

Neural Plasticity in Lower- and Higher-Level Visual Cortex Processing

by

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ABSTRACT

Perceptual learning by means of coherent motion training paradigms has been shown to produce plasticity in lower and higher-level visual systems within the human occipital lobe both supra- and subliminally. However, efficiency of training methods that produce consolidation in the visual system via coherent motion has yet to be experimentally determined. Furthermore, the effects of coherent motion training on reading comprehension, in clinical and normal populations, are still nascent. In the present study, 20 participants were randomly assigned to one of four experimental conditions. Two conditions had a participation requirement of four days while two conditions required eight days of participation. These conditions were further divided into 500 or 1000 trials per day (4 x 500, 4 x 1000, 8 x 500, 8 x 1000). Additional pre-test and post-test days were used to attain timed pre- and post-tests on the Wide Range Achievement Test IV (WRAT IV) reading comprehension battery. Furthermore, a critical flicker fusion threshold (CFFT) score was taken on a macular pigment densitometer on the pre-test and post-test day. Participants showed significant improvement in CFFT levels, WRAT IV reading comprehension, and speed of completion between pre-test and post-test; however, degree of improvement did not vary as a function of training condition. An interaction between training condition and degree of improvement was evident in coherent dot motion contrast scores, with significant training plasticity occurring in the 4 x 1000 and 8 x 500 conditions.

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Neural Plasticity in Lower- and Higher-Level Visual Cortex Processing

Neuroplasticity is defined as changes in neural pathways due to variations in behavior and environment and is long lasting. It is a significant biological process because neuroplasticity allows for flexibility in learning new things and enables adaptation over a lifetime. Neuroplasticity has been confirmed to occur in conceptual learning and perceptual learning tasks. Conceptual learning, high-level processing, refers to the capacity for forming a whole from a number of parts; however, the focus of the present study is on perceptual learning (PL), low-level processing, which refers to changes in sensory abilities (i.e. vision, audition, etc.) that occur through training over time. PL is thought to be an important process that enables us to adapt to our physical environment with experience and time (Seitz, Nanez, Holloway, Tsushima, & Watanabe, 2006). Prior research has shown that PL is sensitive to relevant features (targets) and non-relevant features (distracters) during visual tasks in lower-level processing (texture, shading, and contrast) systems of our visual system (Le Dantec, Melton, & Seitz, 2012). Moreover, it has been demonstrated that conscious effort or attention is not needed to increase visual PL (Sasaki, Nanez, & Watanabe, 2010; Seitz, Kim, & Watanabe, 2009).

A number of coherent motion paradigms have been developed in order to generate perceptual learning in experimental laboratory settings. In regards to perceptual tasks, coherent motion refers to the ability to discriminate unidirectional motion among a number of visual distracters. Coherent motion has been demonstrated to increase plasticity to a coherent dot motion task (discriminating between coherently moving dots among random motion dots) over time as well (Sasaki, et al., 2010). It is also known that the plasticity represents learning as opposed to training. While animal research shows

that animals can be trained to increase performance on a perceptual task (Nealey & Maunsell, 1994), for some time it was unclear whether human perceptual learning to a low level visual task constituted short-term learning that disappeared soon after training or remained across time (a definition of learning). Watanabe, Nanez, Koyama, Mukai, Liederman, and Sasaki (2002) showed that PL of a low-visual task persisted for at least 6 months after training, showing that training on a dot motion task can produce long-term learning. Coherent motion PL has also been shown to be related with critical flicker fusion thresholds, the frequency at which an intermittent light stimulus appears to be solid (Seitz, Nanez, Holloway, & Watanabe, 2005), vernier hyper-acuity, the ability of the eye to detect the differences in the spatial locations of two or more stimuli (Fahle, Edelman, & Poggio, 1995; Sotiropoulos, Seitz, & Series, 2011), and contrast perception levels, the ability to distinguish between different levels of brightness (Seitz et al., 2006). However, developing consistency in coherent motion paradigms remains problematic. Experimental methods in coherent motion paradigms vary from 200 – 1024 exposure trials over multiple training sessions (Censor & Sagi, 2008; Dobres & Seitz, 2010) ranging from several sessions within one day, (Censor & Sagi, 2008) to multiple concurrent days of repeated exposures (Le Dantec et al., 2012). The literature shows that there is a need to better understand how time (the number of training days) and trials during individual training sessions affects plasticity (i.e. what is the shortest time frame [in days] and number of trials [per training session] that leads to plasticity on visual PL tasks?). For example, research by Censor and Sagi (2008, 2009) has shown that intensive training reduces performance on PL and sensorimotor tasks (tasks involving both perception and movement). Due to these findings, Censor and Sagi (2008) hypothesize

