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# Effect of the selected carotenoids zeaxantin and lutein on human visual processing speed, chromatic color discrimination, and critical flicker fusion frequency threshold


## Abstract

Zeaxantin (Z) and lutein (L) are two of only three carotenoids highly concentrated in the retina of the eye as macular pigments. These also appear in the visual cortex and frontal lobe and play an essential role in visual acuity. Furthermore, in the brain, these carotenoids can be associated with visual performance such as processing speed and color perception. Previous research on the effect of Z and L processing speed has met with inconsistent results. The aim of this study was to determine if the carotenoids Z and L alone or in combination (Z+L) has an effect on visual reaction time (VRT), critical flicker fusion frequency threshold (CFF) and chromatic color discrimination (CCD). VRT was assessed using a computerized visual reaction test consisting of a large red circle on a blue field. At random intervals, the circle would turn green at which the participant would click the mouse button. CFF was assessed by a computerized program capable of timing participant's perception. CCD was assessed using the Farnsworth Munsell 100 Hue Test. Healthy participants ($n$=50) ranging in age from 18 to 23 years were pre-tested on VRT, CFF, and CCD and subsequently given either 5mg Z, 30mg L, a combination of 5mg Z and 5mg Lutein, or placebo. After one week, participants were tested again. Results of repeated measures ANOVAs yielded no pre- to post-test significance ($p$>0.05) for VRT. However, the three carotenoid supplements recorded slightly faster times than the placebo. For CFF, only the Z+L group improved significantly. In the assessment of CCD, both L and the combination of Z and L resulted in significantly ($p$<0.05) greater accuracy in chromatic contrast discrimination. The enhancement carotenoids in visual processing and hue discrimination may be advantageous is areas that require rapid reaction and hue discrimination such as some sports and job related tasks.


**Keywords:** Vision, carotenoids, zeaxantin, lutein, eye

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## Introduction

Lutein (L) and zeaxanthin (Z) are two only of three dietary carotenoids that are highly concentrated in the retina of the eye as macular pigments[1] and can make up as much as 66% to 77% of the total carotenoid concentration in both the visual cortex and frontal lobe of the brain.[2] These macular pigments play a critical role in visual acuity and help protect the eyes from harmful blue light emitted from electronic devices. In addition, these regions of the brain aid in the learning, memory, executive function, and neurotransmission process. Also, macular pigment, acts as a prereceptoral filter which selectively absorbs short wavelengths.[3] Both Z and L can be found in numerous dietary sources such as dark leafy vegetables, orange and yellow fruits, corn, pistachio nuts, and eggs,[4] which is critical since lutein cannot be synthesized by the body naturally and can only be obtained from dietary supplements. The available research demonstrates that both of these supplements have an important role in the visual and cognitive processes.

The predominance of research has investigated the physiological effects that these carotenoids have on eye health and cognitive function. The primary structure of these carotenoids consists of a polyene backbone made of unconjugated carbon-carbon double bonds that are responsible for pigmentation and their potential antioxidative capabilities to combat free radicals.[5] The pigmentation and high concentration within the macula lutea of the fovea provides filtration for potentially harmful blue light.[6] Researchers have found that higher concentrations of L and Z in the inner retina increase their antioxidative properties,[7] and filtration of blue light.[8] These effects yield meaningful long-term results in the prevention of eye diseases such as age-related macular degeneration (AMD), cataracts, cognition deterioration, light damage to the retina, and non-proliferative diabetic retinopathy.[6]

The macula lutea is found in the light-sensitive area in the center of the retina and is responsible for high visual acuity in central vision and color perception.[9] This high concentration of macular pigments is known as macular pigment optical density (MPOD) and is an important biomarker of cognitive function that can have a positive correlation with reaction time, memory, and processing speed.[10] Several studies have sought to measure the levels of L and Z concentrated in the brain and have found L and Z present throughout the human brain, with MPOD being an accurate metric of brain concentration.[11] This is a area of interest when studying L and Z and their effect on visual reaction time (VRT), critical flicker fusion frequency (CFF), actions per minute (APM), and chromatic contrast discrimination (CCD).[12]

**Visual reaction time** (VRT) is the elapsed time to respond to the sudden appearance of change in a visual stimulus. Therefore, VRT is fundamental to high-speed ball games. For instance, it takes 200-300 ms. to react to a stimulus and make the appropriate action.[13] Previous research has investigated VRT in relationship to table tennis[14] and baseball where visual reaction time is crucial is batting attempts. Hammond Jr. and Fletcher[2] recommends a complete visual assessment that considers the dynamic visual and psychomotor needs that baseball batters need to hit different types of pitches. For example, a 90-mph fastball takes 400 ms. to reach home plate after it leaves a pitcher's hand, and a hitter needs a full 250ms to see the ball and then accurately react with the bat.[2] This led the authors to recommend L and Z on the theory that these supplements may increase temporal processing speed.

