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The effect of lutein supplementation on visual fatigue: A psychophysiological analysis

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ABSTRACT

We used psychophysiological technology to examine the effect of an oral supplement, a combination of lutein, zeaxanthin and blackcurrant extract (LUT), on visual fatigue, within the context of a randomized, double-blind, placebo-controlled cross-over trial. The LUT supplement and placebo samples were randomly assigned to thirteen participants, who took the samples for two LUT (and vice versa) for another 2 week. Each participant completed visual proof reading tasks for 2 h during each of four testing sessions. Saccade tests were administered before and after the proof reading task, during which the participants moved their eyes back and forth between two targets positioned in the center of two checkerboards. We recorded EEG, EOG, heart rate, and facial muscle potential/performance during the saccade tests. Blood pressure was measured and subjective fatigue and stress scores were collected before and after the proof reading task. We averaged EEG starting at saccade offset in order to analyze eye fixation related potentials (EFRP). Our results suggested that the proof reading task induced visual fatigue. An analysis of EFRP and other psychophysiological data revealed significant differences between the LUT and placebo conditions. These results suggest that supplementation with LUT could help to reduce symptoms of visual fatigue.

1. Introduction

Modern society constantly places demands for long hours of visual task performance, in the office, at the factory, and even at the home. These demands lead to visual fatigue, and discomfort in the eyes, the body more generally, and the mind. Recent studies have shown that some natural plant-derived components, including lutein, zeaxanthin and blackcurrant extract, can have positive effects on the visual system (Berendschot et al., 2000; Bone et al., 2000; Nakaishi et al., 2000; Gale et al., 2003; Richer et al., 2004; Snodderly et al., 2004). These studies have suggested that these plant-derived materials might have a positive effect on recovery from visual fatigue.

Yagi et al. (Yagi, 1981; Yagi et al., 2005) have developed a system to examine visual functioning by measuring event related brain potentials (ERPs) during an eye movement task. When a person performs a visual task, the corresponding eye movement record shows a step-like pattern that consists of both fast eye movements (saccades) and eye fixations. A specific ERP can be obtained by averaging EEGs occurring at saccade offset (i.e., at the end of the eye movements). This specific ERP is called the Eye Fixation Related Brain Potential (EFRP). The EFRP itself consists of several components (Yagi, 1981). The most prominent positive component is called the lambda response, and has a latency of about 80 ms. The term "EFRP" is used in this paper instead of "lambda response". EFRP changes as a function of various sensory and cognitive factors, including visual attention (see Yagi, 1981, 1995, 1996; see Yagi, 2001, for a review).

Takeda et al. (2001) reported that EFRP amplitude decreases during a long duration visual task. Daimoto et al. (1998) examined EFRP amplitude in response to the stripe pattern before and after an eye-tracking task, in order to assess visual fatigue. They found that EFRP amplitude in response to the pattern was smaller after the visual tracking task than before the task. Daimoto et al. (1998) concluded that the observed decrease in EFRP amplitude was caused by visual fatigue, and this study suggests that a decrease in EFRP amplitude can serve as an index of visual fatigue.

The present study employed psychophysiological methods to examine whether supplementation with a combination of lutein, zeaxanthin and blackcurrant extract (LUT) could help to reduce symptoms of visual fatigue. We measured task performance, EFRP

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as a central response, and peripheral physiological responses in order to assess visual fatigue. We assessed sensory-motor peripheral responses, including forehead/neck muscle potentials and eye blink, as well as autonomic responses such as heart rate and blood pressure. Questionnaires assessing visual fatigue were also used to provide a subjective assessment.

2. Method

2.1. Participants

Healthy adults (age range = 22–45 yrs) who satisfied inclusion and exclusion criteria were recruited by Sogo Clinical Holdings Co., Ltd. (Tokyo) (Sogo CH). Participants were Japanese and Chinese individuals who could speak and read the Japanese language. The inclusion criteria were non-smoker, non-heavy user of alcohol, and normal or corrected-to-normal visual acuity. Potential participants were excluded if they had consumed any health food supplements containing carotenoids or anthocyanosides within the past 6 weeks, or if they had consumed foods high in caffeine and/or anthocyanosides within the past 7 days.

Sogo CH managed the recruitment of participants and subsequent appointments, according to the study protocol.