that there may be a point of saturation (an overload of information) or habituation (slowing of response time as a result of repeated activation) due to overtraining which may limit processing efficiency. Alternatively, short training produces consolidation of memory (PL) within the visual system, i.e. plasticity; however, this case remains to be determined. Additionally, it has been found that after an initial increase in PL performance, performance then decreases within a single session with further training (Ofen, Moran, & Sagi, 2007), supporting the saturation/habituation hypothesis. Mednick, Arman, and Boynton (2005) suggest that detriments to learning during training may also be due to changes in the ability of visual attention to enhance low-level orientation-selective neuron responses (i.e. the threshold for stimulation of specific neurons is not attained after initial training). Furthermore, multisensory feedback (audio and visual pairing of feedback about correct vs. incorrect responses) has been shown to facilitate visual learning over unisensory (audio or visual feedback alone) visual training (Seitz, Kim, & Shams, 2006; Seitz et al. 2006). Additionally, physical rewards (e.g. water after a period of fasting) have been shown to elicit PL (Seitz, Kim, & Watanabe, 2009). Thus, multiple researchers have found interesting findings about visual PL. A crucial step in developing a more consistent PL research paradigm is to establish the parameters (i.e. time (in days) and number of trials) of the most effective methodology on PL visual tasks. Accomplishing this task is important, as it will allow researchers to conduct PL experiments using uniform methodology in PL studies.

Besides the issues of exploring the time (number of days) x trials (number of trials per training session) that produce plasticity, there is the issue of identifying the neural system (systems) involved in brain plasticity to visual PL tasks. The dual stream theory

for visual processing proposed by Milner and Goodale (2007) suggests that there is a visual stream for action, the dorsal stream, and a visual stream for perception, the ventral stream. This theory has been validated using a range of techniques. For instance, in trans-cranial magnetic stimulation (TMS) studies, participants receive magnetic stimulation to specific cortical areas of the brain (temporal/ventral and parietal/dorsal), essentially causing a brief period of ablation during which participants function without a dorsal or ventral stream (Lee & van Donkelaar, 2002). In size-contrast illusions studies, participants' visual responses to visual illusions (Titchener circles) deviate from their motor responses. While their ventral visual stream is unable to distinguish between the size of two objects in a visual illusion, their motor action to pick up objects (influenced by the dorsal visual stream dorsal) remains unaffected (Aglioti, DeSouza, & Goodale, 1995). Support for the dual visual stream theory of visual processing also comes from neuroimaging studies (Kassubek, Schmidtke, Kimmig, Lucking, & Greenlee, 2001; Mochizuki-Kawai, Tsukiura, Mochizuki, & Kawamura, 2006).

Coherent motion paradigms are believed to generate plasticity in the dorsal stream by way of the magnocellular pathway. This pathway begins at the lateral geniculate nucleus of the thalamus into area V1 of the cortex. Once information reaches V1, it moves toward higher order processing areas in the cortex. This leads to the interesting question of whether PL in a lower-level (V1) task (i.e. dot motion detection and processing) is related to or facilitates PL in other more cognitive PL tasks. Recent research (Seitz et al., 2004) has demonstrated that critical flicker function can be significantly enhanced by pairing repeated flicker fusions task with dot motion across time. The critical flicker fusion threshold (CFFT), which is thought to be related to

cognitive ability (Seitz et al., 2005), involves quick amplitude modulations of a light source that becomes undetectable as the frequency modulation. A long-standing theory is that CFFT is a measure of cognitive abilities that is stable over time. Interestingly, Seitz et al. (2004) found that when a critical flicker task is paired with a dot motion task over 1600 trials over 9 days, CFFT improved significantly over a control group that did not experience the dot motion task. The control condition results supported the original hypothesis that CFFT is stable over time. The new finding challenges this long-standing hypothesis and demonstrates that pairing an established task with a new PL task can lead to increased plasticity in both tasks. Preliminary research has also shown that pairing the dot motion and CFFT paradigms enhances word decoding ability, the ability to distinguish nonsensical words from actual words (Holloway, Nanez, & Seitz under revision). Nanez, Holloway, Donahoe, and Seitz (2006) showed that individuals with higher CFFT thresholds out performed individuals with a lower-level CFFT on a word decoding task, regardless of whether the words were real or non-words. This preliminary finding is interesting because further supported, it opens the door for future research in which pairing a low-level visual perception task (dot motion) with a higher-level visual task CFFT may lead to improvement on an orthographic task (word decoding).

The current study did not include a word detection task. Rather, it went directly to a reading performance task to see if plasticity in dot motion and CFF enhance reading ability. A primary objective of the current study was to see if there is a relational effect between V1 task (dot motion) plasticity and a dorsal stream task (CFFT) with a complex cognitive task (reading). To explore this relationship, we used the reading comprehension sections of the Wide Range Achievement Test (WRAT IV) Reading Comprehension

Inventory. The WRAT IV Reading Comprehension Inventory consists of 50 fill-in-the-blank sentences that increase in difficulty as the test continues. Processing of the dot motion and CFFT tasks involves progressively increasing visual/cognitive function of the dorsal (magnocellular) stream; whereas, reading involves increased cognitive processes beyond dot motion and CFF. Normal readers show a distinct processing ability relative to clinical populations (e.g. dyslexics). The magnocellular theory of developmental dyslexia, purported by Stein (2001), suggests that the visual magnocellular system is responsible for timing visual events while reading. Additionally, good magnocellular function is necessary for motion sensitivity, and stable binocular fixation, both of which are necessary for successful reading. Without a properly functioning magnocellular system, readers are prone to retinal slip in which images move off the fovea, creating difficulties in visual tracking during the reading process (Lovegrove, 1993; Stein, 2001). Magnocellular defects have been found through physiological studies of dyslexic brains (Galaburda & Livingstone, 1991), and fMRI studies in individuals who have been diagnosed with developmental dyslexia (Cohen, Henry, Dehaene, Martinaud, Lehericy, Lemer, & Ferrieux, 2004). However, there is still little research on the relationship between coherent motion training, CFFT, and their influence on reading performance in normal non-dyslexic readers. Moreover, because most of the current literature focuses on children with low-reading scores (Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998) and relatively little research has examined adolescent and adult populations. The current study focused on young adults attending a larger Southwestern University.

