Behavioral training to improve collision detection

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Young drivers are a high-risk group for vehicle crashes due to inexperience in detecting an impending collision and are one group that may benefit from perceptual learning (PL) training. The present study assessed whether PL could be used to improve performance in collision detection. Ten college-aged subjects participated in the first experiment, which consisted of seven 1-hr sessions conducted on separate days. Thresholds at three observer/object speeds were measured prior to training using a two-alternative forced choice procedure during which they indicated whether an approaching object would result in a collision or noncollision event. Participants were then trained near threshold at one of these speeds for 5 days. After training, participants showed a significant reduction in the time needed to detect a collision at the trained speed. This improvement was also found to transfer to the higher observer speed condition. A second experiment was conducted to determine whether this improvement was due to training near threshold or whether this improvement was merely due to practice with the task. Training with stimuli well above threshold showed no significant improvement in performance, indicating that the improvement seen in the first experiment was not solely due to task practice.

Introduction

It is well documented in the literature that visual perceptual learning (PL)—repeated exposure or practice with a visual task—can improve visual performance. Improved performance has been found for a wide range of early-level visual tasks, including discrimination of orientation (Fiorentini & Berardi, 1981), motion (Ball & Sekuler, 1987), contrast (Sowden, Rose, & Davies, 2002), and texture (Karni & Sagi, 1991). These studies suggest that the visual system maintains plasticity into adulthood, and recent studies have demonstrated that these methods can be used as interventions to improve visual function for populations ranging from amblyopia patients (Levi & Li, 2009; Li et al., 2013) to older adults (Andersen, Ni, Bower, & Watanabe, 2010; Bower & Andersen, 2012; Bower, Watanabe, & Andersen, 2013; DeLoss, Watanabe, & Andersen, 2013). Although a number of studies have suggested that PL results in processing changes in early levels of visual processing (Karni & Sagi, 1991) such as V1 (Yotsumoto, Watanabe, & Sasaki, 2008), other studies have suggested that PL training effects are the result of changes in higher-level task configuration (Jeter, Dosher, Petrov, & Lu, 2009).

The research briefly reviewed above has focused on examining changes in processing of early level features of vision: contrast, motion, or orientation. Given these findings, an important question is whether PL can result in improved performance for stimuli that involve higher levels of processing beyond early visual cortex. Although studies have found that training with early-level processing can improve performance for higher-level visual tasks, such as batting (Deveau & Seitz, 2014), it is unclear whether training with high-level visual tasks can improve performance. The goal of the present study was to examine this issue.

In the present study, we examined whether PL would occur when practicing with a high-level perceptual task: the detection of an impending collision. Successfully detecting and avoiding collisions is an important issue

Citation: DeLoss, D. J., Bian, Z., Watanabe, T., & Andersen, G. J. (2015). Behavioral training to improve collision detection. *Journal of Vision, 15*(10):2, 1–7, doi:10.1167/15.10.2.

doi: 10.1167/15.10.2 Received March 2, 2015; published July XX, 2015 ISSN 1534-7362 © 2015 ARVO

in driving safety and reducing accident risk. Consider the data from the fatal analysis reporting system of the National Highway Traffic Safety Administration. Recent data indicates that 42.7% of 25,840 fatal crashes involved two moving vehicles (Evans, 2004). The incidence of crashes is particularly high among younger drivers, especially drivers under the age of 25 (Evans, 2004; Williams & Carsten, 1989). Thus, determining whether collision detection performance can be improved through training is an important step in developing training protocols to reduce crash risk.

