3.3, 3.4 and 3.5) in Experiment 2. The standard errors of the mean are represented by error bars.

demonstrated not to differ between the first perceptual training session and the first 2.5-minute perceptual learning specificity assessment session. However, accuracy did not differ between session 2.3 ($M = 91.500$, $SE = 1.555$) and session 3.2 ($M = 77.500$, $SE = 6.564$), session 3.3 ($M = 75.250$, $SE = 7.487$), session 3.4 ($M = 77.750$, $SE = 5.893$) and session 3.5 ($M = 78.250$, $SE = 7.739$), $p = 1.000$. Therefore, accuracy was the same between the last perceptual training session and all except the first perceptual learning specificity assessment sessions (2.5 and 25 minute-long sessions).

Self-report data. It is important to note that no formal analyses were performed on the self-report data. When participants were asked about the difficulty rating they would give to the experiment they had just performed, they all rated it as difficult or very difficult. In addition, all participants reported that the experiment became easier through practice. Moreover, participants reported that the task became slightly more challenging on the first perceptual learning specificity assessment session. However, they failed to report any conscious awareness of the target locations throughout the experiment. They also reported noticing having committed errors.

Discussion

This experiment was primarily designed as a first follow-up to Experiment 1. The experiment assessed whether subjective perception of difficulty for 50-millisecond stimulus displays may vary according to the context of stimulus display durations within a given time frame and, consequently, influence perception and action. It was designed in an attempt to explain the dramatic decrease in target identification accuracy in the perceptual learning specificity assessment phase in Experiment 1.

With training, a significant improvement in performance for trials with a 50-millisecond stimulus display duration (difficult visual discriminations) resulted when such trials were embedded within 25-minute sessions containing a variety of longer stimulus display durations (easier discriminations). However, this improvement was lost when difficult trials were no longer embedded within the context of easier trials in the first 2.5-minute perceptual learning specificity assessment session and, in fact, returned to pre-training accuracy. However, the level of performance attained following the perceptual training phase was maintained in the remaining perceptual learning specificity assessment sessions (2.5 and 25 minute sessions).

Overall, since the performance gains attained during the perceptual training phase were maintained throughout most of the perceptual learning specificity assessment phase in the current experiment, the results suggest that difficult visual discriminations cannot be uninterruptedly performed for a sustained period of time, even if they are well learned. Experiment 2, however, brings up an additional point that merits further investigation. As noted previously, performance did deteriorate between the last perceptual training session and the first 2.5-minute perceptual learning specificity assessment session. It can be concluded, however, that 2.5 minutes is not a sufficiently long period of time for participants to re-familiarize themselves with the task following a 24-hour delay. Nonetheless, the role of the 24-hour delay in the performance drop between those 2 sessions in Experiment 1, in which the first perceptual learning specificity assessment session was 25-minutes long and presumably gave participants ample opportunity to re-familiarize themselves with the task, remains unclear. This issue is disambiguated in Experiment 3.

Experiment 3

Purpose

Experiment 3 was designed with the goal to assess the role of the 24-hour delay separating the last perceptual training session from the first perceptual learning specificity assessment session in Experiment 1. In order to do so, the perceptual learning specificity assessment session in the current experiment was performed immediately following the last perceptual training session. Thus, if the 24-hour delay was responsible for the drop in performance on 25-minute long sessions containing only 50-millisecond stimulus displays in Experiment 1, it was expected that there would not be a similar drop in performance on the same sessions in Experiment 3.

Method

Participant sample. Four Concordia University psychology students (3 females and 1 male between the ages of 23 and 28) participated in this experiment. All observers had normal (20/20) or corrected-to-normal vision, based on self-report. Participants were recruited from the undergraduate and graduate psychology population at the university. They received $25.00 compensation. All participants were naïve as to the experimental hypotheses and had not participated in Experiments 1 or 2. Prior to being subjected to the testing protocol, they were asked to sign an informed consent form describing the purpose of the study, the methodological proceedings that were to transpire and their rights and responsibilities as participants (see Appendix A3 for a copy of the informed consent form). All participants were formally debriefed as to the underlying rationale of the study following complete data collection (See Appendix B for a copy of the participant debriefing sheet).

Stimuli, apparatus and laboratory space. The same as in Experiment 1.

Design and procedure. A 6 x 10 within-subjects factorial design was used in this investigation. The two independent variables were the session and the stimulus display duration. In total, the experiment encompassed 6 sessions and 10 stimulus display durations. The stimulus display durations ranged from 50 to 500 milliseconds (ms). The dependent variable was the accuracy for target identification (% correct).

The study was divided into an uninterrupted series of three 280-trial sessions per day for a period of 2 consecutive days. Testing for each participant was scheduled to occur at approximately the same time on both days.

The experiment consisted of 2 successive phases. The first was operationally defined as the perceptual training phase. This phase was designed to train participants on a context of stimulus display durations. The training phase encompassed the 3 sessions on Day 1 of the experiment (session 1.1, session 1.2 and session 1.3) and the 2 first sessions on Day 2 of the experiment (session 2.1 and session 2.2). On each trial within each training session, either the vertical target replaced one of the 7 distractors in quadrant 2 (50% of vertical target trials) or quadrant 4 (50% of vertical target trials), or the horizontal target replaced one of the 7 distractors in quadrant 1 (50% of horizontal target trials) or quadrant 3 (50% of horizontal target trials). Each session within the training phase incorporated a single fully randomized replication of each of the 14 vertical target locations and of each of the 14 horizontal target locations for the complete range of stimulus display durations (50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 milliseconds).

