Comparing Different Types of Visual Perceptual Learning Tasks' Effects on Reading Ability

by

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ABSTRACT

Magnocellular-Dorsal pathway's function had been related to reading ability, and visual perceptual learning can effectively increase the function of this neural pathway. Previous researches training people with a traditional dot motion paradigm and an integrated visual perceptual training "video game" called *Ultimeyes pro*, all showed improvement with regard to people's reading performance. This research used 2 paradigms in 2 groups in order to compare the 2 paradigms' effect on improving people's reading ability. We also measured participants' critical flicker fusion threshold (CFFT), which is related to word decoding ability. The result did not show significant improvement of reading performance in each group, but overall the reading speed improved significantly. The result for CFFT in each group only showed significant improvement among people who trained with Ultimeyes pro. This result supports that the beneficial effect of visual perceptual learning training on people's reading ability, and it suggests that Ultimeyes pro is more efficient than the traditional dot motion paradigm, and might have more application value.

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TABLE OF CONTENTS

Effect of Different Types of Visual Perceptual Learning on Reading Ability

The notion that perception is trainable has been around for over a century, and it appears to be true based on many "real life" instances (Gibson, 1953). For example, from an X-ray scan a lay person or novice might find nothing, but an expert radiologist can identify low contrast dots which might represent tumors (Snowden, Davies & Roling, 2000). In many perceptual learning studies the effect of learning is specific. For instance, Karni and Sagi's (1991) documented that visual perceptual learning has three characteristics: 1) local (on a retinotopic sense), 2) orientation specific but asymmetric, 3) strongly monocular. However, other research suggests the effect of visual perceptual learning is generalized. Ahissar and Hochstein's (1997) research shows that the specificity of visual perceptual learning changes with the difficulty of the tasks. Although in cases of high difficulty the learning effect is specific, when the task difficulty decreased (SOA between stimulus and masks become longer), learning can generalize to other orientations and retinal locations.

Neural changes in structure and function accompanying learning is thought to be the underlying mechanism of perceptual learning. Research has found a causal relationship between neural change and perceptual learning; merely training participants to generate some kind of neural change without being exposed to visual stimuli can cause visual perceptual learning (Shibata, Watanabe, Sasaki & Kawato, 2011). A changed activity pattern has been found in different brain areas for different tasks, such as V1 and V4 for the texture discrimination task (i.e. let participants identify letters on a background of certain texture; Merigan, 2000, Schoups, Vogels, Qian & Orban, 2001, Yotsumoto, Watanabe & Sasaki, 2008, Yotsumoto et al., 2009), and V3A, V5, lateral intraparietal area (LIP) or/and V4 for dot motion tasks (i.e. dots presented on the background are moving and a subset of them move in the same direction; Shibata et al., 2012, Chowdhury & DeAngelis, 2008, Law & Gold, 2008, Gilaie-Dotan et al., 2013). However, visual information move along dorsal and ventral streams and lead to response in many brain areas that connected by neural streams (Sasaki, Náñez, & Watanabe, 2010), which imply that visual perceptual learning could influence cortical areas that broader than what observed by neural imaging (see Appendix 1). Some researches propose that the changes in the primary visual cortex might be a result of modulation from higher level structures (Lu & Dosher, 2004; Xiao et al., 2008), and some research has shown activation in the left lateral prefrontal cortex accompanying the learning process in primary visual cortex (Schwartz, Maquet & Frith, 2002, Yotsumoto et al., 2009). Thus, we may wonder if it is possible that visual perceptual learning, mostly low level perceptual function improvement, might also change higher level cognitive abilities.

One study conducted by Seitz, Náñez, Holloway and Watanabe (2006) shows that participants trained with the coherent dot motion task show increased critical flicker fusion threshold (CFFT, the ability to process a rapidly flickering light until it perceptually fuses into a steady light). The improvement in CFFT, accompanying the increase in visual motion sensitivity caused by visual motion perceptual learning, remained for at least one year. CFFT was thought to be stable, and was found to relate to some intelligence tests' scores and was suggested to be a measurement of intelligence (Tanner, 1950, Zlody, 1965). The CFFT change caused by dot motion training might indicate the broad influence of this form of visual perceptual learning on cortical processing ability. Research has also found that people vary on word decoding ability as a function of CFFT, and this effect is evident in reading both real words and meaningless pseudo-words (Holloway, Náñez & Seitz, 2013). Therefore, this research suggests the possibility that visual perceptual learning might enhance reading ability.

Reading ability is profoundly influenced by vision. When reading a text, people need to make quick saccades (about 25 ms each) and fixate on right locations precisely (about 250 ms each), which requires control of eye movement and visual-spatial attention (Vidyasagar & Pammer, 2009). Developmental dyslexic patients complain about visual confusion during reading, such as letter reversals, distortion and blurring, and superimposition (Stein & Walsh, 1997, Stein, 2001). According to Stein's (2001) magnocellular theory of developmental dyslexia, these problems are caused by deficits in magnocellular pathway. People with developmental dyslexia are found to have smaller cells in the lateral geniculate nucleus' magnocell layer, and have less magnocells in retina (Stein, 2001, 2003). Information transmitted by the magnocellular pathway mainly goes to the visual dorsal stream. Research found that functions relating to the dorsal stream, such as flicker perception, are also impaired among dyslexic people (Gori et al., 2014). Vidyasagar & Pammer (2009) went further to propose that the visual dorsal pathway receives location and motion information in order to control eye movement and fixation of attention which provides information about location for further processing. They proposed that deficits in the magnocellular-dorsal stream cause failure to control visual-spatial attention and this is the mechanism underlying phonological decoding deficit, which used to be thought as the main cause of dyslexia.