In the present research, we compared reading comprehension and rate of reading across four coherent motion training conditions (4 days 500 trials/day, 4 day 1000

trials/day, 8 days 500 trials/day, 8 days 1000 trials/day). All participants took part in pre-test assessments in which a critical flicker fusion threshold score was obtained, as well as a timed reading comprehension test that is scored based on age and performance. During the training participants were presented with coherent dot motion on a computer monitor. Auditory and visual feedback indicating whether participants' responses were correct or incorrect was given after completion of each trial. Additionally, participants completed a post-test that included obtaining their critical flicker fusion threshold score and an alternate timed reading comprehension test.

We reason that critical flicker fusion threshold scores will improve after PL coherent dot motion training as found in prior research (Seitz et al., 2005, 2006). Additionally, it is hypothesized that reading comprehension and speed will improve. That is, to the extent that the link between coherent motion training and magnocellular stimulation facilitates improvements in eye tracking and preventing retinal slip, reading abilities may also be enhanced (Stein, 2001). It is further hypothesized that all training conditions will be sufficient for improving reading comprehension and speed. A major goal of this study is thus to determine the most efficient number of days and trials for producing an optimal will increase in visual plasticity in low- and high-level processing. This finding will enable future PL studies to produce sufficient plasticity (i.e. changes in CFFT, contrast) in a minimal amount of time and trials.

METHOD

Participants

Twenty participants (Males = 6 , Females = 14, aged 18-28 years, $M = 20.95$, $SD = 3.03$) were recruited from a large Southwestern university. Participants were randomly

assigned to one of four experimental conditions (4 day x 500 trials, 4 day x 1000 trials, 8 day x 500 trials, or 8 day x 1000 trials). Participants were compensated for their time with a monetary payment of \$10 dollars a day to be paid daily or in whole at completion of the study. All participants reported good ocular health, (verbally and via medical history responses on Qualtrics survey software) and had a best corrected visual acuity (tested on-site) of 20/40 Snellen. Informed consent was obtained from all participants and all participants were naïve to the purpose of the study.

Materials and Procedure

All participants performed a practice paradigm in which stimuli were presented on a 19-inch cathode ray tube monitor with a resolution of 1,152 x 768 pixels and a refresh rate of 75 Hz using custom software written for a Macintosh G4 computer. The distance between the subjects' eyes and the monitor was fixed by having them position their head in a chin rest 32 inches from the monitor screen. In a dimly lit room, participants reported the off-cardinal direction (70° , 160° , 250° , or 340°) of a motion display consisting of 200 coherently moving dots that were displayed in an annulus (1° inner diameter, 10° outer diameter) at a luminance-contrast level of 11.8 cd/m^2 RMS for all trials. Subjects viewed a 500-ms stimulus presentation and were asked to report the direction of dot motion by selecting an appropriate directional arrow with the computer mouse. The practice paradigm lasted approximately 15 minutes and consisted of 40 trials in each of 3 blocks (120 total trials). Next, participants completed a timed reading comprehension section selected from the Wide Range Achievement Test IV (WRAT IV). The WRAT IV is separated into an equally weighted green and blue version which was alternated for each participant. A critical flicker fusion threshold (CFFT) score was then

obtained using a macular pigment densitometer. CFFT was calculated psychophysically by measuring each participant's sensitivity to a green light (peak wavelength = 550 nm at 1.5 cd/m²) flickered on a solid blue background (peak wavelength = 460 nm at 4.3 cd/m²) in a 1° circle. The green light is increased in frequency until it appears to match the solid blue background. Once this occurs the frequency of flickering green light is used as the CFFT. This is measured six times in order to attain an average for each participant.

Throughout the training days, all participants performed a training direction discrimination paradigm that was identical to the practice paradigm that had been administered on the pre-test day, with the exception of two minor changes. First, with the training paradigm, participants received feedback after each trial regarding whether or not they had made a correct selection. The feedback included a green "+" symbol coupled with a high-pitched tone for correct responses or a red "x" coupled with a low-pitched tone for incorrect responses. Second, in the training paradigm, the motion display of 200 coherently moving dots was presented at varying luminance-contrast levels (0, 0.14, 0.2, 0.28, 0.42, 0.6, 0.9, 1, 1.9, 11.8 cd/m² RMS contrast). The number of correct selections of coherent dot motion direction, at all levels of contrast, which allowed for computation of plasticity. Experimental training conditions of 500 trials were separated into 10 blocks of 50 trials each lasting for approximately 20 minutes for completion of all blocks, while training conditions of 1000 trials were separated into 20 blocks of 50 trials and lasted approximately 45 minutes for completion of all blocks.