The perceptual training phase was followed by the perceptual learning specificity assessment phase. The specificity assessment phase encompassed the 3rd session on Day 2 of the experiment (session 2.3). In this phase of the experiment, only 50-millisecond stimulus displays were presented. It was designed to assess the duration context specificity of 50-millisecond stimulus displays on the same day as perceptual training (no 24-hour delay between perceptual training and perceptual learning specificity assessment). Within these sessions, only the trained target locations were maintained (i.e. target locations were the same as in the perceptual training phase). Each session consisted of 10 fully randomized replications for each of the target locations.

At the end of the experiment, each participant answered a series of questions on a paper paper-based feedback questionnaire (see Appendix C3 for a copy of the feedback questionnaire). The questionnaire was designed as a tool to assess the subjective experience of participants during the course of the experiment. This information was meant to supplement the formal data collected during computerized testing. The questionnaire was in part structured (participants were required to give specific answers to specific questions) and in part open (participants could elaborate on their specific answers and/or make additional comments).

All other aspects of the procedure were the same as in Experiments 1 and 2.

Results

Statistical analyses. For each participant, VPixx recorded the responses and saved the raw data in a Microsoft Excel (v11.3.5) worksheet. Within Excel, the averaged accuracy (% correct) data for every participant was individually tabulated for each possible combination of session and stimulus display duration permissible by the given experimental design, resulting in 53 averaged values. The averaged data was subsequently analyzed using SPSS (v11.0.4).

Within SPSS, an analysis of variance (ANOVA) was conducted. The ANOVA assessed duration specific perceptual learning for 50-millisecond stimulus displays during the perceptual training phase and the perceptual learning specificity assessment phase. All statistical tests were conducted using an alpha level of .05. See Appendix D for complete proofs.

Duration context specific perceptual learning. For 50-millisecond stimulus display durations, a significant main effect of session was obtained, $F(5, 15) = 61.144$, $p < 0.001$, $\eta^2 = 0.953$ (See Figure 11). Bonferroni pairwise comparisons revealed that accuracy for target identification significantly improved between session 1.1 (M = 61.000, SE = 3.719) and session 2.2 (M = 85.750, SE = 3.860), $p = 0.048$. Thus, accuracy was significantly higher on the last training session than on the first training session. Furthermore, the comparisons showed that accuracy deteriorated between session 2.2 (M = 85.750, SE = 3.860), and session 2.3 (M = 59.500, SE = 2.958), $p = 0.034$. Therefore, accuracy deteriorated between the last perceptual training session and the perceptual learning specificity assessment session. Also, accuracy in session 1.1 (M = 61.000, SE = 3.719) did not differ from accuracy in session 2.3 (M = 59.500, SE = 2.958), $p = 1.000$. Therefore, accuracy was demonstrated not to differ between the first training session and the perceptual learning specificity assessment session.

Self-report data. It is important to note that no formal analyses were performed on the self-report data. When participants were asked about the difficulty rating they would give to the experiment they had just performed, they all rated it as difficult or very difficult. In addition, all participants reported that the experiment became easier through practice. Moreover, participants reported that the task became slightly more challenging on the perceptual learning specificity assessment session. However, they failed to report any conscious awareness of the target locations throughout the experiment. In their additional comments, some participants reported that the stimulus display durations in the perceptual learning specificity assessment phase were briefer than any stimulus display duration they had been exposed to during the perceptual training phase. They also