As visual perceptual learning can effectively improve visual ability, and perceptual learning tasks like dot motion training can improve the function of neural structures in the magnocellular-dorsal pathway (such as V1, V5/MT+, LIP, etc.), it is reasonable for us to think about the possibility that visual perceptual leaning might be able to increase reading ability by improving magnocallular-dorsal pathway capacity. One of the visual perceptual learning tasks we could consider is the coherent dot motion task. Brain areas in visual dorsal stream, such as middle temporal area, are sensitive to motion speed and direction (Born & Bradley, 2005). Stein (2003) also proposed to use visual motion sensitivity as an indicator of developmental dyslexia. Research has shown that coherent dot motion training can lead to changes in neurons in the middle temporal area (Britten, Shadlen, Newsome & Movshon, 1992) and can improve people's visual motion sensitivity (Ball & Sekular, 1982). In fact, one study using supraliminal coherent dot motion training demonstrated that participants trained for 4 days and exposed to 1000 trials each day have shown a significant improvement in reading comprehension scores as measured by the Wide Range Achievement Test 4th edition (WRAT IV; Groth, 2013). This improvement is also accompanied by increased CFFT. In our study we will use a rapid serial visual presentation task, with subliminal dot motion on the background, which can also lead to significant perceptual learning (Watanabe, Náñez & Sasaki, 2001, Watanabe et al., 2002).

Recently new training paradigms on visual perceptual learning have been developed to make visual perceptual learning more applicable. These new paradigms are designed to overcome the specificity of perceptual learning, and integrate multiple approaches to amplify the learning effect (Deveau & Seitz, 2014). Ultimeyes pro is one of the new training paradigms and it is an integrated perceptual training "video game" (Deveau, Lovcik & Seitz, 2014). In this video game, participants are required to select Gabor patches of specific orientations and spatial frequency that appear on different locations of the screen, and a score based on accuracy and speed is given at the end of each session as feedback. When a Gabor patch has been correctly chosen, participants will hear a sound with different pitches. The pitch identifies the targets location on the screen (e.g. correctly choosing targets on the upper side of the screen are identified by a higher pitch sound and correctly choosing targets on the lower side of the screen are paired with a lower pitch). As an integrated perceptual training paradigm, this "video game" has several advantages over traditional visual perceptual training paradigms. Firstly, this program uses many different mechanisms in order to diversify the training effect including multiple orientations, spatial frequencies, locations, and distractor types which according to research using the “double training” paradigm, could transfer the learning effect to different locations on the visual field, and lead to more general learning (Xiao et al., 2008). Secondly, this program is shorter than traditional training paradigms, and the diversity of tasks presented in this program may prevent the perceptual saturation effect which can be induced by intense testing and can decrease the overall learning effect (Censor & Sagi, 2008). Thirdly, this training program includes multiple features that may lead to beneficial effects that go beyond the M-D stream because targets are paired with auditory signals (different pitches of sound correspond to different location of target), which allows for multisensory learning (Shams & Seitz, 2008).

Research has shown that Ultimeyes pro can significantly increase lower level visual abilities in normal participants, such as visual acuity and contrast sensitivity (Deveau, Lovcik & Seitz, 2014), and it can also help improve real time performance such as baseball players’ performance in matches during a season (Deveau, Ozer & Seitz, 2014). This program has also shows an effect on people’s reading ability; participants trained by this program increased their reading acuity (the smallest word that can be read) and reading speed (Deveau & Seitz, 2014). However, whether the new paradigm is more powerful that traditional paradigm on different aspects of visual perceptual learning has not been tested. In this research, I will compare two groups of normal college students who are trained by either Ultimeyes pro or the coherent dot motion task, in terms of their effects on participants’ reading ability and CFFT.

Method

Participants

The participants were 21 normal college students (mean age = 22.90, SEM = 7.09) with normal or corrected to normal visual acuity (better than 20/40 on Snellen scale). They were randomly assigned to the Ultimeyes pro training group (10 participants, 4 of them are male) or the dot motion training group (11 participants, 2 of them are male). The age in 2 the groups was the same according to independent t- test, t (19) = 1.390, p = .181. All participants have at least 20/40 visual acuity on the Snellen scale for corrected or uncorrected vision. Participants signed consent forms and are compensated with either $75 or 12 class research credits for their participation.

Measurements

Critical Flicker Fusion Thresholds (CFFT) was assessed in a dark room with a Macular Pigment Densitometer, which is a tabletop device that has the same function as Maxwellian view (Wooten, Hammond, Land & Snodderly, 1999). The method used was the method of limits (the mean of three descending measures from a high to a low frequency of flicker in which the participants report when the stimulus begins to flicker, and three ascending measures from a low frequency to a high frequency in which the participant reports when the flicker stops) and the stimulus is a 1-deg diameter green (543nm) round flicking light area on black background. During testing participants were asked to put their right eye close to the eyehole in order to fixate their fovea on the green light. The experimenter changes the flickering frequency slowly using a knob, and participants report when the flickering green light stops flickering for low to high frequency trails, or when the solid green light starts to flickering for the high to low frequency trails. The frequency they reported is recorded and the average of the 6 frequencies is the participants' Critical Flicker Fusion Threshold.

To test reading speed and comprehension we used the word reading and sentence comprehension part of Wide Range Achievement Test 4^{th} edition (WRAT IV). The test has 2 versions that are equivalent to each other, one is blue and the other is green, which are served for pre- and post- tests. The participants were pre-tested with either the green version and post-tested with the blue version, or pre-tested with the blue version and post-tested with the green one. The order of administration of the 2 versions of test was counterbalanced between participants. For every test we started with the word reading part, then the sentence comprehension test, and then the score of sentence comprehension was normalized using the scale of the inventory. All the participants are naïve to this test. The method of administrating the test is based on the Wide Range Achievement Test 4 Professional Manuel (Wilkinson & Robertson, 2006).