All 22 participants gave their written informed consent to participate, and were given monetary compensation for their participation. Each participant was briefed about the entire experiment schedule. Participants were provided with instructions regarding the consumption of test samples. They were told that a designated medical doctor would draw blood before each visual task session, and that a 2-h visual task along with the measurement of EFRP would occur at Kwansei Gakuin University on four different days. The need for good sleep on nights prior to the visual task experiment was emphasized, along with the more general need to live a healthy lifestyle during the course of the study. Participants were told that they could discontinue participation in the study at any time.

Nine participants did not complete all four sessions of the visual task experiment, given that the visual task used was quite demanding. Only 13 participants (seven females aged from 22 to 34 yrs and six males aged from 28 to 42 yrs) completed the entire study (the four sessions of the visual task experiment plus blood sampling).

2.2. Study design

The study was a randomized, double-blind, placebo-controlled cross-over design, with a 2 week washout period. Participants were randomly assigned to take either LUT or a placebo (PC), two tablets daily for 2 weeks. This was followed by a two-week washout period. After the washout, the LUT group was switched to placebo for two more weeks, and the placebo group was switched to LUT. Neither the participants nor the investigators had knowledge about the contents of the randomized test samples. The LUT and PC tablets looked exactly alike and were dark purple in color. Sample identities were disclosed upon completion of data analysis.

The daily dosage of the LUT supplement contained 200 mg of blackcurrant fruit extract (containing 20% anthocyanosides), 5 mg of lutein, and 1 mg of zeaxanthin (Cerebos Pacific Limited, Singapore). Over the course of the entire study, each participant attended a total of four visual task testing sessions, on the first and final days on which they took the samples. Participants consistently attended the experimental sessions either in the morning or the afternoon, according to the time of their first experimental session.

2.3. Experimental procedure

A blood sample was taken from each participant before the visual task and EFRP measurement components of each experimental session. Electrodes for measuring physiological responses were attached to the head and body surfaces of the participants, following an explanation of the saccade and proof reading tasks.

The order of the experimental tasks was as follows:

1. Electrode attachment, 2. Saccade test 1 (pre-test), 3. Blood pressure measurement 1 (pre-test), 4. Questionnaires 1, 5. Main task (Proof reading task, 2 h), 6. Saccade test 2 (post-test), 7. Blood pressure measurement 2 (post-test), 8. Questionnaires 2, 9. Electrode removal.

2.4. Main task (proof reading task)

Each participant sat on a chair in front of a 19-inch liquid crystal visual display terminal (VDT) and a document stand. The main task consisted of four proof reading tasks, similar to those that a person might undertake in an actual office. Sentences that appear in four separate Japanese writings were downloaded from Aozora Bunko (Blue Sky Literature). The sentences were taken from pieces of short fiction, essays, and an autobiography. Correct sentences were presented on printed papers, and sentences containing errors were presented on the VDT. A document stand holding the papers was placed 55 cm in front of the participant, to their right side. The background of the display screen was changed to a bluish color, with blue color fixed at maximum and red color at mid-level, in order to cause visual fatigue.

The participant was instructed to search for incorrect words by comparing the printed sentences to what was seen on the VDT. The participant was required to correct errors by changing word color from blue to red on the display screen. Three to ten incorrect words were randomly inserted into each page displayed on the screen.

2.5. Saccade test

Saccade tests were conducted before and after the proof reading task. Two disks with embedded checkerboard patterns were placed at 57 cm and 228 cm in front of each participant. These placement positions ensured that the visual angles and checkerboard size of the two disks would be the same for all participants. The visual angles of the checkered disk and the square within the checkerboard pattern were 20° and 0.5° respectively. A red fixation point at the center of each disk served as the target for eye movements.

A participant was asked to move his or her eyes between the far left and the near right target according to recurrent pip tones (1000 Hz, 0.2 s) presented every 0.8 s, after a 2 s fixation period. Each saccade test consisted of 10 trials in which a participant performed six saccadic eye movements (for a total of 60 saccades). The inter-trial interval (ITI; rest period) was about 12 s.

2.6. Measurements

Collected blood samples were used to determine serum lutein and zeaxanthin concentrations. Five millilitres of blood was drawn from each participant per sample, using vacutainer serum separator tubes with no anti-coagulant. Each blood sample was centrifuged for 10 min and the serum was then removed for further analysis (Berendschot et al., 2000; Bone et al., 2000).