In the present study, subjects were presented with scenes simulating forward locomotion at a constant speed and along a linear path—similar to driving at a constant speed on a straight roadway—over a random texture pattern. In each trial, an object was presented that approached the subject at a constant speed and translated along a linear path. The linear path of the object was varied such that in half the trials the object would collide with the observer whereas in the remaining trials the object would pass to the left or right of the observer. Under these conditions, a collision event is defined by the presence of expansion or looming of the object and a constant angular direction or fixed position in the visual field (see Bootsma & Oudejans, 1993; Henderson & Burg, 1974; Kaiser & Mowafy, 1993). This latter source of information is referred to as a constant bearing. Previously, we have found that both types of information are important for the task (Andersen & Kim, 2001) with a decrease in performance occurring when the speed of forward motion of the observer is increased (Andersen & Enriquez, 2006).

Although many PL studies have found perceptual improvements after training, these benefits are often limited to the trained stimuli. As a result, an important issue in PL is the degree to which improved performance transfers to nontrained stimuli. For example, Karni and Sagi (1991, 1993) found that texture discrimination task training did not transfer to different locations in the visual field or to a different orientation. Fahle, Edelman, and Poggio (1995) found that hyperacuity learning was specific to the retinal location, orientation of stimuli, and to the trained eye. Ball and Sekuler (1982) trained participants to discriminate the direction of random dot cinematograms. They found that direction discrimination improvements were constrained to within 45° of the trained direction. In all of these studies, changing the parameters of the stimuli from those used during training reduced transfer of PL. This reduction of transfer may be associated with the activation of different cortical cells that respond to different orientations or locations in the visual field. In the present study, we examined whether training to detect a collision at a specific speed would transfer to detection at other speeds.

Experiment 1

Experiment 1 was designed to determine whether a standard PL paradigm could be used to performance in a high-level collision detection task. Transfer to untrained stimulus conditions was also assessed by testing participants at three speed levels but training at only one of these speeds.

Methods

Subjects

Ten younger individuals ($M = 21.9$ years, $SD = 1.5$) from the University of California, Riverside (seven male and three female) participated in the experiment. All participants had normal or corrected-to-normal visual acuity. Participants were reimbursed at a rate of $10 per hour and were naïve concerning the experimental purpose.

Apparatus

Stimuli were generated using custom experimental software written using MATLAB (The Mathworks, Inc., version 7.8.0.347), and the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). The stimuli were presented on a 58-in. professional plasma display (Panasonic TH-58PF12UK) at a resolution of 1920 × 1080 with a refresh rate of 60 Hz (noninterlaced). A Dell Precision T7500 equipped with dual Intel Xeon E5506 processors using the Windows 7 (Service Pack 1) operating system equipped with an NVIDIA Quadro FX 4800 graphics card was used.

Stimuli and procedures

The experiment consisted of 1 hr per day of testing or training over a total of 7 days. The monitor was viewed at a distance of 60 cm, and stimuli were viewed binocularly. Any visual correction normally used by the participants was allowed during the experiment. The experiment took place in a darkened room, and the only source of light during the experiment was the display. The stimulus presented was a 3-D scene consisting of a ground texture generated randomly that consisted of a random midpoint displacement fractal. This texture was chosen to prevent participants from using local texture elements as landmarks or a roadway for determining the change in bearing of the object. The viewpoint was 1.2 m above the ground plane. In each trial, the participant translated toward a white sphere (2.4 m diameter). The object motion trajectories were generated using the same method employed in a number of previous studies (Andersen & Enriquez,