On the post-test day, participants completed the WRAT IV alternate color (green pre-test, blue post-test) reading comprehension section. An adjusted score, based on age and created by the test publishers, was used to compare changes from the pre-test to post-

test days. Furthermore, the length of time needed to complete the reading comprehension section was compared on pre- and post-test days. Lastly, a second CFFT score was obtained and compared to the participants' initial CFFT.

RESULTS

To test our hypothesis that a coherent dot motion task can strengthen neurons in the magnocellular pathway and therefore improve not only low-level visual discrimination abilities such as contrast discrimination, but also higher-level processing such as reading comprehension, reading rate, and CFFT, a series of mixed model ANOVAs were performed. Specifically, separate 4 x 2 mixed model ANOVAs with training condition (4 day 500 trials vs. 4 day 1000 trials vs. 8 day 500 trials vs. 8 day 1000 trials) as the between subject factors and testing day (pre-test vs. post-test) as the within subjects factor were used to predict each of the four outcome variables: CFFT, WRAT IV reading comprehension, reading rate, and directional contrast discrimination. Increases in plasticity were determined by comparing participants' scores on each of these outcome measures from the first to last day of training. Furthermore, changes in scores between pre-test and post-test were compared between conditions to determine the most efficient training method.

CFFT

Analysis of CFFT scores revealed a significant main effect of testing day, $F(1, 16) = 33.23, p = .001, \eta_p^2 = .68$, (Table 3.), demonstrating an increase in CFFT from pre-test to post-test (Figure 3). Because CFFT is believed to be a general measure of cortical processing capacity, a significant increase in CFFT shows an effective change in cortical

processing thus provides evidence of plasticity in the visual system. This finding corroborates the findings by Seitz et al. (2005) regarding resultant improvement in CFFT when paired with a dot motion task over time, but not when CFFT is repeatedly presented alone. A significant interaction was not found between training conditions indicating that training conditions did not have an effect on CFFT improvements.

WRAT IV Reading Comprehension

Similarly, in the analysis predicting reading comprehension, a significant main effect of testing day emerged, $F(1, 16) = 5.37, p = .03, n_p^2 = .25$ (Table 5), indicating improvement in participants' WRAT IV reading comprehension scores from pre-test to post-test (Figure 4). A significant interaction was not found between training conditions indicating that training conditions did not have an effect on WRAT IV reading comprehension scores.

WRAT IV Reading Rate

In the analysis predicting reading rate a significant main effect of testing once again emerged, $F(1, 16) = 7.72, p = .013, n_p^2 = .325$ (Table 7). Overall, participants completed the WRAT IV reading comprehension at a faster rate on the post-test day than they did on the pre-test day (Figure 5). There were no effects for training condition.

Directional Coherent Dot Motion Contrast Discrimination

Finally, in the analysis predicting performance on the directional coherent dot motion contrast discrimination task (Table 9), a significant main effect for testing day was found, $F(1, 16) = 24.36, p = .001, n_p^2 = .60$ (Table 9), such that participants' showed improvement in their ability to distinguish directional coherent dot motion at lower levels of contrast (0, 0.14, 0.2, 0.28, 0.42, 0.6, 0.9, 1, 1.9, 11.8 cd/m² RMS) from the first day to

the last day of training (Figure 6). This finding is consistent with prior research in which coherent motion paradigms alter low-level processing, such as contrast, and show lasting learning effects (plasticity). The main effect for testing day was, however, qualified by a significant interaction with training conditions, $F(1, 16) = 4.75, p = .015, \eta_p^2 = .471$ (Table 9), indicating differences between conditions on levels of improvement within the contrast discrimination task between pre- and post-test (Figures 1 and 2).

To shed light on this interaction, the data were split by condition and separate repeated measures ANOVAs (with pre-test vs. post-test as the within subjects factor) were performed. Only participants in the 4 day x 1000 trial condition, $F(1, 4) = 9.385, p = .038, \eta_p^2 = .701$, and the 8 day 500 trial condition, $F(1, 4) = 397.762, p = .001, \eta_p^2 = .990$, showed significant increases in their ability to distinguish coherent motion direction at lower levels on contrast between pre-and post-test (Table 10). Interestingly, when we account for the number of total trials in each of the training conditions, (4 x 500 = 2000 trials, 4 x 1000 = 4000 trials, 8 x 500 = 4000 trials, and 8 x 1000 = 8000 trials), we see that participants in the two conditions that showed significant improvement on the coherent dot motion task experienced the same number of trials over a different number of days. Furthermore, the improvements of participants in shortest training paradigm (4 x 500) trended toward significance $p = .097$, while participants in the longest training paradigm (8 x 1000) showed no significant improvement on the coherent dot motion task, $p = .754$.

DISCUSSION

The goal of this study was to identify a training paradigm for visual perceptual learning that is efficient in time and trials (low number of trials, low number of days), but

sufficient to produce plasticity in the low-level visual cortex (V1), measured through changes in coherent motion directional contrast discrimination, and plasticity in high-level visual cortex, measured via CFFT. An additional goal of this study was to determine if coherent motion and CFFT plasticity will increase reading capabilities in a non-clinical population. Participants in all four training conditions showed a significant increase in CFFT, reading comprehension, and reading rate. Coherent motion contrast scores also improved significantly; however, this improvement was moderated by training condition, with the 4 x 1000 and 8 x 500 training paradigms emerging as the most efficient paradigms for eliciting plasticity of contrast. Whereas, the 4 x 1000 (days x trials) is the most efficient with regards to time (days), the 8 x 500 (days x trials) is the most efficient in the number of trials. The present findings suggest that the most efficient paradigm is the 4 x 1000 (days x trials).