Blood pressure and heart rate were measured using a portable sphygmomanometer (National, EW 3003P) attached at the left wrist. Participants were asked to support their left arm using their right hand, to keep the level of the sphygmomanometer at the heart during measurement of blood pressure. Systolic blood pressure, diastolic blood pressure, and heart rate were shown on the display.

An EEG electrode placed at Oz referred to linked ears. EOGs (horizontal and vertical eye movements) and EMG (muscle activity) at the forehead and left neck were also measured. Bioelectrical signals were amplified using Nihonkoden amplifiers and were recorded on a Teac tape recorder. Signals were analyzed in a Melon-Technos system (Yagi et al., 2006).

In addition, number of errors made during the proof reading task and number of pages completed during this task were also recorded.

2.7. Analysis of data

2.7.1. Serum lutein and zeaxanthin concentrations

Sogo CH managed the analytical measurement of serum lutein and zeaxanthin concentrations. Sogo CH sent these data to Kwansei Gakuin University.

2.7.2. EFRP

EEG epochs were not subjected to EFRP analysis when large and/or irregular head or neck movements contaminated EEG recording. EEG recordings that were not distorted by noise or artifact (e.g., excessive eye blinking and muscle potentials) were averaged at offset of saccades using a system developed by Yagi et al. (2006). The proof reading task was divided into three sections, first, middle, and last, in order to analyze temporal changes in EFRP during this task. Data collected during the two saccade tests (before and after) were also analyzed. Data were averaged about 40–50 times for each section, during the proof reading task and saccade tests.

In many traditional ERP studies, amplitudes from a base level have been utilized as an index of the variable of interest. However, in an EFRP study base levels can shift as a function of eye movements. In the present study, we used the positive (P80) and negative peaks (N120) as an index of EFRP amplitude. The peak-to-peak amplitude of the EFRP changes during visual information processing (e.g., Yagi, 1981).

2.7.3. Muscle potentials (EMG)

The recorded facial and muscle potentials (EMGs) included both positive and negative potentials. Waveforms were rectified in order to obtain the absolute values of the potentials. The value was integrated for each participant. Because the absolute value has large inter-individual differences, the value was transformed into a *z*-score for each participant. Data were then averaged across participants.

2.7.4. Eye blinking

The number of eye blinks during the three sections of the proof reading task was counted using a vertical EOG.

2.8. Questionnaires

Participants were asked to complete three questionnaires before and after each proof reading task.

2.8.1. Subjective symptoms of fatigue test

Participants were asked to endorse items assessing various fatigue symptoms that fall into three categories: Dullness, concentration difficulties, and physical disintegration (Working Group for Occupational Fatigue, 1967, Japan Society for Occupational Health).

2.8.2. PSS (phasic stress scale)

Participants were asked to rate their psychological state (e.g., sleepy, tired) and subjective emotions (e.g., relaxed, anxious, fearful, happy, etc.) on a ten-point scale (Suzuki et al., 1999).

2.8.3. KSS (Kwansei Gakuin Sleepiness Scale)

Participants were asked to complete the sleepiness scale (e.g., 22 items, e.g., full of vitality, fall down by sleepiness, etc.), a standard scale developed at the University (Ishihara et al., 1982).

2.9. Statistical analysis

Statistical analyses were performed using SPSS. Data were analyzed using separate repeated measures ANOVAs. Statistical significance levels were set at $p < .05$.

3. Results

The results described here were obtained from the 13 participants who completed all four visual task testing sessions that the study required. We expected that more participants would have been able to complete all of the study requirements. As described earlier, there were nine drop outs that either withdrew from the study or did not complete all four visual task testing sessions.

3.1. Serum lutein and zeaxanthin concentrations

Table 1 shows concentrations of lutein + zeaxanthin in participants' blood serum. Lutein + zeaxanthin blood serum concentrations were significantly elevated following intake of the LUT supplement, $F(1,12) = 151.32$, $p < .0001$. Concentrations returned to normal levels during the washout period. PC produced no reliable changes in blood serum levels. There was a significant interaction between the conditions (experiment − placebo × before − after; $F(1,12) = 23.92$, $p < .0004$). There were no other significant effects on blood serum concentrations.