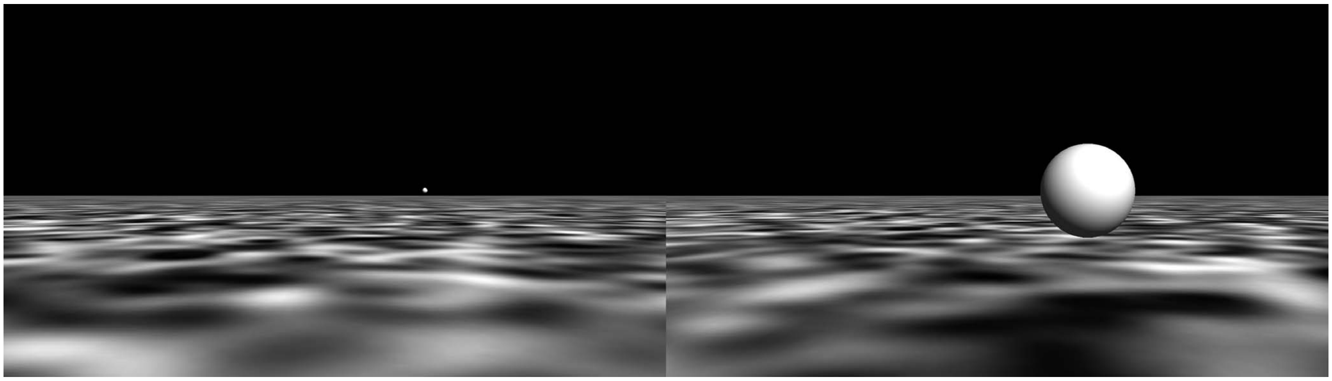

Figure 1. An example of the stimuli used in the experiment. The frame on the left shows the initial starting position of the sphere. The frame on the right shows the sphere after 7000 ms, the presentation time used during training in the second experiment.

2006; Ni, Bian, Guindon, & Andersen, 2012). In each trial, the sphere was placed 300 m away from the observer at a point randomly chosen along an arc (±20° from the center of the display). Each trial had a 50% chance of being a collision or noncollision event, and each noncollision trial had a 50% chance of passing the observer on the left or right side at a distance of 2.4 m. An example of one possible scene is displayed in Figure 1. Three speed conditions were used. In the first condition, the observer traveled at 100 km/h, and the sphere approached the observer at 20 km/h. In the second condition, the observer traveled at 60 km/h, and the sphere approached the observer at 60 km/h. In the last speed condition, the observer traveled at 20 km/h, and the sphere approached the observer at 100 km/h. A constant relative speed between the sphere and the observer was used so that the time to contact (TTC) remained at a constant of 9000 ms across the three speed conditions and that expansion information from the sphere was also constant across all three conditions. Previous studies have shown that increases in observer speed are correlated with decreased sensitivity to detect impending collisions (Andersen, Cisneros, Atchley, & Saidpour, 1999; Andersen & Enriquez, 2006). The maximum allowable duration presented was 9000 ms, and the minimum duration allowed was 16.67 ms.

Task practice: On the first day of the study, before the experiment began, all participants were given a six-trial practice session to familiarize them with the task. Participants were presented an equal number of trials at each of the three speeds presented in random order. Before presentation of the motion display, participants were presented with the trial number and pressed the space bar to begin each trial. The trial then proceeded with the display of the motion stimuli, after which a blank screen appeared. Participants were instructed to press the "4" key on the number pad to indicate that the trial presented an impending collision or the "6" key to indicate that no collision would occur. During practice, the duration of the motion stimuli was set to 7000 ms.

Testing: Testing of motion display duration thresholds occurred during the first and last days of the study. Thresholds were derived for each of the three speed levels. During days 1 and 7, pretraining TTC thresholds for the three speed levels were assessed using QUEST (Watson & Pelli, 1983). QUEST was initialized with a criterion level of 75% correct (0.75), $\beta = 1.6^1$, $\delta = 0.01$, and $\gamma = 0.5$. On testing days, the initial estimate for the duration threshold for QUEST in all three speed conditions was set at 7000 ms. Participants completed 100 trials at each speed level during testing. Trials occurred in the same manner as during the task practice with the exception that the duration of the presented motion path in each trial was determined by QUEST.

Training: Training occurred on days 2 through 6 using the same stimuli used in the testing phase. During training, all participants completed 300 trials in the second speed condition (60 km/h observer speed and 60 km/h object speed). Trials progressed in the same manner as in the testing phase. QUEST was initialized using the same parameters as during the testing days with the following exceptions: First, the duration threshold derived on the previous day of testing or training was used as the estimate. Second, the testing thresholds started at an initial duration threshold of 7000 ms whereas the training duration thresholds were based on the 75% correct threshold during training and were updated in each trial based on the current estimate of the 75% correct threshold provided by QUEST. This allowed for the optimization of training and accounted for any improvement occurring within or between sessions. Training for all subjects resulted in a total of 1,500 training trials over the course of the study.