In line with our first hypothesis, CFFT scores increased significantly in all conditions. This result is consistent with previous findings by Seitz et al. (2004) demonstrating that CFFT is affected by coherent motion training. In addition to CFFT levels increasing, reading comprehension and speed of completion of the reading task improved significantly. This outcome is very exciting because it shows that plasticity in the magnocellular pathway is still present in the adult brain, and that non-clinical populations can benefit from coherent motion training. Furthermore, these findings support Stein's (2001) theory of developmental dyslexia, demonstrating that coherent motion, a PL training paradigm affecting the magnocellular pathway, does have a beneficial effect on reading abilities. It is our belief that coherent dot motion helps prevent retinal slip, allowing for more efficient eye tracking during the reading process.

When the eyes remain on target, it allows for better comprehension and speed of reading as demonstrated in this study.

It is interesting that the 4 day x 1000 trial and 8 day x 500 trial conditions produced the greatest improvements in coherent motion contrast scores. Due to the fact that these two conditions have the same number of total trials over different number of days, this finding suggests that the number of trials experienced by the participants is more important to PL than the number of days. Furthermore, these results support findings in previous experiments (Ofen et al., 2007; Censor & Sagi, 2008, 2009) that indicate that overtraining is a detriment to PL tasks, and thus support the saturation/habituation hypothesis.

Although this study implicates a great deal of progress in PL research, there are a few methodological weaknesses. For instance, we did not require our participants to train on the weekends. Therefore, in the four day conditions, there was a two day break between the final day of training and the post-test. In the eight day conditions, participants had a two-day break between their fourth and fifth day of training. Additionally, participants in the eight day conditions were given the post-tests with no break after training. Secondly, our participants were all college students. A review of the literature on the WRAT IV reading comprehension section reveals that this section has been used on college students with learning disabilities (Hughes & Smith, 1990) and non-native speakers (Ganschow, Sparks, Javorshy, & Pohlman, 1991). This suggests that there is a possible ceiling effect of reading comprehension scores in a normal college population. In one case, a participant received a perfect score on the pre-test and then missed only one answer on the post-test dropping their score by 12 points on the post test.

In future studies, we would like to work with a non-college student population and use both an older population (no college or years removed from college) and a younger population of participants. Additionally, we would like to refine our findings for an efficient training PL paradigm, removing weekend breaks as a confound. We would also like to see if changes in reading comprehension and reading rate are plastic. We would accomplish this by bringing participants back after 6 months to see if the resultant changes remain. Moreover, we would like to examine if reading comprehension scores and rates can be improved via subliminal exposure to coherent dot motion paradigms. Although further research is needed, the findings in this study demonstrate a great deal about coherent motion perceptual learning tasks and the link between CFFT and reading comprehension and reading speed. Additionally, we believe that we have helped lay the groundwork for establishing a uniform number of trials needed in order to produce plasticity in perceptual learning paradigms.

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TABLES

Table 1
Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	20	18.00	28.00	20.9500	3.03445
Sex	20	1.00	2.00	1.7000	.47016
Education	20	12.00	17.00	14.1500	1.78517
Valid N (listwise)	20				

1= Male, 2= Female

Education: Number of years in school

Table 2
Pre- and Post-Critical Flicker Fusion Thresholds by Condition

Condition	cff	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
4x500	1	2066.000	108.325	1836.361	2295.639
	2	2323.400	134.454	2038.370	2608.430
4x1000	1	2182.800	108.325	1953.161	2412.439
	2	2362.600	134.454	2077.570	2647.630
8x500	1	2072.200	108.325	1842.561	2301.839
	2	2194.200	134.454	1909.170	2479.230
8x1000	1	1947.000	108.325	1717.361	2176.639
	2	2128.600	134.454	1843.570	2413.630

1= Pre-test, 2= Post-test

Table 3.
Critical Flicker Fusion Threshold 4 x 2 ANOVA

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
cff	Pillai's Trace	.675	33.227 ^b	1.000	16.000	.000	.675
	Wilks' Lambda	.325	33.227 ^b	1.000	16.000	.000	.675
	Hotelling's Trace	2.077	33.227 ^b	1.000	16.000	.000	.675
	Roy's Largest Root	2.077	33.227 ^b	1.000	16.000	.000	.675
cff * Condition	Pillai's Trace	.123	.747 ^b	3.000	16.000	.540	.123
	Wilks' Lambda	.877	.747 ^b	3.000	16.000	.540	.123
	Hotelling's Trace	.140	.747 ^b	3.000	16.000	.540	.123
	Roy's Largest Root	.140	.747 ^b	3.000	16.000	.540	.123