3.2. Questionnaires

3.2.1. Subjective symptoms of fatigue

The proof reading task appeared to cause significant fatigue. Fig. 1 shows mean subjective symptoms of fatigue scores, before and after completion of the proof reading tasks. There were significant first category effects of task on Sleepiness and Dullness scores, $F(1,12) = 9.34$, $p < .01$, a second category effect on concentration difficulties, $F(1,12) = 5.42$, $p < .04$, and a third category effect on physical wrongness, $F(1,12) = 9.60$, $p < .01$. These findings indicate that the proof reading task caused significant physical and psychological fatigue. There was a trend toward a significant interaction between supplement and task effects, $F(1,12) = 4.67$, $p < .06$. This trend was likely the result of higher physical fatigue scores after the task in the placebo condition, as compared to the LUT condition (placebo; $F(1,12) = 10.44$, $p < .01$; LUT; $F(1,12) = 4.08$, $p < .07$).

Table 1
Mean and SD of contents of Supplement A (LUT) and Supplement B (PC) in the blood.

	Supplement A		Supplement B	
	Before	After	Before	After
Lutein + zeaxanthin (μ dl)	111.6 ± 5.6	189.8 ± 5.5	116.0 ± 5.7	11,456 ± 2.4
Lycopene (μ dl)	14.9 ± 93	12.3 ± 9.8	17.5 ± 91	13.6 ± 84
β Cryptoxanthin (μ dl)	42.2 ± 8.5	39.2 ± 5.6	40.2 ± 4.7	41.8 ± 8.5
α Carotene (μ dl)	23.6 ± 4.7	19.5 ± 2.8	23.4 ± 6.4	22.8 ± 3.5
β Carotene (μ dl)	55.1 ± 8.8	55.1 ± 4.6	57.00 ± 5.4	55.1 ± 4.6

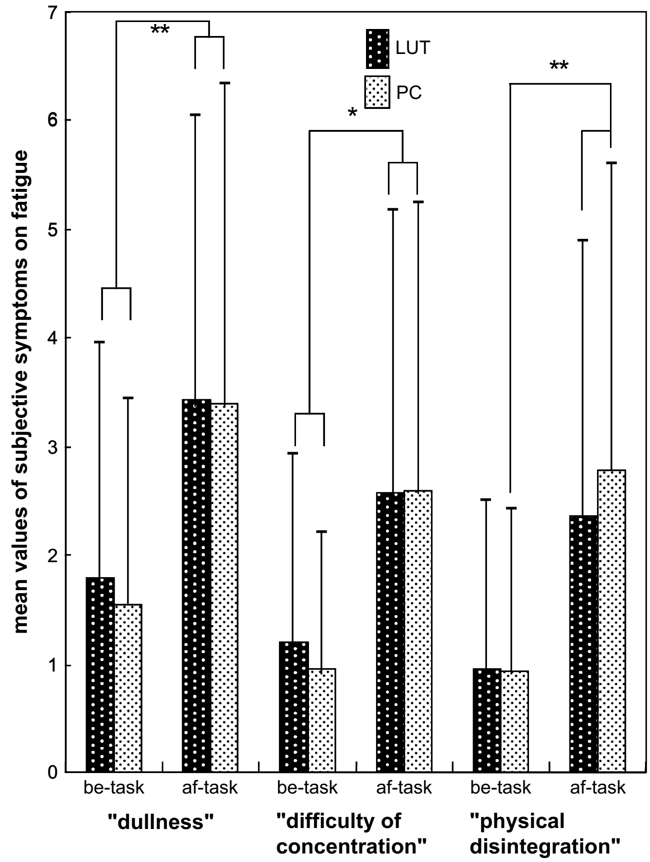

Fig. 1. Subjective symptoms of fatigue (before and after the proof reading task) in the lutein and placebo conditions.