Visual Perceptual Training

Dot Motion Training and Tests

All motion test and training sessions are run using custom software on computers with 19'' CRT monitors, at a resolution of 1280 x 768, at 75Hz, controlled by Dell Optiplex Computers running Windows 7 or greater. Participants view the display at a distance of approximately three feet, and data were collected in a dim room with the ambient light level held constant during the experiment.

Motion stimuli consisted of a dynamic array of grey dots (0.2 degree radius, 400 dots for test and 300 dots for training) on a light grey background with each dot having a 3-frame lifetime for both the testing and the training phase.

Motion testing that occurring during the pre and post-test phases shows dim dynamic motion in four non-cardinal directions (45°, 135°, 225°, 315°), which display for 1000ms. Following that is a forced-choice display with arrows pointing in four directions that match the possible motion directions (see Appendix 2). The participant clicked on the arrow that represents the direction of motion in which they believe the dots were traveling. The percentage correct responses was assessed over 5 blocks of 200 trials each, for a total of 1000 trials per test.

The main task was to identify a pair of brightly colored target shapes from a serial display of brightly colored distracter shapes (see Appendix 3.), similar to Seitz, Náñez, Holloway and Watanabe's (2006), except for the alteration of the central task. In previous research the central task was remembering letters, in this task it has been changed into shape pairs in order to avoid confounds in testing the effect of dot motion on reading ability. Each trial starts with a pair of shapes as target which displayed for 1000ms. Then, the paired shapes are replaced with a serial presentation of seven randomly generated paired distracter shapes and one pair of target shapes each displayed for 250ms. At the end of the serial display the participant is required to indicate with a mouse click if the target shapes were present. A dim, task-irrelevant dot motion (as described herein for each experiment) is presented in conjunction with either the initial display of the paired shape target or within the serial presentation in conjunction with the target pair. This dot motion is the training stimulus and its direction is constant for each individual participant. This procedure is repeated in 5 blocks of 50 trials each for a total of 250 trials per training session.

Ultimeyes pro training

A custom video-game based Gabor-patches training platform (UltimEyes pro) is run on a MD510LL/A iPad. The objective for the participant is to press on all the Gabor targets as quickly as possible; a score is shown on the top of the screen, which is determined both by correctly choose a target and the reaction time for that correct response. At the beginning of each session the participants is shown Gabor patches of different contrast in one screen containing the contrast level from subliminal to supraliminal, and the calibration determines the initial contrast in each training session.

Each game training session contains 8 to 12 exercises for approximately 2 min each. The exercises alternate between static and dynamic types; in the static game an array of targets of a single spatial frequency and random orientations is presented at once. In the dynamic game, targets of a combination of random orientation/spatial frequency were presented one at a time, which fades in at random locations on the screen. As the training progresses distracters were added in each trial, and choosing distracters leads to losing points. Together, these games were designed to broadly exercise visual processes. A screen shot of the game is shown in Appendix 4.

Procedure

For all the participants at the pre-test, the visual acuity was assessed with a Snellen scale, to ensure that they had 20/40 correct or non-corrected vision. Then they were tested for Critical flicker fusion threshold on Macular Pigment Densitometer in a dark room without ambient sound or light. After that, they were tested with the word reading and sentence comprehension part of the WRAT IV.

Next, one group of participants was trained on the Ultimeyes Pro task in a dark room without ambient light or sound during 8 training sessions; each test session lasted for approximately 25 min. Participants completed 1 session per test day. IPad screens were wiped and cleaned after each session. During training, the participant’s performance was recorded by the program.

In the other group, participants were trained with the dot motion tasks in a room with controlled for ambient light and sound. Participants took one motion test on pre-test day, which lasted about 45 min, and the contrast level of the moving dots in shape training were determined by the contrast level at which they performed at 50% correct accuracy in the motion test. On successive days they were trained on shape training task for 8 days and 1 session per day. The shape training also took about 45 min each session.

On the post-test day, every participant was tested for CFFT and on the WRAT IV word reading and sentence comprehension part of the alternative color version. For the dot motion training group, they also went through a motion test to assess the effect of perceptual learning. The flow chart of experiment procedure is in Appendix 5.

Results

Firstly, the pre- and post-test performance of each group on reading and CFFT were analyzed separately using paired t-test. For the Ultimeyes pro group, the CFFT after the training (M = 21.20 Hz, SD = 1.73) significantly larger than pre-test (M= 19.85 Hz, SD = 1.08), t (9) = -2.38, $p < .05$, $\eta^2 = .39$. The reading performance had not shown significant improvement after Ultimeyes training. Reading speed was the time used in completing WRAT IV sentence comprehension part, which was measured in seconds. In the pre- and post-tests, the reading speed increase showed a trend toward significance, with the post-test reading time (M = 496.18 s, SD = 69.42) shorter than pre-test (M = 534.04 s, SD = 60.33), t (9) = 2.05, $p = .07$, $\eta^2 = .32$. The sentence comprehension score are the number of correct answers in fifty questions transformed into standard score based on WRAT IV professional manual (Wilkinson & Robertson, 2006). This score did not significantly change after training, t (9) = -.38, $p = .72$, $\eta^2 = .02$. These results are shown in Appendix 6.

For the dot motion training group, the CFFT increase only showed a trend toward significance, from pre-test (*M* = 18.57 Hz, *SD* = 1.75) to post-test (*M* = 19.21 Hz, *SD* = 2.48), *t* (10) = -1.95, *p* = .08, η^2 = .28. Reading speed increase also only showed a trend toward significance, the reading speed for post-test (*M* = 574.65 s, *SD* = 140.39) is shorter than pre-test (M = 639.64 s, SD = 206.28), *t* (10) = 1.94, *p* = .08, η^2 = .27. Sentence comprehension score did not significantly increase after training, *t* (10) = -1.31, *p* = .22, η^2 = .15. For the dot motion training, we also did a dot motion detection test in order to see the effect of visual perceptual learning. Unexpectedly, the dot motion test failed to show the effect of perceptual learning; the percentage of correct response in identifying dot moving direction did not increase after training, *t* (10) = -.17, *p* = .87, η^2 = .003. The detailed results are shown in Appendix 7.