Results

To examine the data, a training (pretraining vs. posttraining) by observer speed (20 km/h, 60 km/h, 100 km/h) analysis of variance was used. One participant was

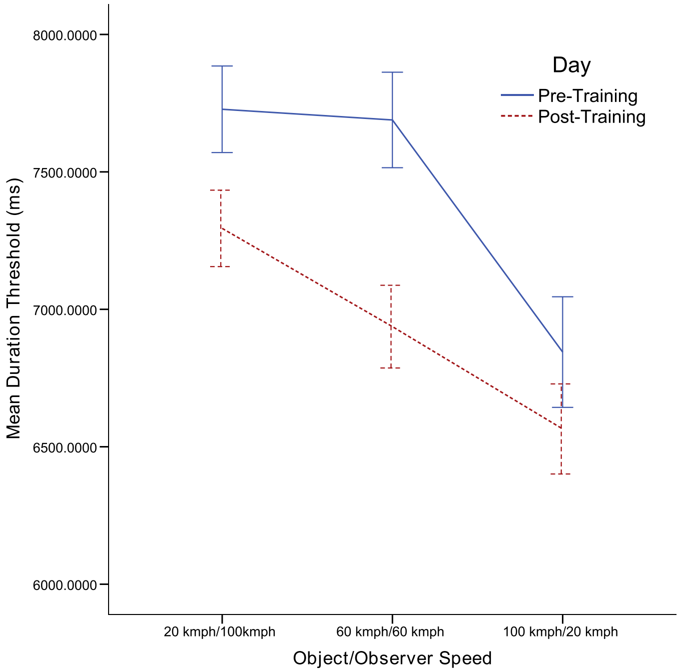

Figure 2. Mean duration thresholds as indicated by day (pretraining/post-training) and speed. Error bars indicate ±1 *SEM*.

removed from the analysis as QUEST was unable to converge on a stable estimate in at least one speed condition pre-/post-training. A significant effect of training, $F(1, 8) = 22.212$, $p = 0.002$, indicated significant improvement after training (see Figure 2). A significant effect of speed, $F(2, 16) = 83.395$, $p < 0.001$, was also found. Participants showed improved performance at higher speeds. A significant training by speed interaction was also found, $F(2, 16) = 9.997$, $p = 0.002$. To examine this interaction, simple effects analyses were performed at each speed level. A significant effect of training was found for the 20 km/h object speed condition, $F(1, 8) = 13.126$, $p = 0.007$, and the 60 km/h object speed condition, $F(1, 8) = 46.063$, $p < 0.001$. No significant improvement was found in the 100 km/h object speed condition, $F(1, 8) = 4.539$, $p = 0.066$.

To examine the degree of transfer between the two speed conditions with significant learning, a two-tailed *t* test of the difference scores (post-test, pretest) for the 20 km/h object speed condition and the 60 km/h object speed condition was conducted. The result of this test showed no significant difference in the magnitude of learning between the two conditions, $t(16) = 1.954$, $p = 0.068$. This suggests that there was a large degree of transfer between the trained condition and the slower object speed condition. Figure 3 shows the mean duration threshold for participants on each day of testing/training for the trained speed (60 km/h object speed/60 km/h observer speed). The greatest learning occurred after the first day of testing. Learning then continued steadily until day 6, where it seems to have reached a plateau. Thresholds on days 6 and 7 are nearly identical. However, a small amount of learning also took place between days 2 and 3; future research will be needed to determine whether there is any additional benefit of training for more than 5 days.