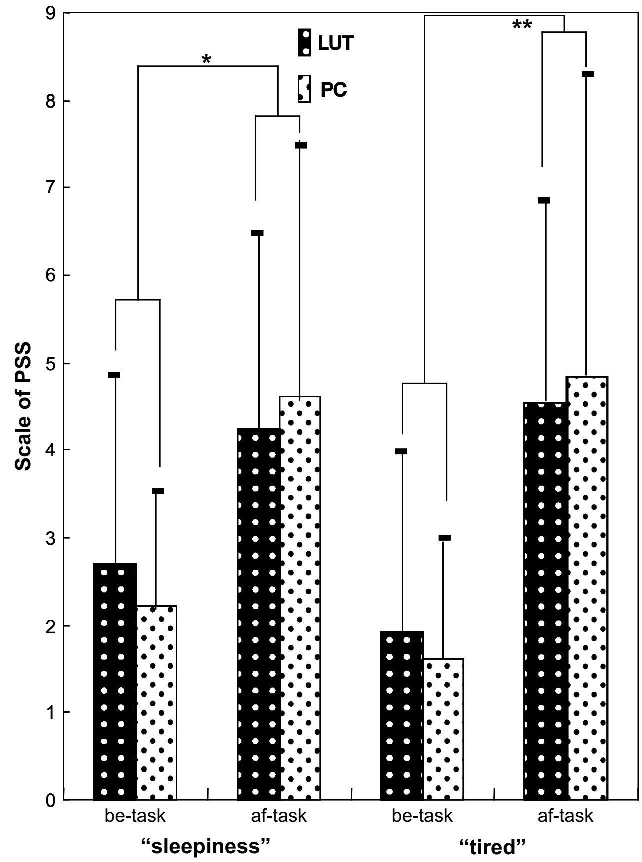

Fig. 2. Mean PSS (phasic stress scale) scores (before and after the proof reading task) in the lutein (LUT) and placebo conditions (PC).

3.2.2. Phasic stress scale (PSS)

Fig. 2 shows differences between LUT and PC on PSS scores. There were significant changes from pre- to post-test, especially on physical fatigue scores, $F(1,12) = 13.27$, $p < .004$. There was no significant effect of supplementation on these scores, and no significant interaction between the effects of supplementation and the proof reading task. The effects on other PSS subscales were also non-significant.

3.2.3. KSS (Kwansei Gakuin Sleepiness Scale)

Fig. 3 shows the pre- versus post-test differences on KSS (Kwansei Gakuin Sleepiness Scale) scores, $F(1,12) = 5.12$, $p < .044$. There was no significant effect of supplementation on KSS scores. The pattern of findings across the three questionnaires used here is consistent in suggesting that the proof reading task fatigued the participants.

3.3. Proof reading task performance

Participants proof read more pages after taking LUT compared to placebo, although this difference was not statistically significant.

3.4. Psychophysiological responses

3.4.1. EFRP

First, EFRP values for each participant were obtained by averaging EEGs at saccade offset. The grand mean potential value was obtained by averaging the separate EFRP values of the individual participants.

Fig. 4 shows the grand mean EFRPs obtained from the 13 participants, collected during saccade tests conducted before and after the proof reading task, on either LUT or PC. EFRP waveforms appeared in all conditions. In an EEG study, a potential is shown as upward negativity. A zero point (0) with a vertical line in each figure represents the moment of saccade offset. Two negative peaks at about zero and 120 ms, and two positive peaks at about 80 ms and 200 ms, occur after a saccade. The practical offset point of a saccade is around the negative peak, at 0 ms. A large positive EFRP component appears at about 80 ms. The amplitude between the positive component at about 80 ms and the negative component at about 120 ms was determined to be an index of EFRP amplitude for each participant.

Fig. 5 shows the mean peak-to-peak amplitudes across participants after either LUT or PC supplementation, both before and after the proof reading task. We obtained a significant main effect of proof reading task, $F(1,12) = 5.16$, $p < .043$. There was a trend toward a significant interaction between the task effect and supplementation, $F(1,12) = 4.09$, $p < .066$. Post hoc tests revealed that the amplitude after the task was significantly larger than that before the task, but only in the LUT condition, $F(1,12) = 10.01$, $p < .009$. The result indicated that supplementation with LUT could help to reduce symptoms of visual fatigue.

We could not obtain enough EFRP data during the proof reading task to conduct statistical analyses, due to excessive irregular head and body movements of the participants.