CFFT, reading speed and sentence comprehension in two groups were analyzed together in order to compare the performance in two groups. Repeated measure ANOVA was performed on the three dependent variables separately. For CFFT, the main effect by training is significant; overall the CFFT in post-test (*M* = 19.18 Hz, *SD* = 1.58) increased from pre-test (*M* = 20.16 Hz, *SD* = 2.34), *F* (1, 19) = 9.63, *p* < .05, η^2 = .32. The main effect by group was significant; in the Ultimeyes pro group the CFFT was higher than the dot motion training group, *F* (1, 19) = 4.85, *p* < .05, η^2 = .20, and the interaction between training and group was not significant, *F* (1, 19) = 1.252, *p* = .277, η^2 = .04 (see Appendix 9). For reading speed, the main effect by training was significant; participants used less time completing the sentence comprehension in the post-test (*M* = 537.28 s, *SD* = 116.77) than in the pre-test (*M* = 589.35 s, *SD* = 160.73), *F* (1, 19) = 6.84, *p* < .05, η^2 = .26; the main effect by group (*F* (1, 19) = 2.71, *p* = .12, η^2 = .12) and the interaction between training and group (*F* (1, 19) = .48, *p* = .50, η^2 = .02) were not significant (see Appendix

10). For sentence comprehension, the main effects of group and training and the interaction between group and training were not significant. The results are shown in Appendix 8, 9 & 10.

Discussion

The results shows that, overall, visual perceptual training improved participants' CFFT and reading speed, which is consistent with previous research. This study was the first to show that the Ultimeyes pro can improve CFFT, which indicates that this visual perceptual learning video game can improve people's temporal processing ability. The improvement in the group trained by Ultimeyes pro was greater than that of the group trained with the dot motion task. Though the difference in improvement between the 2 groups is not very large, we should note that that participants using the Ultimeyes pro generally take around 25 min to complete a session, while the dot motion training usually takes 45 min, and both training tasks are conducted for 8 sessions. Thus, Ultimeyes pro took about half the time required by the dot motion training, and the effect was larger, which indicates that this integrated video game is possibly better at improving people's neural functions than the traditional perceptual learning paradigm.

When CFFT and reading performance in 2 groups were analyzed separately, the only significant improvement was in the CFFT in Ultimeyes pro group. This effect was much weaker than has been reported on previous research. This lack of significance might be caused by the relative small sample size and short training time. In Seitz, Náñez, Holloway and Watanabe's (2006) study using dot motion training to improve CFFT, there were 26 participants and the training lasted for nine days. In Deveau and Seitz's (2014) study using the Ultimeyes pro to improve participants' reading speed, 44 participants were used. In our study, even when the increase was not significant, the effect size was at least medium for CFFT and reading speed in each group. When the 2 groups were combined together, the CFFT and reading speed improved considerably. This also suggests that the lack of significant in each group was probably due to the small sample size. Thus, from our results, we can still infer that both of the visual perceptual learning paradigms used in our study are promising in improving participants' reading ability.

In our study the reading comprehension performance did not increase even when the results of the 2 groups are combined, which is different from previous research conducted in our lab (Groth, 2013). However, in that study, compared to other improvements, sentence comprehension score did not increase as much (n_p^2 = .25). For visual perceptual learning, although fMRI scans during consolidation process show that brain areas that are related to higher order cognitive abilities such as left lateral prefrontal cortex have activity, when performing the tasks that measures the effect of perceptual learning after training, the area that shows increased activation is restricted to the primary visual cortex such as V1 (Yotsumoto et al., 2009). This indicates that the learning process might involve higher level areas, but the learning effect is largely restricted to primary perceptual areas. According to Vidyasagar & Pammer's (2009) hypothesis, the role of visual dorsal stream in reading is to control eye movement and in turn control visual-spatial attention during reading. Stein (2001; 2003) also indicated that dyslexic children show disability in tuning binocular disparity. Sentence comprehension is related to many aspects of cognitive abilities, such as defining orthographic writings and retrieving semantic memory, and eye movement and visual-spatial attention are just two of the factors involved in it. For normal people, this dorsal stream function might affect reading speed significantly but, for reading comprehension, the normal eye-moving ability is good enough and improvement in it will not much affect comprehension. As the paradigms in our study only shown effect in primary visual functions, and it is very likely that the visual perceptual learning might only be restricted to primary visual areas, it may be reasonable for us to find improvement in reading speed but not in reading comprehension.

Another problem with our results is that for the dot motion training group, the performance in motion test did not increase in the post test, which means that the effect of perceptual learning did not show in the motion detection task. This was possibly caused by the saturation effect. In Censor and Sagi's (2008) research they found that overtraining can cause a saturation effect, which is a decrease in perceptual task performances after intensive training. This effect is feature specific and location specific, and long lasting, as it persists throughout the training process. This indicates that saturation could happen at primary visual cortex at the area in which perceptual learning usually happens. In our research this saturation effect might also have happened in some participants, which decreased their performance after training. Perhaps their performance on CFFT and reading was also affected by the saturation effect. This effect shows the deficit of traditional perceptual training paradigm; they generally present similar stimulus to participants repetitively, and the tasks are hard and tedious, as participants complained. The Ultimeyes pro avoided these deficits, and is less likely to cause this negative effect.