Experiment 2

The results of the first experiment indicated that collision detection performance could be improved through training with near-threshold stimuli. An important question is whether the improved performance is due to training near threshold or merely due to practice with the task. To examine this question, we conducted a second experiment in which subjects were asked to perform the same collision detection task but with stimuli that were well above threshold. Experiment 2 was the same as Experiment 1 with the following exception: all training stimuli were presented well above threshold. If the improved performance observed in Experiment 1 was due solely to task practice, then we should see similar levels of improvement using conditions that are above threshold.

Methods

Subjects

Ten younger individuals ($M = 22.8$ years, $SD = 1.4$) from the University of California, Riverside (six male and four female) participated in the experiment. All participants had normal or corrected-to-normal visual acuity. Participants were reimbursed at a rate of $10 per hour and were naïve concerning the experimental purpose.

Apparatus

The apparatus used in Experiment 2 was identical to that used in Experiment 1.

Stimuli and procedures

Experiment 2 was identical to Experiment 1 with one exception. Participants in the control group were not trained at threshold. The duration of the display was set to 7000 ms in all trials during the training sessions.

Results

An identical day (pretraining vs. post-training) by observer speed (20 km/h, 60 km/h, 100 km/h) analysis

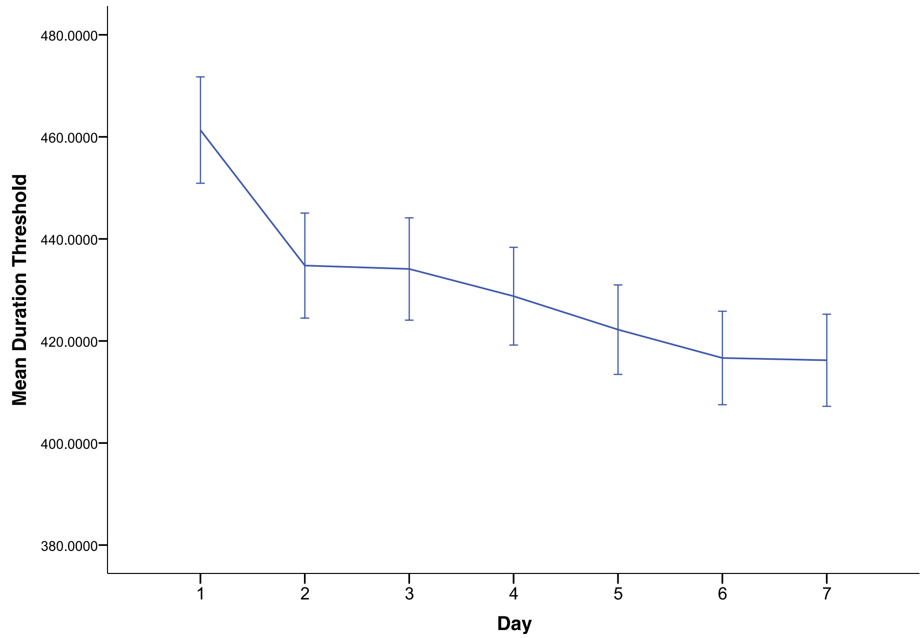

Figure 3. Mean duration thresholds as indicated by day for the trained speed. Error bars indicate ±1 *SEM*.

of variance was used as in Experiment 1. Two participants were removed from the analysis as QUEST was unable to converge on a stable estimate in at least one speed condition pre-/post-training. No significant effect of day, $F(1, 7) = 0.811$, $p = 0.398$, was found. In addition, no significant effect of speed, $F(2, 14) = 2.256$, $p = 0.141$, and no interaction were found, $F(2, 14) = 2.214$, $p = 0.146$. The absence of an effect of speed in the second experiment suggests that there may have been a difference in performance between the two groups. However, an analysis of variance examining the data prior to training showed no group by speed interaction, $F(2, 30) = 1.547$, $p = 0.229$.