**Critical flicker fusion frequency** (CFF) is an associative measure of cognitive performance and neural processing speed.[15] CFF tests measure the frequency (Hz) at which individuals perceive an accelerating flickering light as continuous. Humans have a reputed threshold between 50 and 90 Hz and the highest frequency an individual can perceive is described as the critical flicker fusion threshold (CFF) or the maximum frequency of light able to be perceived. As the ability to distinguish between higher frequencies increases, so does visual system efficiency.[15]

The visual system processes information in spatial and temporal domains. Temporal resolution relates to the temporal features of the stimuli and is the ability to discern luminance changes over time, limited by the time for collecting and processing information.[16] The stimulus (light) can be only be perceived as separate if the flicker rate is below a certain threshold. Thus, when the flicker frequency reaches a certain rate, the intermittent light appears to become a steady, solid light. CFF is an associative measure of cognitive performance and neural processing speed.[17] Hammond and Wooten[18] found that participants with higher macular pigment optical density also had higher critical flicker fusion thresholds suggesting better visual performance. Stringham et al.,[19] and associates found that zeaxanthin and lutein significantly improved CCF over placebo following six months of supplementation. Similarly, Bovier et al.,[12] and associates reached the same conclusion following a similar duration of supplementation.

**Chromatic contrast discrimination** (CCD) is the ability to differentiate between different colors hues which is beneficial for segmenting subtle images into regions. Three types of cones in the retina serve as photoreceptors and each is responsible for maximal sensitivity of short, medium, and long wavelength forms of visual light.[20] The sensitivity of the photoreceptor cell in the cones of the retina decreases and the discrimination of colors becomes more difficult to differentiate between different colors gradients with age. A possibility exists that higher levels of MPOD might increase cone sensitivity and offer the same protective effects expressed elsewhere. Previous research found that supplementation of Z and L for 12 months significantly enhanced visual function of contrast sensitivity, suggesting that the improvements were due, in part, to the antioxidant properties of the carotenoids.[21,22]

Previous research with L and Z supplementation have utilized assessments such as CFF thresholds, visual reaction time, and coincidence anticipation timing to test the impacts these supplements may have on performance.[12] However, the previous studies conducted 3-12 month long supplementation of Z and L.[12,19,21]

Due to the conjecture that the effect of these carotenoids on visual performance has met with mixed results and the effect of vision needs to be further evaluated,[23] the aims of this study was to investigate the effect of acute supplementation with L+Z, Z independently, L independently, or a placebo on visual reaction time (VRT), critical flicker fusion (CFF), and chromatic contrast discrimination (CCD) assessments.

## Methods

### Participants

College aged males (n=20) and females (n=30) ranging from 18 to 23 years of age (Table 1) were recruited from a Midwestern University for this study and each participant read and signed a university approved Institutional Review Board (IRB) consent form prior to participating. Exclusion criteria included astigmatism, eye infection or inflammation, blurred vision, retinal disorder, color blindness, a history of ocular disease, and the use of any vision enhancement supplement. Participants were free from any known musculoskeletal, metabolic, or cardiorespiratory disorders and were considered to be in good health.

**Table 1** Mean characteristics of the participants

| Variable | Mean | SD |
|---|---|---|
| Age (yrs) | 20.38 | 1.14 |
| Weight (kg) | 69.2 | 13.9 |
| Height (cm) | 67.2 | 4.1 |

### Procedures

Participants were asked to complete a study eligibility questionnaire form consisting of health history and eye health. Subsequently, qualifying participants were asked to complete three computer generated assessments consisting of visual reaction time (VRT), critical flicker fusion (CFF) and chromatic contrast discrimination (CCD) accuracy in random order. For all assessments, participants were seated in an adjustable chair adjusted to the participants' height so that participants' were eye level and a comfortable distance from the computer screen.

For the VRT assessment, a large red dot on a blue background appeared on the monitor and at random intervals the red dot would change from red to green at which time the participant clicked the mouse as quickly as possible. Results were calculated in milliseconds (ms) and each participant completed a total of five trials and the average of the five trials was recorded.