Perceptual learning is involved in many learning processes. In order to make people's learning more efficient, it may be necessary to assess the effect of perceptual learning and to know how many functions it can influence. The results of our study showed that perceptual learning has effects on human reading speed and temporal processing ability. It just shown minor effects on normal college students, it might because normal people's M-D pathway have good enough function for them to read. For people with developmental dyslexia, their reading ability is more influenced by deficit in M-D pathway, so perceptual learning enhanced M-D pathway function might improve their reading ability to a larger extent. Also these programs could have better effect on developmental dyslexia children. The disease is named developmental dyslexia because it is found during the development process of brain, and traditional treatment on it, such as monocular occlude (Stein, 2001), also only works for children in certain age. We can expect that in future research we can find that visual perceptual training programs, especially for the Ultimeyes pro, would have high application value in treating people with developmental dyslexia.

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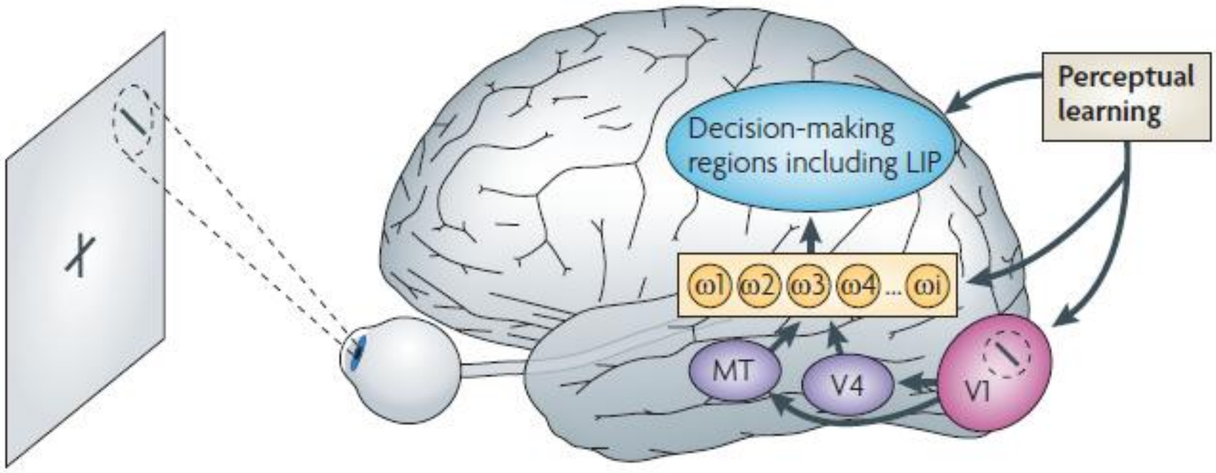
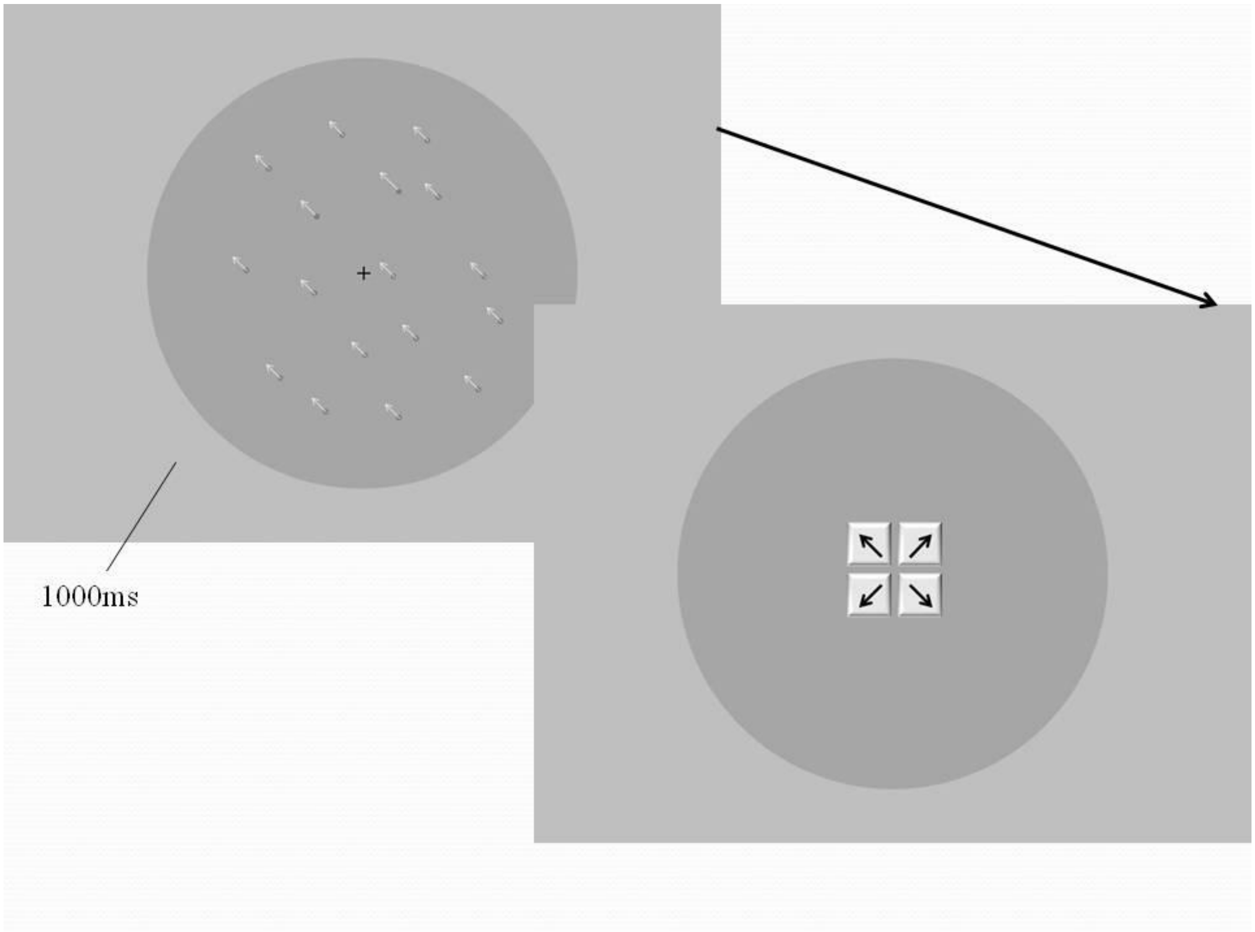
APPENDIX