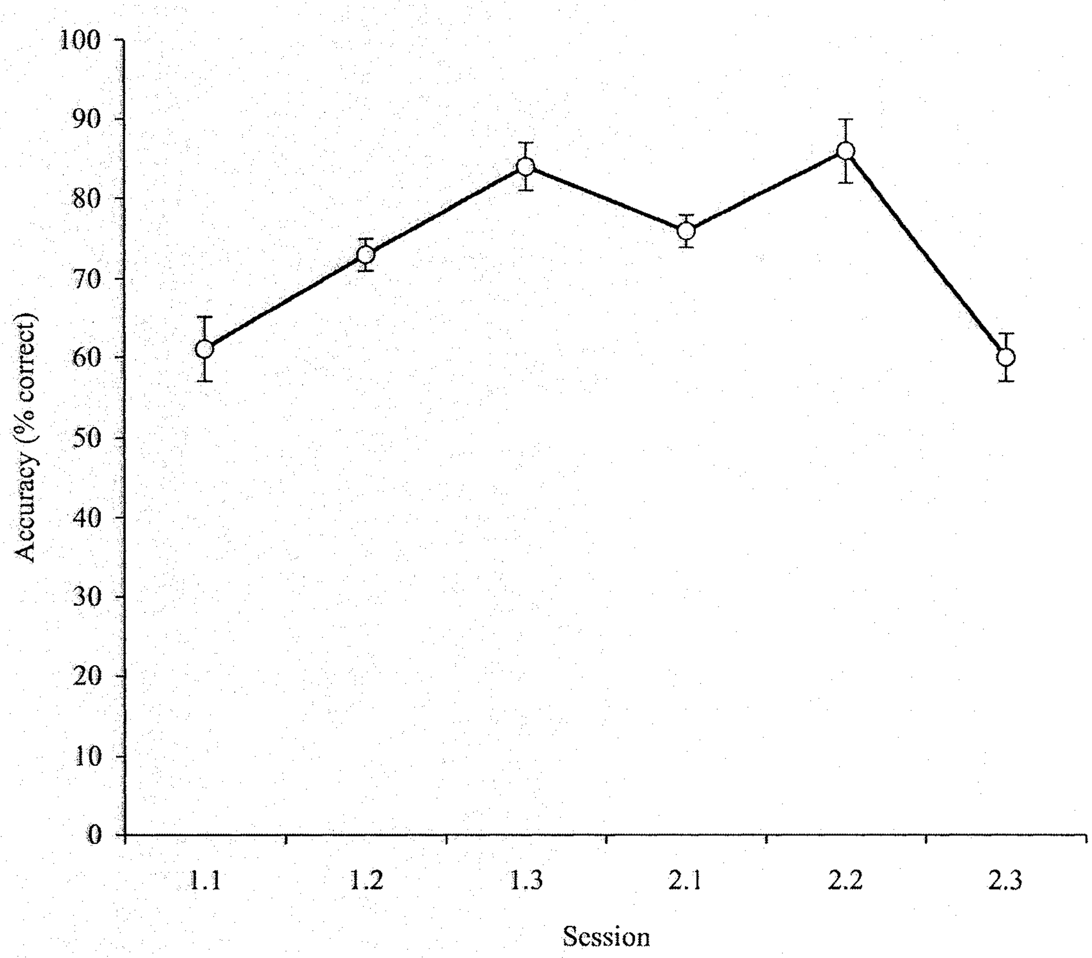

Figure 11. Target identification accuracy for 50-millisecond stimulus display durations in the perceptual training phase (1.1, 1.2, 1.3, 2.1 and 2.2) and in the perceptual learning specificity assessment phase (session 2.3) in Experiment 3. The standard errors of the mean are represented by error bars.

reported noticing having committed errors.

Discussion

Experiment 3 was primarily designed as a second follow-up to Experiment 1. The experiment assessed whether the drop in target identification accuracy between the last perceptual training session and the first perceptual learning specificity assessment session was due to the 24-hour delay between sessions.

With training, a significant improvement in performance for trials with a 50-millisecond stimulus display duration (difficult visual discriminations) resulted when such trials were embedded within sessions containing a variety of longer stimulus display durations (easier discriminations). However, this improvement was lost when difficult trials were no longer embedded within the context of easier trials and, in fact, returned to pre-training accuracy. Therefore, the results pertaining to the transition between perceptual training and perceptual learning assessment from Experiment 1 were replicated in Experiment 3. Hence, the 24-hour delay between the 2 sessions does not seems to adequately account for the corresponding drop in performance.

General Discussion

Summary of experiments and findings

Experiment 1. The first experiment was a preliminary investigation of a previously unreported form of perceptual learning specificity in visual search tasks consisting of difficult visual discriminations. More specifically, it assessed whether the acquired improvement in target identification accuracy following perceptual learning for trials with a 50-millisecond stimulus display duration (difficult visual discriminations) is specific to the context of stimulus display durations in which they are embedded during training.

During the perceptual training phase, trials with a 50-millisecond stimulus display duration (difficult visual discriminations) were embedded within 25-minute long sessions containing trials with stimulus display durations ranging from 100 to 500 milliseconds (easier visual discriminations). During the perceptual learning specificity assessment phase, trials with a 50-millisecond stimulus display duration were presented without the context of longer stimulus display durations, also in 25-minute long sessions. It was hypothesized that, if perceptual learning was duration context specific, performance would deteriorate in the perceptual learning specificity assessment phase as compared to the perceptual training phase. This is indeed what the results demonstrated.

In addition to duration context specificity, Experiment 1 assessed target location context specificity. This investigation was done simply to confirm that the difficulty of the visual discrimination used in this experiment corresponded to the difficulty of visual discriminations used in past experiments, which have reported perceptual learning specificity. It was hypothesized that, if perceptual learning was location context specific, target identification accuracy would be superior in trials with trained target locations than in trials with novel target locations. The results confirmed the predictions.

It was additionally hypothesized that performance for all stimulus display durations would improve with training. Furthermore, it was hypothesized that that longer stimulus display durations would lead to higher accuracy for target identification than briefer stimulus display durations. Both of these predictions were also satisfied.

Moreover, Experiment 1 raised the possibility that subjective perception of difficulty may vary according to the context of stimulus display durations within a given time frame (each session was 25 minutes long) and may consequently influence perception and action. This possibility was illustrated in the self-report data and suggested by participants' faulty perception that the 50-millisecond stimulus display durations in the perceptual learning specificity assessment phase were briefer than the 50-milliseccond stimulus display durations they had been exposed to during the perceptual training phase. Experiment 2 addressed this issue in greater depth.

Experiment 2. The second experiment was designed as a first follow-up to Experiment 1. Its goal was to assess whether subjective perception of difficulty for 50-millisecond stimulus displays may vary according to the context of stimulus display durations within a 25-minute time frame, influencing perception and action. It was designed in an attempt to explain the dramatic decrease in target identification accuracy in the perceptual learning specificity assessment phase in Experiment 1.