CFF was assessed was assessed by presenting a square-wave stimulus on a computer monitor. The light flicker increased in increasing in frequency until the participant perceived the light source to appear to be a solid light. Each trial was timed from the initial flicker until the participant perceived a solid, non-flickering light. The time the participant stopped the video when flickering stopped was recoded in milliseconds. A total of four trials were completed.

Chromatic contrast discrimination (CCD) assessment was conducted using the Farnsworth Munsell 100 Hue Test which is used to evaluate the ability to discern color. The assessment consisted of four horizontal bars each containing 10 adjacent squares of one color with slightly different hues. The first and last color squares in the bars were fixed, which provided the extreme polar range of each bar. Participants were instructed to arrange the color squares from the deepest color hue to the lightest color hue in each of the bars. Once participants completed the sequence of each bar a score ranging from 0 to 100 was calculated, where a score of 0 represents a perfect score. A total of two trials were performed withe accuracy and time of completion for each of the trials was recorded.

### Lutein and zeaxanthin supplementation

Supplementation followed a double-blind placebo controlled design. Qualifying participants reported to the lab and were provided instructions on each of the three assessments and randomly assigned to the three tests. Following the pre-assessment scores on each test, the participants were randomly divided into four supplement groups consisting of the following: lutein 30mg (L), zeaxanthin 5mg (Z), a combination of lutein 30mg and zeaxanthin 5mg (L&Z), and placebo. Each participant was given a seven-day supply of one of the four supplements, provided directions on how to take the supplement, and given a log to complete in order to remind them to take the supplement/placebo each day. Following the seven days of supplementation, the participants returned to the lab and completed the same visual assessments.-Participants were instructed to report any adverse reactions from supplementation. If participants missed a day of supplementation, they were instructed to take the missed dosage as soon as possible.

### Statistical analyses

Results are expressed as means and standard deviation (SD). Statistical analysis consisted of separate repeated measures ANOVAs with an alpha level set at $p<0.05$. For any significant repeated measure ANOVAs, all pairwise comparisons were examined with Newman-Keuls post-hoc analyses to identify the specific variables of significance.

## Results

Data are illustrated as means, standard deviation (SD) for each dependent variable (Figures 1-6). Results of the repeated measures ANOVAs indicated that for visual reaction time (VRT), no pre- to post-test statistical significance ($p>0.05$) existed among the four supplemented conditions (Figure 1). However, the three carotenoid supplement groups recorded faster (Z+L = 20.2 ms, Z = 21.1 ms, L = 20.5 ms, and C = 10.3 ms respectively). For the critical flicker fusion (CFF) assessment pre-to post-test results yielded significant improvement ($p<0.05$) in the leutein/zenaxantine condition only (Figure 2). Of the non-significant conditions, the lutein (L) condition was the only condition that showed improvement for CFF. The chromatic color discrimination (CCD) assessment resulted in significant pre- to post-test improvement ($p<0.05$) all three supplement (L&Z, Z, and L) conditions while no such improvement was found for the control group (Figure 3). In fact, the Z+L group improved 74.4%, the Z group improved 99.5%, the L group improved 76.7 %, and the placebo improved only 20%,