Appendix 1:



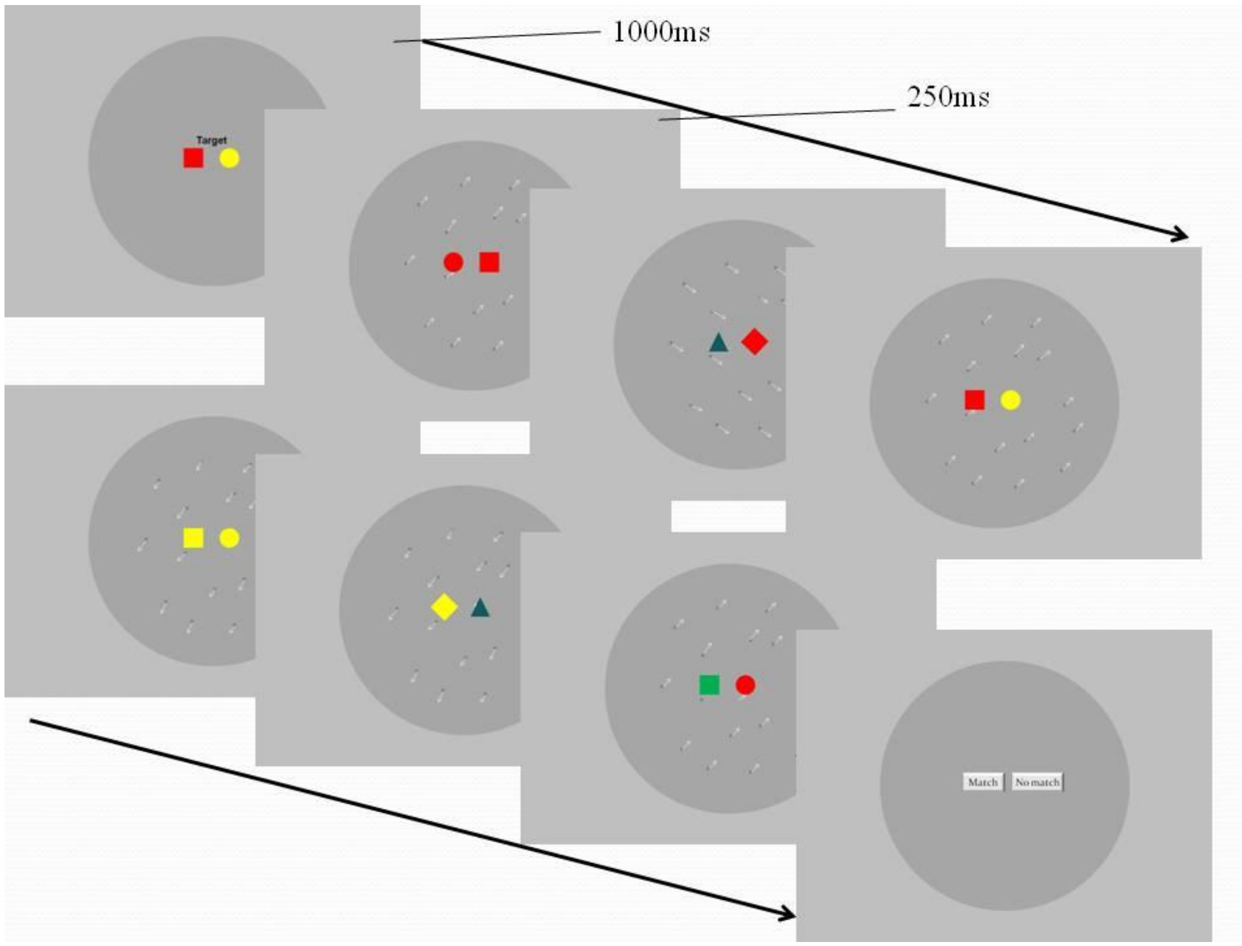
Location where visual perceptual learning occur. For different visual perceptual learning task learning happen at different locations on brain cortex. But the visual information is moving along neural streams which connect different brain areas together, implying that effect of perceptual learning can be generalized. Figure cited from Sasaki, Náñez, & Watanabe, "Advances in visual perceptual learning and plasticity", 2010.