Table 4
Pre- and Post- WRAT IV Reading Comprehension Scores by Condition

Condition	wrat_score	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
4x500	1	100.000	5.968	87.349	112.651
	2	104.000	5.608	92.112	115.888
4x1000	1	113.800	5.968	101.149	126.451
	2	119.600	5.608	107.712	131.488
8x500	1	105.600	5.968	92.949	118.251
	2	106.600	5.608	94.712	118.488
8x1000	1	102.600	5.968	89.949	115.251
	2	104.600	5.608	92.712	116.488

1= Pre-test, 2= Post-test

Table 5
WRAT IV Reading Comprehension Score 4 x 2 ANOVA

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
wrat_score	Pillai's Trace	.251	5.365 ^b	1.000	16.000	.034	.251
	Wilks' Lambda	.749	5.365 ^b	1.000	16.000	.034	.251
	Hotelling's Trace	.335	5.365 ^b	1.000	16.000	.034	.251
	Roy's Largest Root	.335	5.365 ^b	1.000	16.000	.034	.251
wrat_score * Condition	Pillai's Trace	.101	.597 ^b	3.000	16.000	.626	.101
	Wilks' Lambda	.899	.597 ^b	3.000	16.000	.626	.101
	Hotelling's Trace	.112	.597 ^b	3.000	16.000	.626	.101
	Roy's Largest Root	.112	.597 ^b	3.000	16.000	.626	.101

Table 6
Pre- and Post- WRAT IV Reading Comprehension Rate (min.) by Condition

Condition	wrat_speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
4x500	1	9.948	1.045	7.733	12.163
	2	8.542	1.008	6.405	10.679
4x1000	1	8.358	1.045	6.143	10.573
	2	7.028	1.008	4.891	9.165
8x500	1	8.556	1.045	6.341	10.771
	2	8.386	1.008	6.249	10.523
8x1000	1	9.770	1.045	7.555	11.985
	2	7.924	1.008	5.787	10.061

1= Pre-test, 2= Post-test

Table 7
WRAT IV Reading Comprehension Rate (min.) 4 x 2 ANOVA

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
wrat_speed	Pillai's Trace	.325	7.720 ^b	1.000	16.000	.013	.325
	Wilks' Lambda	.675	7.720 ^b	1.000	16.000	.013	.325
	Hotelling's Trace	.482	7.720 ^b	1.000	16.000	.013	.325
	Roy's Largest Root	.482	7.720 ^b	1.000	16.000	.013	.325
	Pillai's Trace	.116	.701 ^b	3.000	16.000	.565	.116
wrat_speed * Condition	Wilks' Lambda	.884	.701 ^b	3.000	16.000	.565	.116
	Hotelling's Trace	.131	.701 ^b	3.000	16.000	.565	.116
	Roy's Largest Root	.131	.701 ^b	3.000	16.000	.565	.116
	Pillai's Trace	.116	.701 ^b	3.000	16.000	.565	.116
	Wilks' Lambda	.884	.701 ^b	3.000	16.000	.565	.116

Table 8
Percentage of Correct Direction Selection in Coherent Dot Motion Contrast by Condition

Condition	contrast	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
4x500	1	.443	.031	.377	.509
	2	.483	.036	.408	.559
4x1000	1	.456	.031	.389	.522
	2	.482	.036	.406	.558
8x500	1	.399	.031	.333	.465
	2	.498	.036	.423	.574
8x1000	1	.384	.031	.318	.451
	2	.394	.036	.319	.470

1= Pre-test, 2= Post-test

Table 9

Percentage of Correct Direction Selection of Coherent Dot Motion 4 x 2 ANOVA

Effect		Value	F	Hypothesi s df	Error df	Sig.	Partial Eta Squared
contrast	Pillai's Trace	.604	24.359 _b	1.000	16.000	.000	.604
	Wilks' Lambda	.396	24.359 _b	1.000	16.000	.000	.604
	Hotelling's Trace	1.522	24.359 _b	1.000	16.000	.000	.604
	Roy's Largest Root	1.522	24.359 _b	1.000	16.000	.000	.604
contrast * Condition	Pillai's Trace	.471	4.745 ^b	3.000	16.000	.015	.471
	Wilks' Lambda	.529	4.745 ^b	3.000	16.000	.015	.471
	Hotelling's Trace	.890	4.745 ^b	3.000	16.000	.015	.471
	Roy's Largest Root	.890	4.745 ^b	3.000	16.000	.015	.471

Table 10
 Percentage Correct Direction Selection of Coherent Dot Motion 4x2 ANOVA by
 Condition

Conditio n	Effect	Value	F	Hypothesi s df	Error df	Sig.	Partial Eta Squared	
4x500	contrast	Pillai's Trace	.537	4.645 ^b	1.000	4.000	.097	.537
		Wilks'	.463	4.645 ^b	1.000	4.000	.097	.537
		Lambda						
		Hotelling's Trace	1.161	4.645 ^b	1.000	4.000	.097	.537
		Roy's Largest Root	1.161	4.645 ^b	1.000	4.000	.097	.537
		4x1000	contrast	Pillai's Trace	.701	9.385 ^b	1.000	4.000
Wilks'	.299			9.385 ^b	1.000	4.000	.038	.701
Lambda								
Hotelling's Trace	2.346			9.385 ^b	1.000	4.000	.038	.701
Roy's Largest Root	2.346			9.385 ^b	1.000	4.000	.038	.701
8x500	contrast			Pillai's Trace	.990	397.76 2 ^b	1.000	4.000
		Wilks'	.010	397.76 2 ^b	1.000	4.000	.000	.990
		Lambda						
		Hotelling's Trace	99.44 1	397.76 2 ^b	1.000	4.000	.000	.990
		Roy's Largest Root	99.44 1	397.76 2 ^b	1.000	4.000	.000	.990
		8x1000	contrast	Pillai's Trace	.030	.122 ^b	1.000	4.000
Wilks'	.970			.122 ^b	1.000	4.000	.745	.030
Lambda								
Hotelling's Trace	.030			.122 ^b	1.000	4.000	.745	.030
Roy's Largest Root	.030			.122 ^b	1.000	4.000	.745	.030