3.4.2. Muscle potential and eye blinking

We measured muscle potentials at the forehead and neck. Muscle potentials have large inter-individual differences, depending on the difficulty of unification in the size of the muscle and the

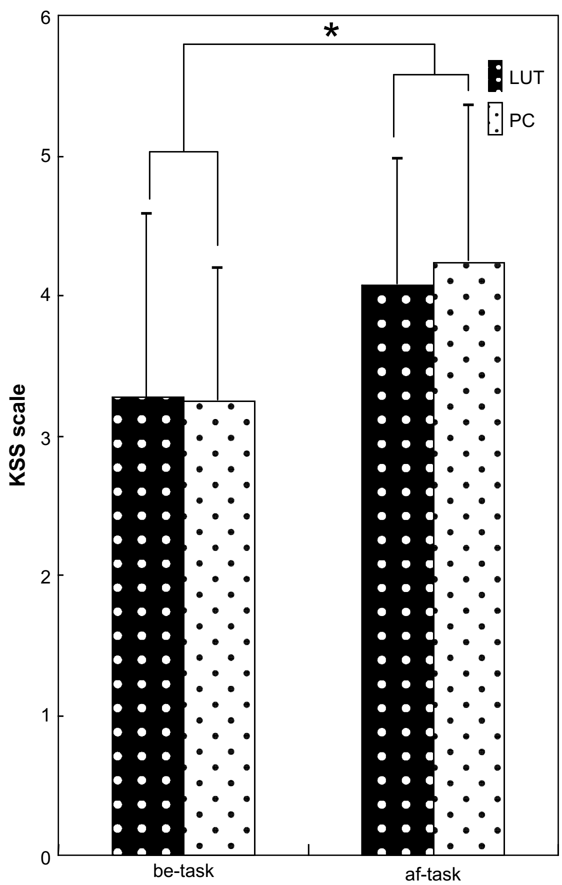

Fig. 3. Mean KSS (Kwansei Gakuinn Sleepiness Scale) scores (before and after the proof reading task) in the lutein and placebo conditions.

distance between electrodes. These potentials were therefore transformed into z-scores for each participant. The mean z-scores were very small at the forehead and neck. There were no differences as a function of supplementation.

The mean frequency of eye blinks per minute slightly increased, but again there were no significant differences between the conditions.

3.4.3. Blood pressure and heart rate

Fig. 6 shows mean systolic (SBP)/diastolic (DBP) blood pressures and mean heart rate (HR), before and after the proof reading tasks in the LUT and PC conditions. The figure appears to show that both SBP and DBP were higher after the task. However, only DBS was significantly increased after the task, $F(1,12) = 10.74$, $p < .008$; there was no significant effect on SBP.

There was a significant interaction between task and supplementation on the heart rate measure, $F(1,12) = 5.41$, $p < .04$. Post hoc tests showed that heart rate after the proof reading task was lower in the LUT than in the PC condition, $F(1,12) = 9.98$, $p < .009$.

4. Discussion

Participants in the present study completed a relatively strenuous proof reading task that was intended to cause visual fatigue. Participants completed this task four times, across four testing sessions. Each testing session consisted of the visual proof reading task, three subjective tests (questionnaires), performance measurements, and psychophysiological measurements.

4.1. Subjective scores

Subjective feelings of fatigue were compared before and after the visual proof reading task. On all subjective measures, the proof reading task appeared to effectively cause fatigue. According to introspections provided by participants after the experiment, the visual task we used was extremely difficult and strenuous.

There were few significant effects of supplementation on participants' subjective fatigue scores. There was an interaction between the supplement and task effects, such that physical fatigue scores were higher in the placebo condition (post-proof reading task) than they were in the supplement condition. It would appear that LUT might help to mitigate the physical effects of engaging in a strenuous visual task.

4.2. Performance

We measured number of pages completed in the proof reading task as an index of task performance. The LUT supplement was associated with a greater number of pages completed relative to placebo, although this effect was not statistically significant.

As mentioned above, some ethnic Chinese were among the participants. This development was unexpected. However, our Chinese participants all spoke, read and understood Japanese. A few of the Chinese participants did not understand the meaning of some of the questionnaire items. However, most of letters in the sentences examined during the proof reading task were Chinese characters, with which the Chinese participants were familiar. In the proof reading task itself, comparing letter shapes was more important that ascertaining the meaning of the sentences.