Appendix 2:



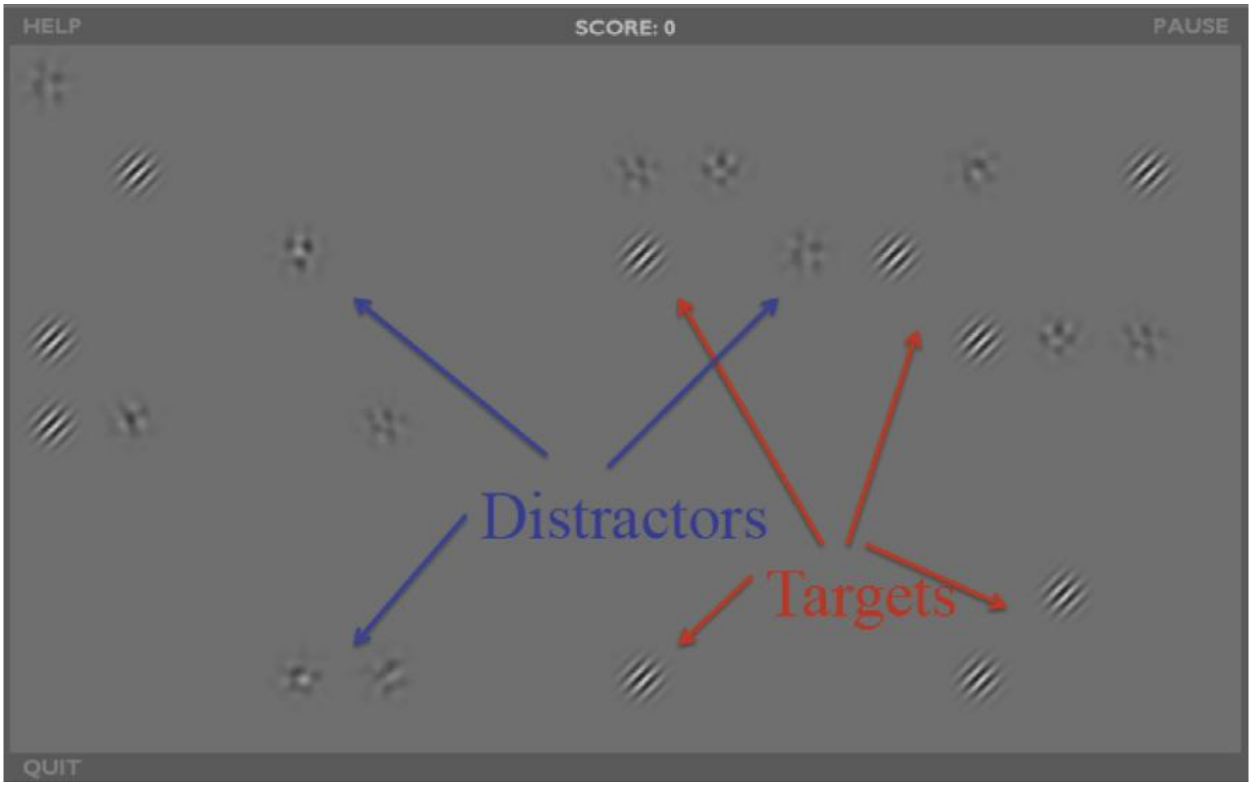
Dot motion test. For each trial of the motion test the moving dots will first show on the back ground for 1000ms, then they stops move and 4 choices come out for participants to choose with mouse click.

Appendix 3:



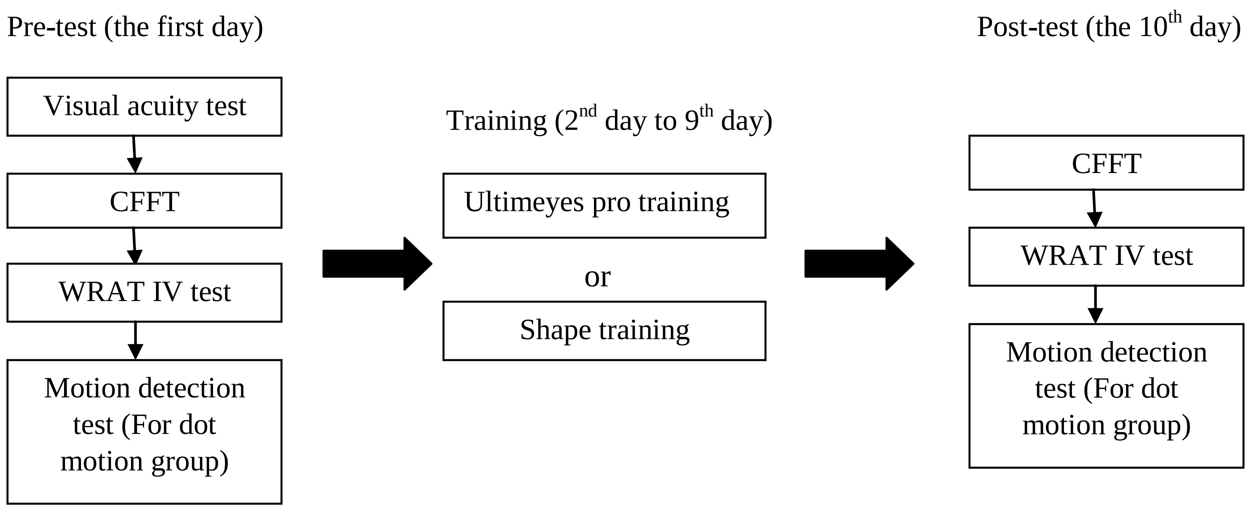
Shape training. Each trial start with a target which present for about 1000ms, then a sequence of random pairs of shapes show up, each present for 250ms. Participants need to find if any shape pair matches the target. At the end of each trial, the participants will need to choose between “match” and “no match” by mouse clicking. Stimulus that right below participants’ threshold of perception appear at the time contingent with all of the presented shape pairs and only one direction is paired with the targets during training for each participants.

Appendix 4:



Game screenshot. In static exercise the Gabor patches will come out all together, in the dynamic exercise the Gabor patches will come out one by one. As training progress distractors will come out with targets, and the distractors will become more like thetargets as the exercise become harder. Participants need to press on the targets as quick as possible and avoid choosing the distractor. (Picture from Deveau, Lovcik & Seitz, “Broad-based visual benefits from training with an integrated perceptual-learning video game”, 2014)

Appendix 5:



Experiment procedure. In the pre-test we first tested the visual acuity for every participants to ensure 20/40 vision on snellen scale. Then participants' Critical flicker fusion threshold (CFFT), reading speed and reading comprehension on WRAT IV sentence comprehension test are measured. For participants that trained with dot motion task, there is a motion detection pre-test to test their perception of motion. Then participnats were trained by either by ultimeyes pro or shape training test 1 session per day for during 8 training days. Then at the last day CFFT, WRAT IV sentence compreension and motion detection test for dot motion group are retested to measure the effect of training.