FIGURES

Figure 1

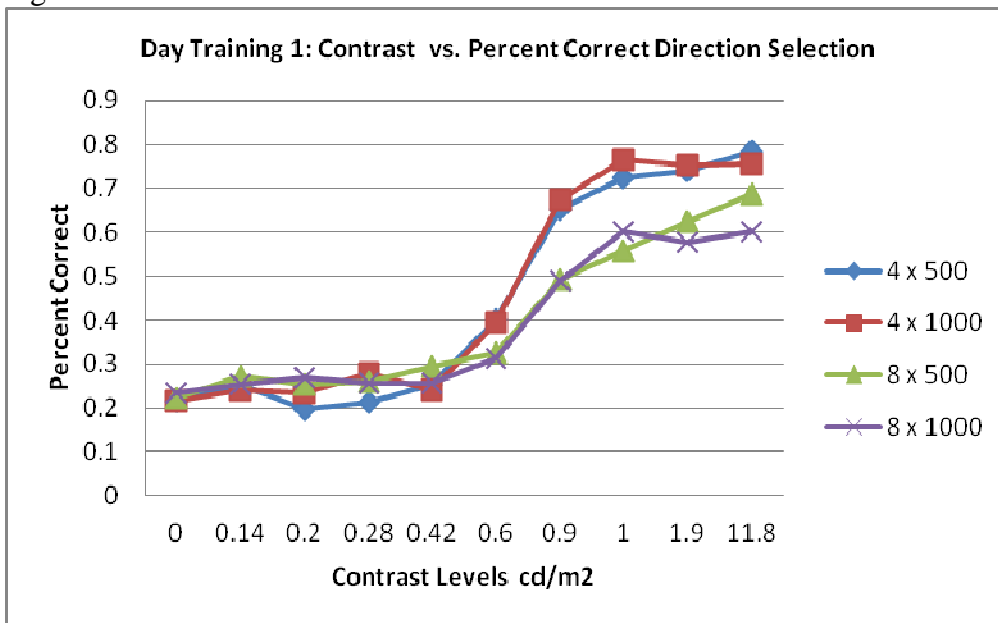


Figure 2.