General discussion

In the present study, we examined whether PL could be used to improve performance in a collision detection task. The results indicate training with near-threshold conditions resulted in improved collision detection performance. The time saved in the trained condition corresponds to reducing the distance traveled by the observer before initiating a response of 22.7 m or providing the driver with nearly 750 ms of additional reaction time. In addition, the improved performance was not dependent on the speed of locomotion used during training but transferred to the higher observer speed condition. These results suggest that collision detection performance—a high-level visual task—can be improved through training.

In the second experiment, we examined whether collision detection performance could be improved through repeated practice with the task. Unlike the results of Experiment 1, we did not find that performance significantly improved as a result of training. These results would suggest that training with near-threshold stimuli is an important condition for training methods to improve collision detection performance. This suggests that learning in Experiment 1 was not exclusively due to practice with the task.

In addition to training effects in Experiment 1, we also found transfer of learning. These results suggest that the improved performance may be at a higher level of task configuration rather than improving performance due to improved processing of collision detection events. However, the finding of transfer suggests that PL training may be a useful approach to reducing crash risk due to difficulty in detecting an impending collision. Indeed, the transfer of training to a higher observer speed is an important finding as collision detection performance declines at higher speeds. An important next step will be to examine whether training using a collision detection paradigm such as this reduces the incidence of vehicular crashes.

An important issue is whether the improved performance is the result of training low-level stimulus features or the result of training high-level features, such as 3-D motion, and how the conditions in the present study may have resulted in transfer of training. Consider previous research on low-level motion training. For example, Ball and Sekuler (1987) used coherent motion stimuli presented in a single position in the central field and at a constant velocity. The results indicated little transfer of training to untrained motion directions. The present study, which found transfer of training, included several factors that resulted in improvement of high motion processing and which contributed to the likelihood of transfer of training. A common low-level feature in PL stimuli is that the location of the target is constant in the visual field. In our study, collision and noncollision objects were positioned randomly along ± 20° relative to the center of the display (as indicated in the methods section). Thus, the location of the stimuli was not constant. In addition, the projected bearing of non-collision objects was determined by the initial position and 3-D trajectory of its motion path. As a result, the bearing change was random. A second low-level feature in PL stimuli is that the visual information surrounding a target is constant. The present study included a global optic flow field simulating observer motion. The random positioning of the initial target position across a 40° range resulted in adjacent flow field velocities that varied (a target near the focus of expansion has near zero velocities, and targets further from the focus of expansion have greater velocities). A third characteristic of low-level motion training is that the stimuli have a constant speed. In the present study, the motion included expansion that was not constant but involved acceleration. These stimulus characteristics would necessarily require an observer to judge the 3-D trajectory of the motion paths rather than low-level stimulus characteristics, such as 2-D position and local velocity information. Furthermore, the variations of these factors in the stimuli increased the likelihood that learning would not be stimulus-specific. This suggests that the improved performance from training was due to more generalized learning as opposed to stimulus-specific learning that has been obtained in previous motion training studies.

In summary, the results of the present study indicate that PL can be used to improve a high-level visual task: the detection of an impending collision. The results indicate that training transferred to another display condition, suggesting that these methods can be used potentially to reduce crash risk by allowing drivers to detect collisions before they occur. These findings suggest that PL has the potential to be useful as an intervention to improve visual performance in tasks important for the health and safety of the general population. Reducing crash risk for inexperienced young drivers has been an important goal of driving safety research. Methods to reduce this risk have included graduated licensing (Ferguson, 2003) and instruction that includes crash risk and distracted driving (Senserrick, 2006). The present study suggests that, in addition to these methods, training drivers to detect impending collisions during licensing may be a useful approach to improving driver response time and reducing the likelihood of a crash.

Keywords: perceptual learning, collision detection, specificity

Acknowledgments

Support for this research was provided by NIH grant AG031941.

Commercial relationships: none.
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Footnote

[1] The beta value for the task was determined during a pilot study using the same task and stimuli.

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