Appendix 6:

Performance of Ultimeyes pro training group

		Mean (SD)	t-score	p	η^2
CFFT	Pre-test	19.85 (1.08)	-2.354*	.042	.39
	Post-test	21.20 (1.73)			
Reading speed (seconds)	Pre-test	534.04 (60.33)	2.054^{+}	.070	.32
	Post-test	496.18 (69.42)			
Sentence comprehension	Pre-test	104.80 (13.74)	-.375	.717	.02
	Post-test	106.10 (15.61)			

Note.$^{+}$ = $p \leq .1$, * = $p \leq .05$, *** = $p \leq .001$.

Appendix 7:

Performance in dot motion training group

		Mean (SD)	t-score	p	η^2
CFFT	Pre-test	18.57 (1.75)	-1.95^{+}	.08	.28
	Post-test	19.21 (2.48)			
Reading speed (seconds)	Pre-test	639.64 (206.28)	1.94^{+}	.08	.27
	Post-test	574.65 (140.39)			
Sentence comprehension	Pre-test	99.64 (10.36)	-1.31	.22	.15
	Post-test	104.00 (12)			
Motion detection test	Pre-test	.57 (.15)	-.17	.87	.003
	Post-test	.57 (.13)			

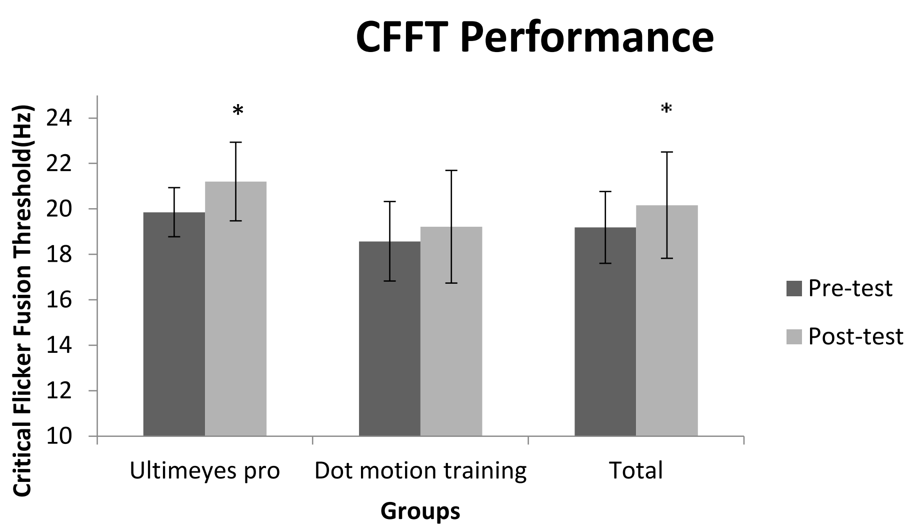
Note.$^{+}$ = $p \leq .1$, * = $p \leq .05$, *** = $p \leq .001$.

Appendix 8:

Performance of two groups on CFFT, reading speed and sentence comprehension.

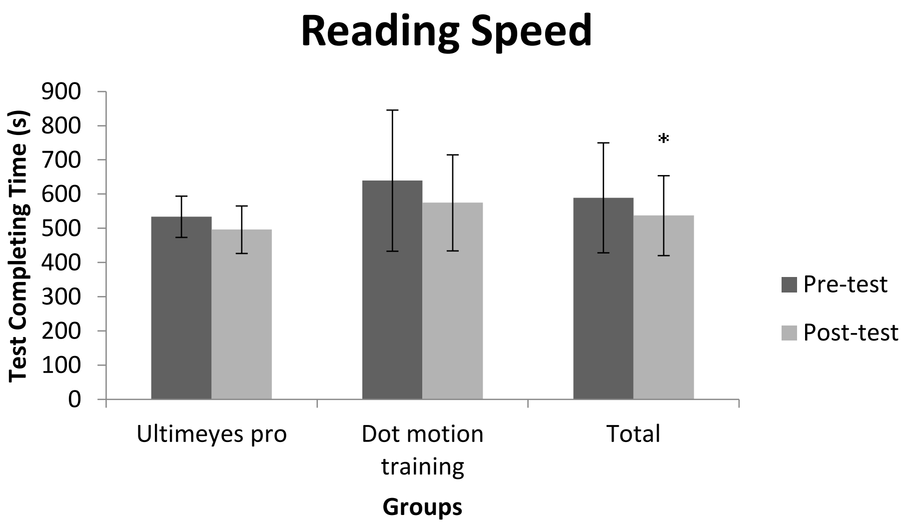
	Ultimeyes group		Dot motion group		Total	
	Pretest(M/SD)	Posttest(M/SD)	Pretest(M/SD)	Posttest(M/SD)	Pretest(M/SD)	Posttest(M/SD)
CFFT	19.85/1.08	21.20/1.73	18.57/1.75	19.21/2.48	19.18/1.58	20.16/2.34
Reading speed (seconds)	534.04/60.33	496.18/69.42	639.64/206.28	574.65/140.39	589.35/160.73	537.28/116.77
Sentence comprehension	104.80/13.74	106.10/15.61	99.64/10.36	104.00/12.00	102.10/12.07	105.00/13.52

Appendix 9:



Note. * = $p \leq .05$, *** = $p \leq .001$.

Appendix 10:



Note. * = $p \leq .05$, *** = $p \leq .001$.