In Experiment 2, the perceptual training phase was identical to the one used in Experiment 1. However, the perceptual learning specificity assessment phase consisted of an alternating sequence of three 2.5-minute long sessions containing 50-millisecond stimulus displays only and two 25-minute long sessions containing all stimulus display durations (the same as those used in the perceptual training phase). If the performance drop in the perceptual learning specificity assessment phase in Experiment 1 was due to the fact that participants were unable to perform 50-millisecond visual discriminations outside of the context of easier visual discriminations for a fairly lengthy period of time (25 minutes), then it was expected that performance in all sessions of the perceptual learning specificity assessment phase in Experiment 2 would not be subject to a similar drop.

Overall, the results showed that performance gains attained during the perceptual training phase were maintained throughout most of the perceptual learning specificity assessment phase (2.5 and 25 minute sessions), suggesting that difficult visual discriminations cannot be uninterruptedly performed for a sustained period of time, even if they are well learned. That is, they could be performed uninterruptedly for a brief period of time (2.5 minutes) or intermingled with easier discriminations within a longer time frame (25 minutes). The drop in target identification accuracy on the first 2.5-minute perceptual learning specificity assessment session, however, brought out a point that merited further investigation regarding the 24-hour delay between the perceptual training and perceptual learning specificity assessment phases in Experiment 1. This issue was disambiguated in Experiment 3.

Experiment 3. Experiment 3 was designed as a second follow-up to Experiment 1. Its goal was to assess the role of the 24-hour delay separating the last perceptual training session from the first perceptual learning specificity assessment session in Experiment 1. The perceptual learning specificity assessment session in this investigation was, therefore, performed immediately following the last perceptual training session. If the 24-hour delay was responsible for the drop in performance on 25-minute long sessions containing only 50-millisecond stimulus displays in Experiment 1, it was expected that there would not be a similar drop in performance on the same session in Experiment 3.

The results pertaining to the transition between perceptual training and perceptual learning assessment from Experiment 1 were replicated in Experiment 3. Hence, the 24-hour delay between the 2 sessions does not seems to adequately account for the corresponding drop in performance.

Possible explanations

Automatic versus controlled visual processing. Within the self-report data in all experiments, participants' inability to correctly identify the vertical and horizontal target locations within each session, suggests an element of implicit learning. Additionally, participants' *post hoc* awareness of errors committed, suggest the involvement of an automatic process.

Processing can either be controlled or automatic (e.g. Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977; Schneider and Chein, 2003; Anderson, 1992; Logan, 1980; Pashler, Johnston, & Ruthruff, 2001; Stanovich, 1987). Following extensive practice on a task, controlled processing is often substituted by implicit and automatic processing, allowing us to perform the task with the highest efficiency possible. However, when the task requirements are altered in some respect, the fixed nature of an automatic visual search strategy can instead impede efficient performance.

The involvement of implicit and automatic processing may help to explain the detriment in performance on the 25-minute perceptual learning specificity assessment sessions containing only 50-milisecond stimulus displays in Experiments 1 and 3. Although the task *per se* was not altered between perceptual training and perceptual learning specificity assessment in those experiments, an aspect of the context in which the task was performed was altered (i.e. trials with 50-millisecond stimulus displays were no longer embedded within a session containing trials with a variety of longer stimulus display durations). Controlled processing may, thus, have been required to re-learn the task in its new context.

Low-level visual processing. Based on past research findings (e.g., Ahissar and Hochstein, 1997), we know that difficult visual discrimination search tasks lead to specific perceptual learning. The results demonstrating target location context specificity in Experiment 1, consequently suggest that low-level visual areas were involved in target identification within the difficult visual discrimination search task put forth in the present experiments. Although, to the extent of my knowledge, no such claim is made in the relevant literature, these regions may also be specific to the duration context of sessions.

Strain on cognitive resources. Lavie (1995) conceptualized perception as a limited capacity process in which cognitive processing resources can be allocated to a visual scene up until the point of exhaustion. As the search task becomes increasingly complex, an increasing amount of cognitive processing resources become necessary (e.g., Lavie, 1995; Facoetti and Molteni, 2000; Sanders and Lamers, 2002).

The inability to perform 50-millisecond visual discriminations for a sustained period of time (25 minutes) in the present study may therefore be a reflection of the increased demand placed on attentional resources in such sessions. This claim is further supported by the lack of a similar performance drop for 2.5-minute sessions containing only 50-millisecond stimulus displays.

Working memory. Visual masking is defined as the reduction or elimination of the visibility of one stimulus by the presentation of a second stimulus, referred to as a "mask". Masking was introduced near the end of the 19th and beginning of the 20th century (e.g. McDougal, 1904; Sherrington, 1897). It has been used extensively since then as a tool for exploring the temporal dynamics of visual information processing (Breitmeyer, Ro and Öğmen, 2004; Breitmeyer & Öğmen, 2006; Breitmeyer, 2007; VanRullen and Thorpe, 2001; Lamme et al., 2002). The backwards mask used in the current experiments limited the duration of neuronal responses to the stimulus display by interrupting neuronal firing at one of 10 possible latencies, ranging from 50 to 500 milliseconds. In the difficult visual discriminations, activity was interrupted after 50 milliseconds.