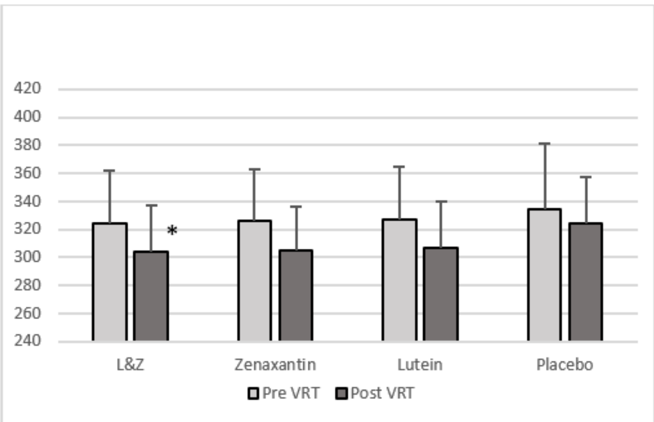


**Figure 1** Visual Reaction Time (MS) means and SD by condition.

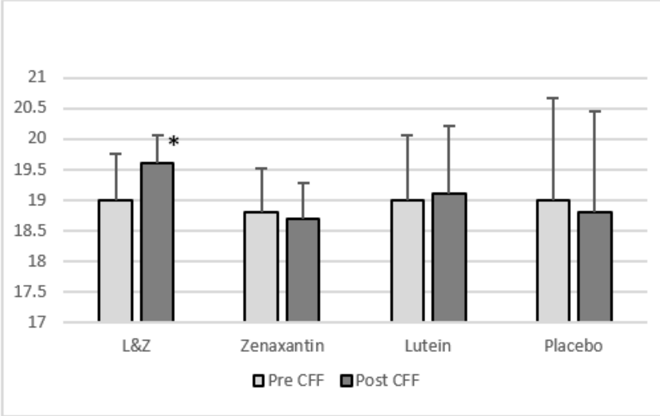


**Figure 2** Critical flicker fusion (MSEC) means and SD by condition.

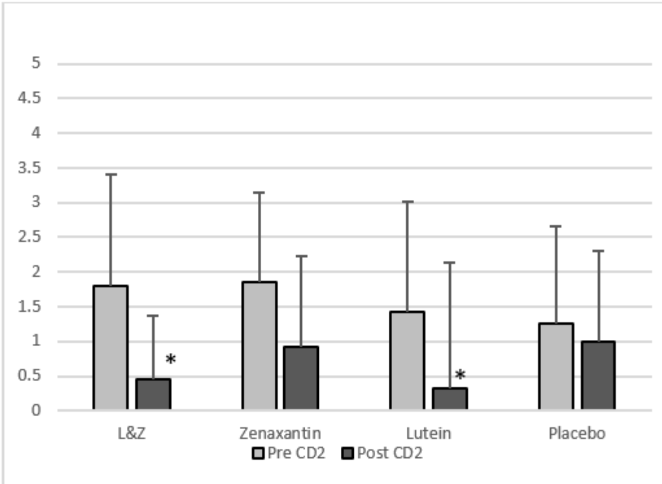


**Figure 3** Chromatic color discrimination.

## Discussion

Considering the length of supplementation of Z and L in previous studies, the current study aimed to investigate the acute supplementation effects of selected, eye-related carotenoids on critical flicker fusion, reaction time, and chromatic contrast. Regarding CFF, the results of the current study agrees with the outcomes of Bovier et al.,[12] and Stringham et al.,[19] in that Z and L may improve CFF. Both of the aforementioned works utilized a six-month supplementation schedule, a much longer period than for the present study of one week, indicating that improvements in CFF can be observed in a shorter time. For VRT, no significant differences were found among the four groups. This is in contrasts to the findings of Bovier et al.,[24] and associates who concluded that Z and L supplementation results in significantly faster visual greater processing speed presumably due to their continued supplementation for six-months in comparison to the week-long supplementation period of the present study.

Increases in processing speed and reaction time have been reported in younger individuals who have supplemented with lutein and zeaxanthin. The exact underlying mechanism for the increases in these two factors is not entirely understood, but the neural efficiency

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hypothesis is believed to help explain this phenomenon. The neural efficiency hypothesis supports the notion that lutein and zeaxanthin may have an influence in neural communication networks in the brain. Evidence for the support of this hypothesis stems from lutein and zeaxanthin being concentrated in the visual cortex of the brain where important neural substrates necessary to influence neural processing. Furthermore, supplementing with lutein and zeaxanthin have been shown to enhance synaptic gap junction communication between neurons that may help to explain the faster neural processing speed in the cognitive and visual domains.[18]

Both Z and L are retina related carotenoids, light must traverse Z and L before being processed by the photoreceptors and absorbed by the pigments which may function to enhance contrasts.[25] Regarding carotenoids, Roark and Stringham[26] suggested that relevant research seems to support the use of Z and L to enhance visual performance such as contrast sensitivity. In the chromatic color discrimination (CCD) assessment, all three of the carotenoid groups demonstrated significant improvement ($p<0.05$). In fact, the Z+L group improved 74.4%, the Z group improved 99.5%, the L group improved 76.7 %, and the placebo improved only 20%, presumably due to a practice effect. Similarly, Rodrigues-Carmona et al.,[27] in a Z and L 12 month supplementation duration determined that these carotenoids improved red-green color discrimination sensitivity.

## Conclusion

Several sports require optimal eye health and rapid visual processing in many different illuminated environments.[2,14,28,29] As previously mentioned, L and Z has been recommended in sports on the theory that these supplements may increase temporal processing speed thereby increasing the chance for success. Furthermore, increases in the visual parameters assessed in the current study may not only serve in enhancing the performance of certain tasks, but also may reduce sport related injuries.[30–32]

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None.

## Conflicts of interest

The authors declare that there are no conflicts of interest.

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