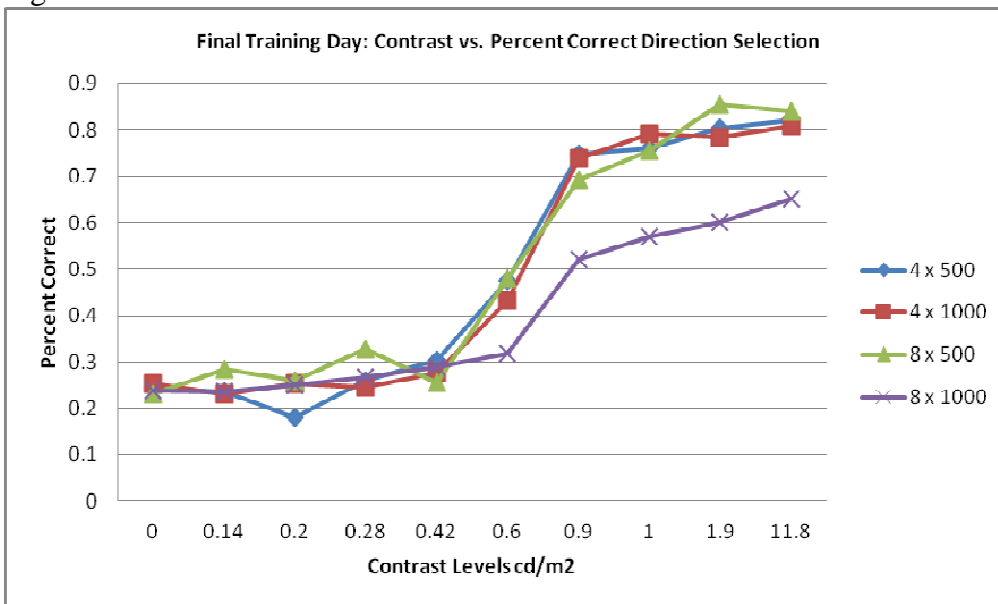


Figure 3

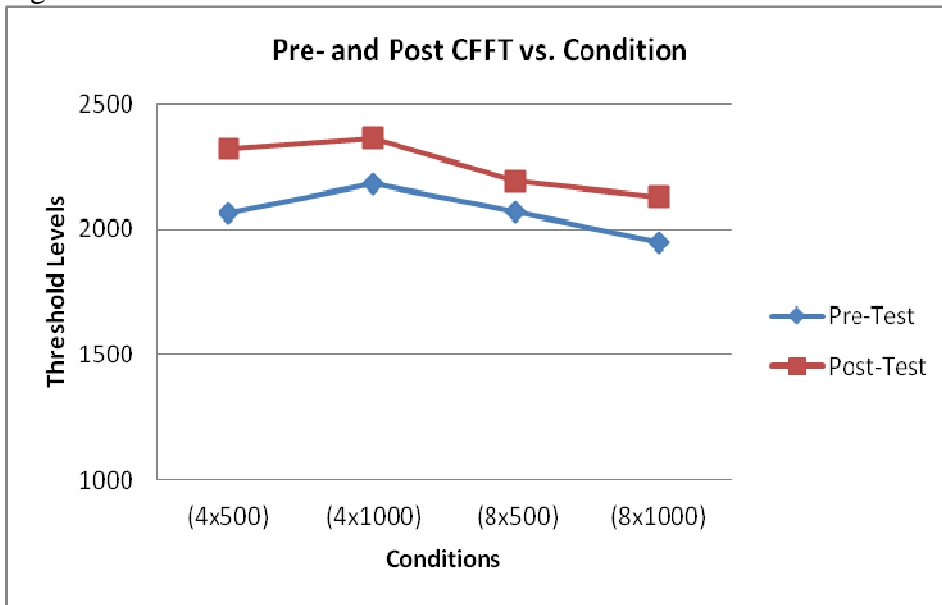


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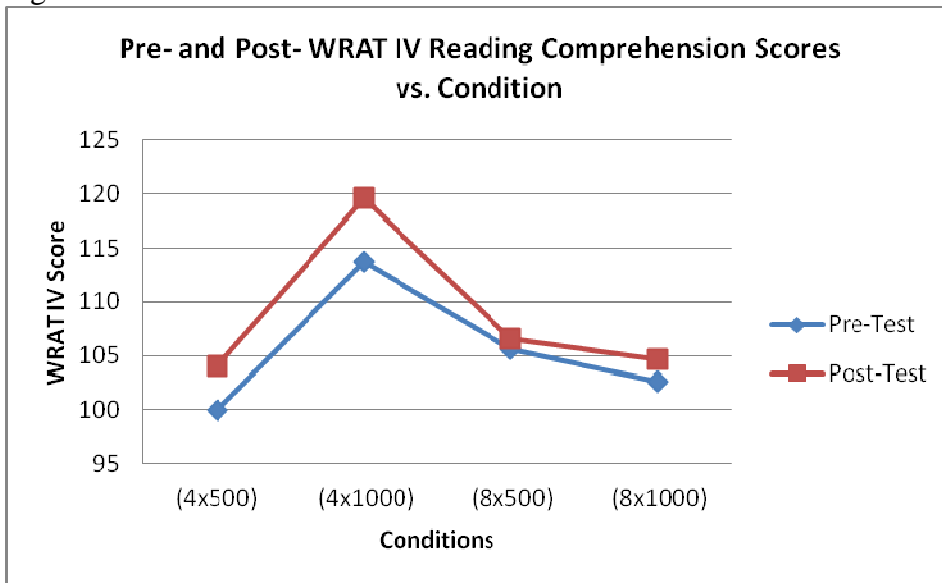


Figure 5

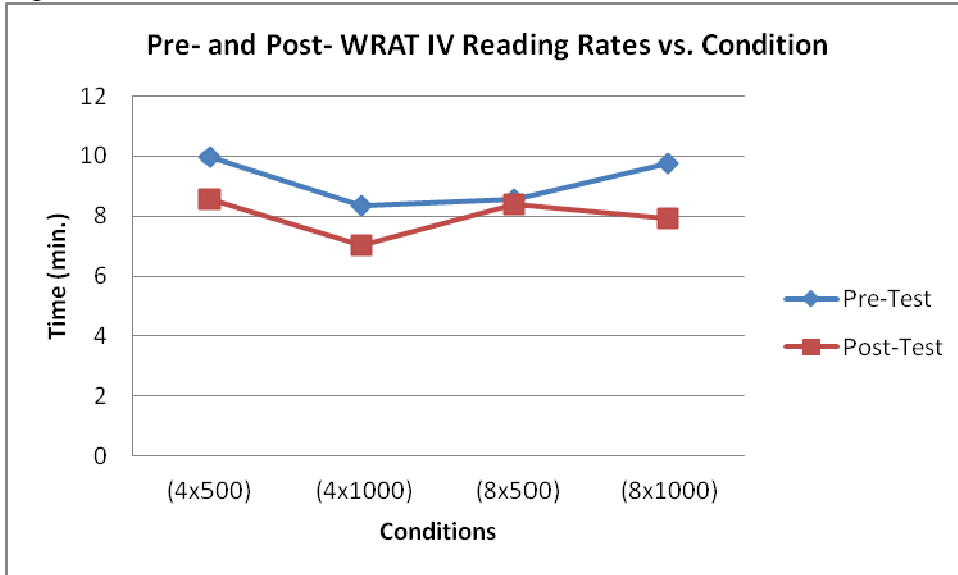


Figure 6