Within a single trial of visual search and across trials, memory representations of targets and distractors contribute to efficient processing (e.g., Shore and Kline, 2000). As previously mentioned, the spatial configuration of distractors within the stimulus display remained constant throughout all experiments. On each trial either the vertical or horizontal target replaced one of the distractors, while the others remained unaltered. The longer-lasting neuronal activity characteristic of the trials with longer stimulus display durations could, thus, be useful in the learning of the invariant representation of distractors within the stimulus display. This working memory representation may then carry over to trials with 50-millisecond stimulus display durations within the same session. However, the representation within working memory of distractor configuration may not be enduring enough to carry over to another session.

Target recognition, attention, and visual resolution. Humans are driven by their need for arousal and an aroused state may spring from a diverse set of stimuli. Spaces offering a task of searching and initiating object recognition are, for the most part, reported to be enjoyable. Thus, it has been suggested that the awareness of correctly identifying a given target within a given visual scene may be a form of incentive salience, involving the activation of our dopaminergic system and, consequently, leading to an aroused state of attention. Furthermore, outcomes of actions are known to shape overt behaviour and covert behaviour (such as visual attention). In a study by Libera and Chelazzi (2006), variable monetary rewards were given to participants who performed a series of prime-probe sequences, based on their performance on the task. The results showed evidence that the distractor was ignored more effectively in highly rewarded selections.

Selective visual attention is widely recognized to modulate neural activity in the extrastraite visual cortex. However, it has also been demonstrated to strongly influence perceptual processing in the low-level cortical stage of the striate cortex (V1). In a study by Somers and colleagues (1999), functional Magnetic Resonance Imaging (fMRI) was used to study humans during attentionally demanding visual discriminations. The results indicated similar robust attentional modulations in both striate and extrastriate cortical areas. These data suggest that neural processing in V1 is not governed simply by sensory stimulation, but, like extrastriate regions, V1 can be strongly and specifically influenced by attention.

Attention, in turn, has been shown to affect spatial resolution within the primary visual cortex. In a study by Wörgötter and colleagues (1998), performed on anesthetized cats, the shape of receptive fields in V1 underwent significant modifications. These modifications were correlated with the general state of the brain as assessed by electroencephalography (EEG). More specifically, receptive fields were wider during synchronized states (drowsiness) and smaller during non-synchronized states (attentive perception). This shrinking of the receptive field allows the cells in the visual cortex to become more highly sensitized to receiving detailed information regarding visual stimuli.

In the current experiments, longer stimulus display durations lead to greater target identification accuracy. This increased accuracy may have been intrinsically rewarding to participants and have lead to an increased state of cortical arousal (attentive perception). Increased levels of attention may have then lead to the shrinking of cortical receptive fields and, consequently, to better detail discrimination and accuracy. This cycle seems not to have been easily interrupted when performing occasional trials with 50-milllisecond stimulus display durations in 25-minute sessions containing trials a variety of longer stimulus display durations. It was also not affected on 2.5-minute sessions containing only trials with 50-millisecond stimulus display durations, so long as such sessions were immediately preceded by sessions containing trials with the full range of stimulus display durations. However, when 50-millisecond discriminations needed to be performed continuously for 25-minutes, performance suffered, presumably because the cycle was broken.

Conclusion

Findings from this study imply that perceptual learning in difficult visual discrimination tasks is not only specific to the context of target locations presented during training, but also specific to the context of trained stimulus display durations. The results from this study may be interpreted in light of several cognitive or neural mechanisms. However, the present experiments still remain largely preliminary and, therefore, require follow-up investigations. Nonetheless, the compilation of psychophysical experiments in this study has provided another piece of the puzzle on the road to understanding the plasticity in learning processes involved in the acquisition of task-relevant information from our visual environments.

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Appendix A

Informed Consent Forms

(Experiment 1, Experiment 2 and Experiment 3)

Form A1

Informed Consent Form Used in Experiment 1

INFORMED CONSENT

FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a **Masters Thesis** study being conducted by **Angela Vavassis** under the supervision of **Dr. Michael von Grünau** in the **Visual Perception Laboratory** of **Concordia University's Psychology Department**.

A. PURPOSE

I have been informed that the purpose of this study is to investigate the properties of visual spatial perceptual learning.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.
- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the key labeled "START TRIAL" (space bar) on the computer keyboard.
- My task on each trial will consist of reporting the identity of the target stimulus (a vertical bar or a horizontal bar) in the test display that will be presented, while maintaining fixation on the cross in the centre of the screen.
- I will be required to indicate my responses on a computer keyboard using the keys labeled "V" (left arrow key) and "H" (right arrow key).
- Testing will be divided into 9 sessions, spread across 3 consecutive days (3 25-min sessions/day). A brief feedback questionnaire will follow testing on the 3rd day.

- I will receive $35 compensation as an acknowledgement for my time after having completed the final experimental session and feedback questionnaire.
- I will be debriefed as to the underlying rationale and hypotheses of the study, if I do so wish, following completion of the study. Yes, please debrief me ____ No ____

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.
- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.
- The data collected from this study may be published.
- My participation in this study will be kept confidential (My name will not be reported in the results).
- There is no hidden motive of which I have not been informed.
- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ________________________________

SIGNATURE: ________________________________

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ________________________________

Form A2

Informed Consent Form Used in Experiment 2

INFORMED CONSENT

FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a **Masters Thesis** study being conducted by **Angela Vavassis** under the supervision of **Dr. Michael von Grünau** in the **Visual Perception Laboratory** of **Concordia University's Psychology Department**.