4.3. EFRP

In the LUT condition, mean EFRP amplitude was significantly increased after the proof reading task than before it. There was no such difference in the PC condition. EFRP amplitude usually decreases after a long duration task (Daimoto et al., 1998; Takeda et al., 2001). We therefore expected that EFRP amplitude would have decreased after the proof reading task induced fatigue. The findings of the present study are inconsistent with previous work.

In the study of Takeda et al. (2001), the proof reading task lasted for more than 5 h (from 9:00 a.m. to 5:00 p.m.), although some rests periods were inserted. In the study of Daimoto et al. (1998), the task used was very monotonous and lengthy, which may have brought about satiety and fatigue. It is also the case that participants in these studies completed only one testing session, whereas in the present experiment, each participant completed the fatigue-inducing task four times. The participants had already experienced the proof reading task from zero to three times at the beginning of each testing session, which may have enabled them to predict task difficulty and hence drop out of the experiment prematurely. Indeed, nine participants chose to discontinue the experiment.

Interestingly, EFRP amplitude in the LUT condition increased from pre- to post-proof reading task. In previous studies, EFRP amplitude increased under conditions of enhanced visual attention (Yagi, 1981). In a study of traditional ERP (event related brain potentials), ERP amplitude gradually decreases as a function of fatigue, habituation, satiety, and declines in attention as an experimental task goes on. Stimuli are presented passively to participants in ERP studies.

Participants in an EFRP study actively look at stimuli with moving eyes. When participants play and enjoy a computer game (Yagi et al., 2003) or perform a computer graphics task (Yagi & Ogata, 1995), EFRP shows very small changes in amplitude as time goes on. When novices in one study were asked to perform

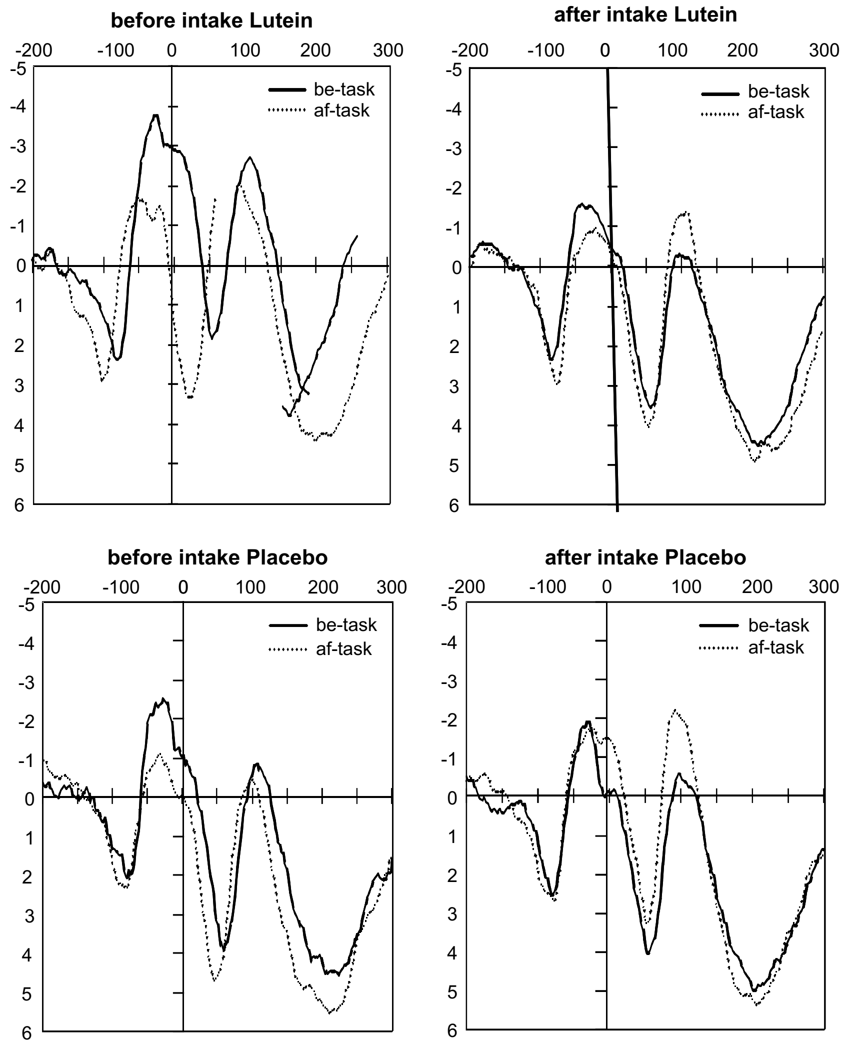

Fig. 4. Grand mean EFRPs during saccade tests (before and after the proof reading task) in lutein (LUT) and placebo (PC) conditions. Vertical scale; micro V, horizontal scale; ms.