A. PURPOSE

I have been informed that the purpose of this study is to investigate the properties of visual spatial perceptual learning.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.
- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the key labeled "START TRIAL" (space bar) on the computer keyboard.
- My task on each trial will consist of reporting the identity of the target stimulus (a vertical bar or a horizontal bar) in the display that will be presented, while maintaining fixation on the cross in the centre of the screen.
- I will be required to indicate my responses on a computer keyboard using the keys labeled "V" (left arrow key) and "H" (right arrow key).
- Testing will be divided into 11 sessions, spread across 3 consecutive days (3 25-min sessions/day on days 1 and 2; 2 25-min sessions/day and 3 5-min sessions/day on day 3). A brief feedback questionnaire will follow testing on the 3rd day.

- I will receive $35 compensation as an acknowledgement for my time after having completed the final experimental session and feedback questionnaire.

- I will be debriefed as to the underlying rationale and hypotheses of the study, if I do so wish, following completion of the study. Yes, please debrief me ____ No ____

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential (My name will not be reported in the results).

- There is no hidden motive of which I have not been informed.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ______________________________

SIGNATURE: ______________________________

EXPERIMENTER'S SIGNATURE: ______________________________

DATE: ______________________________

Form A3

Informed Consent Form Used in Experiment 3

INFORMED CONSENT

FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a **Masters Thesis** study being conducted by **Angela Vavassis** under the supervision of **Dr. Michael von Grünau** in the **Visual Perception Laboratory** of **Concordia University's Psychology Department**.

A. PURPOSE

I have been informed that the purpose of this study is to investigate the properties of visual spatial perceptual learning.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.
- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the key labeled "START TRIAL" (space bar) on the computer keyboard.
- My task on each trial will consist of reporting the identity of the target stimulus (a vertical bar or a horizontal bar) in the display that will be presented, while maintaining fixation on the cross in the centre of the screen.
- I will be required to indicate my responses on a computer keyboard using the keys labeled "V" (left arrow key) and "H" (right arrow key).
- Testing will be divided into 6 sessions, spread across 2 consecutive days (3 25-min sessions/day). A brief feedback questionnaire will follow testing on the 3rd day.

- I will receive $35 compensation as an acknowledgement for my time after having completed the final experimental session and feedback questionnaire.

- I will be debriefed as to the underlying rationale and hypotheses of the study, if I do so wish, following completion of the study. Yes, please debrief me ____ No ____

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential (My name will not be reported in the results).

- There is no hidden motive of which I have not been informed.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ________________________________

SIGNATURE: ________________________________

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ________________________________

Appendix B

Participant Debriefing

(Experiment 1, Experiment 2 and Experiment 3)

PARTICIPANT DEBRIEFING

The Concordia University Visual Perception Lab thanks you for your participation in this study!

Topic under investigation:

Perceptual learning specificity to the trained context of stimulus display durations in difficult visual discriminations

Experimenter:

Angela Vavassis (M.A. candidate)

Supervisor:

Dr. Michael von Grünau (Professor)

Rationale:

Numerous psychophysical studies have successfully demonstrated that visual search tasks can undergo perceptual learning. The performance of adult observers on such perceptual tasks has been shown to be dramatically enhanced and enduring following practice.

Further research has established that this considerable improvement in performance can either be general or specific to the training context, depending upon the difficulty of the given perceptual task. Easy search tasks typically lead to general learning, whereas difficult search tasks typically lead to specific learning.

The current experiment aimed to assess whether these effects manifest themselves, not only in the spatial domain (as shown in previous studies), but also in the temporal domain.

Appendix C

Feedback Questionnaires

(Experiment 1, Experiment 2 and Experiment 3)

Questionnaire C1

Feedback Questionnaire Used in Experiment 1

<u>Feedback Questionnaire</u>

***** Please answer the questions in order *****

1) Overall, how would you rate the visual search task you were asked to perform?

very easy	easy	difficult	very difficult

2) Did you notice any changes in *the difficulty of the visual search task* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

3) Did you notice any changes in *your performance* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

4) How would you rate *the difficulty* of session 2.3 relative to session 3.1?

a) session **2.3** was **easier** than session **3.1**
b) session **2.3** was **more difficult** than session **3.1**
c) session **2.3** and **3.1** were at the **same** level of difficulty

5) How would you rate *your performance* on session 2.3 relative to session 3.1?

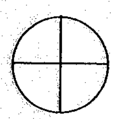
a) my performance on session **2.3** was **better** than my performance on session **3.1**
b) my performance on session **2.3** was **worse** than my performance on session **3.1**
c) my performance on session **2.3** was the **same** as my performance on session **3.1**

6) Did you notice any consistencies or irregularities in terms of the locations in which each of the two targets (vertical bar and horizontal bar) were likely to appear? (yes/no). **If yes, did this differ depending on the session** (yes/no)?

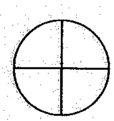
7) To the best of your knowledge, please indicate (draw-in the appropriate regions)**…**

…where the *vertical* bar appeared

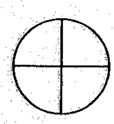
session 1.1



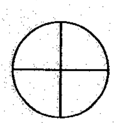
session 1.2



session 1.3

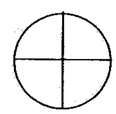


session 2.1

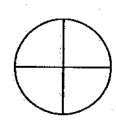


…where the *horizontal* bar appeared

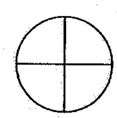
session 1.1



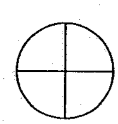
session 1.2



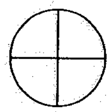
session 1.3



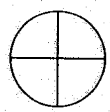
session 2.1



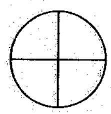
session 2.2



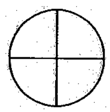
session 2.3



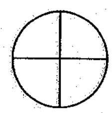
session 3.1



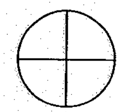
session 3.2



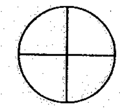
session 3.3



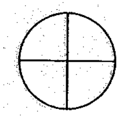
session 2.2



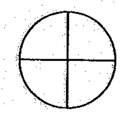
session 2.3



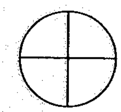
session 3.1



session 3.2



session 3.3



Additional Comments:

Thank you for taking the time to complete this questionnaire!

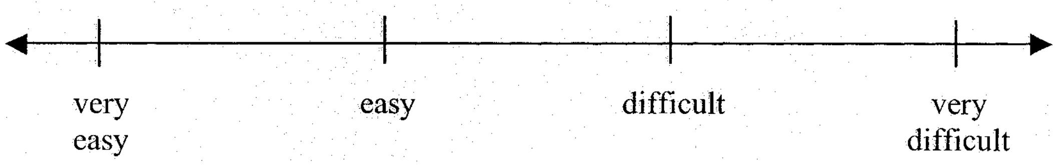
Questionnaire C2

Feedback Questionnaire Used in Experiment 2

<u>Feedback Questionnaire</u>

***** Please answer the questions in order *****

1) Overall, how would you rate the visual search task you were asked to perform?



2) Did you notice any changes in *the difficulty of the visual search task* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

3) Did you notice any changes in *your performance* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

4) How would you rate *the difficulty* of session 2.3 relative to session 3.1?

a) session **2.3** was **easier** than session **3.1**
b) session **2.3** was **more difficult** than session **3.1**
c) session **2.3** and **3.1** were at the **same** level of difficulty

5) How would you rate *your performance* on session 2.3 relative to session 3.1?

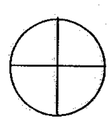
a) my performance on session **2.3** was **better** than my performance on session **3.1**
b) my performance on session **2.3** was **worse** than my performance on session **3.1**
c) my performance on session **2.3** was the **same** as my performance on session **3.1**

6) Did you notice any consistencies or irregularities in terms of the locations in which each of the two targets (vertical bar and horizontal bar) were likely to appear? (yes/no). **If yes, did this differ depending on the session** (yes/no)?

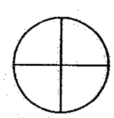
7) To the best of your knowledge, please indicate (draw-in the appropriate regions)**...**

...where the *vertical* bar appeared

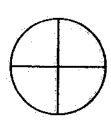
session 1.1



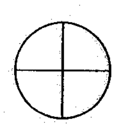
session 1.2



session 1.3

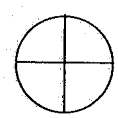


session 2.1

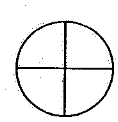


...where the *horizontal* bar appeared

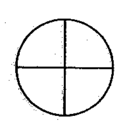
session 1.1



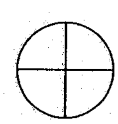
session 1.2



session 1.3



session 2.1



session 2.2	**session 2.2**
session 2.3	**session 2.3**
session 3.1	**session 3.1**
session 3.2	**session 3.2**
session 3.3	**session 3.3**
session 3.4	**session 3.4**
session 3.5	**session 3.5**

Additional Comments:

Thank you for taking the time to complete this questionnaire!

Questionnaire C3

Feedback Questionnaire Used in Experiment 3

Feedback Questionnaire

***** Please answer the questions in order *****

1) Overall, how would you rate the visual search task you were asked to perform?

very easy — easy — difficult — very difficult

2) Did you notice any changes in *the difficulty of the visual search task* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

3) Did you notice any changes in *your performance* between testing days (yes/no) **and/or between sessions on any given day** (yes/no)**?**

If yes, please specify (for both questions)**:**

4) How would you rate *the difficulty* of session 2.2 relative to session 2.3?

a) session **2.2** was **easier** than session **2.3**
b) session **2.2** was **more difficult** than session **2.3**
c) session **2.2** and **2.3** were at the **same** level of difficulty

5) How would you rate *your performance* on session 2.2 relative to session 2.3?

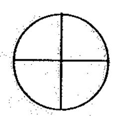
a) my performance on session **2.2** was **better** than my performance on session **2.3**
b) my performance on session **2.2** was **worse** than my performance on session **2.3**
c) my performance on session **2.2** was the **same** as my performance on session **2.3**

6) Did you notice any consistencies or irregularities in terms of the locations in which each of the two targets (vertical bar and horizontal bar) were likely to appear? (yes/no). **If yes, did this differ depending on the session** (yes/no)?

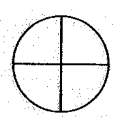
7) To the best of your knowledge, please indicate (draw-in the appropriate regions)**…**

…where the *vertical* bar appeared

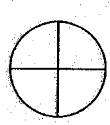
session 1.1



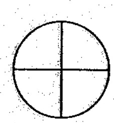
session 1.2



session 1.3

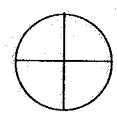


session 2.1

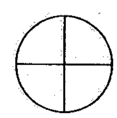


…where the *horizontal* bar appeared

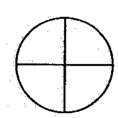
session 1.1



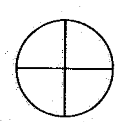
session 1.2



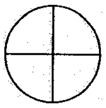
session 1.3



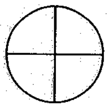
session 2.1



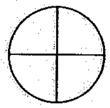
session 2.2



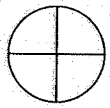
session 2.2



session 2.3



session 2.3



Additional Comments:

Thank you for taking the time to complete this questionnaire!

Appendix D

Source Tables

(Experiment 1, Experiment 2 and Experiment 3)

Table D1

Analysis of Variance for the Perceptual Training Phase in Experiment 1

Source	*df*	*F*	η^2	*p*
		Within subjects		
Duration (D)	9	6.142*	0.672	0.000
Error (D)	27	(110.614)		
Session (S)	5	7.169*	0.705	0.001
Error (S)	15	(177.832)		
D x S	45	1.580	0.345	0.240
Error (D x S)	135	(33.590)		

Note: Values enclosed in parentheses represent mean square errors.

$*p < .05$.

Table D2

Analysis of Variance for 50-Millisecond Stimulus Display Durations in the Perceptual Training and Perceptual Learning Specificity Assessment Phases in Experiment 1

Source	*df*	*F*	η^2	*p*
		Within subjects		
Session (S)	8	16.082*	0.843	0.000
Error (S)	24	(31.977)		

Note: Values enclosed in parentheses represent mean square errors.

*$p < .05$.

Table D3

Bonferoni Pairwise Comparisons for 50-Millisecond Stimulus Display Durations in the Perceptual Learning Specificity Assessment Phase in Experiment 1

Comparison	Mean Difference$^{(i-j)}$	Standard Error	*p*
1.1^i *versus* 2.3^j	-30.500*	2.102	0.026
2.3^i *versus* 3.1^j	30.250*	2.496	0.044
2.3^i *versus* 3.2^j	29.250*	1.931	0.022
2.3^i *versus* 3.3^j	31.750*	0.854	0.002
1.1^i *versus* 3.1^j	-0.250	1.750	1.000
1.1^i *versus* 3.2^j	-1.250	2.175	1.000
1.1^i *versus* 3.3^j	1.250	1.797	1.000

*$p < .05$.

Table D4

Analysis of Variance for Trained and Novel Target Locations in the Location Specificity Component of the Perceptual Learning Specificity Assessment Phase in Experiment 1

Source	*df*	*F*	η^2	*p*
		Within subjects		
Location (L)	1	50.342*	0.944	0.006
Error (P)	3	(6.458)		

Note: Values enclosed in parentheses represent mean square errors.

*$p < .05$.

Table D5

Analysis of Variance for 50-Millisecond Stimulus Display Durations in the Perceptual Training and Perceptual Learning Specificity Assessment Phases in Experiment 2

Source	*df*	*F*	η^2	*p*
		Within subjects		
Session (S)	10	14.064*	0.824	0.000
Error (S)	30	(36.244)		

Note: Values enclosed in parentheses represent mean square errors.

*$p < .05$.

Table D6

Bonferoni Pairwise Comparisons for 50-Millisecond Stimulus Display Durations in the Perceptual Learning Specificity Assessment Phase in Experiment 2

Comparison	Mean Difference$^{(i-j)}$	Standard Error	*p*
1.1^i *versus* 2.3^j	-37.500*	2.723	0.046
2.3^i *versus* 3.1^j	39.250*	2.287	0.024
2.3^i *versus* 3.2^j	14.000	5.672	1.000
2.3^i *versus* 3.3^j	16.250	7.273	1.000
2.3^i *versus* 3.4^j	13.750	4.973	1.000
2.3^i *versus* 3.5^j	13.250	6.537	1.000
1.1^i *versus* 3.1^j	1.750	1.109	1.000

$*p < .05$.

Table D7

Analysis of Variance for 50-Millisecond Stimulus Display Durations in the Perceptual Training and Perceptual Learning Specificity Assessment Phases in Experiment 3

Source	*df*	*F*	η^2	*p*
		Within subjects		
Session (S)	5	61.144*	0.953	0.000
Error (S)	15	(8.075)		

Note: Values enclosed in parentheses represent mean square errors.

$^*p < .05$.

Table D8

Bonferoni Pairwise Comparisons for 50-Millisecond Stimulus Display Durations During the Perceptual Learning Specificity Assessment Phase in Experiment 3

Comparison	Mean Difference$^{(i-j)}$	Standard Error	*p*
1.1^{i} *versus* 2.2^{j}	-24.750*	3.637	0.048
2.2^{i} *versus* 2.3^{j}	26.250*	2.689	0.034
1.1^{i} *versus* 2.3^{j}	1.500	1.190	1.000

*$p < .05$.