a computer graphics task, EFRP amplitude gradually increased as experimental time passed (Yagi et al., 1997). In that study, participants actively enjoyed and wanted to continue the task.

Some studies (Bone et al., 2000; Nakaishi et al., 2000; Gale et al., 2003; Richer et al., 2004; Snodderly et al., 2004) have suggested that lutein, zeaxanthin and blackcurrant extract enhance the visual functioning of the retina. Lutein and zeaxanthin are the main active constituents of a supplement thought to prevent and aid recovery from macular degeneration in the eyes. This supplement also contains anthocyanosides and other carotenoids, which have beneficial effects not only on the retina but on muscle tissue as well.

EFRP is thought to reflect the total functioning of the visual system, consisting of the retina, the muscle of the pupil, the muscles involved in eye movements, and central nervous system functioning. In the present study, LUT may have had beneficial effects on visual functioning that served to counteract or prevent fatigue induced by the proof reading task.

On the other hand, mean EFRP amplitude did not show a systematic change in the PC condition. In previous ERFP and ERP studies, it was reported that the waveform of these potentials became more stable when a participant paid more attention to the assigned task (Yagi, 1982; Yagi et al., 1998). However, when the participant was distracted by other stimuli, EFRP waveform variability increased. High EFRP waveform variability might therefore have caused this inconsistent finding for the PC condition.

We also analyzed EFRP data that were collected while participants were performing the proof reading task. However, some of the participants did not perform the proof reading task as faithfully as the experimenter had instructed to them to do so. One of the reasons for this was likely that the task was extremely difficult. The participants therefore may not have been able to faithfully follow the experimenter's directions. Participant eye movements during this task were not normal. Some subjects showed very large head muscle changes. Participant posture while performing the task also has important implications for data comparison. Again, the postures of some of the participants were not normal, despite experimenter instructions and suggestions. Some of the participants actually feel asleep. We therefore could not get enough reliable EFRP data during the proof reading task to conduct statistical analyses.

4.4. Other physiological responses

Blood pressure changes usually correlate with heart rate. In the present experiment, heart rate measured after the proof reading task was lower than before the task in the LUT condition. However,

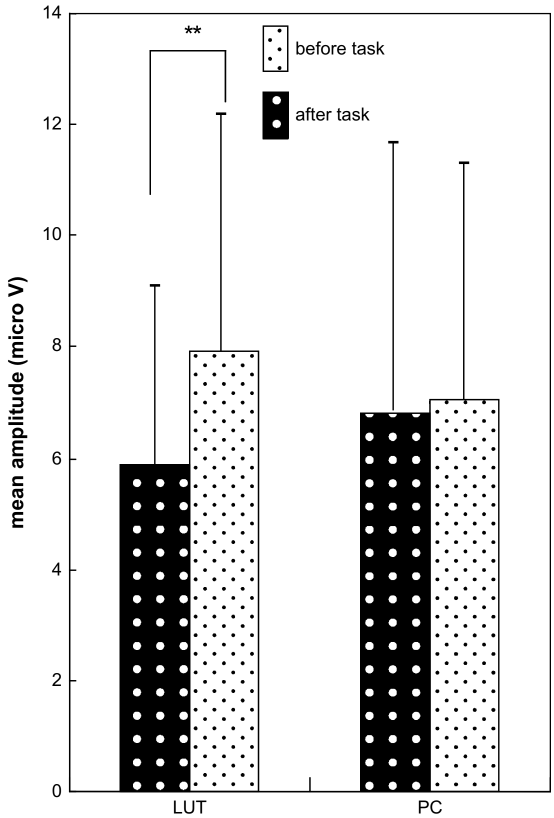

Fig. 5. Mean EFRP amplitudes (before and after the proof reading task) in the lutein (LUT) and placebo conditions (PC).

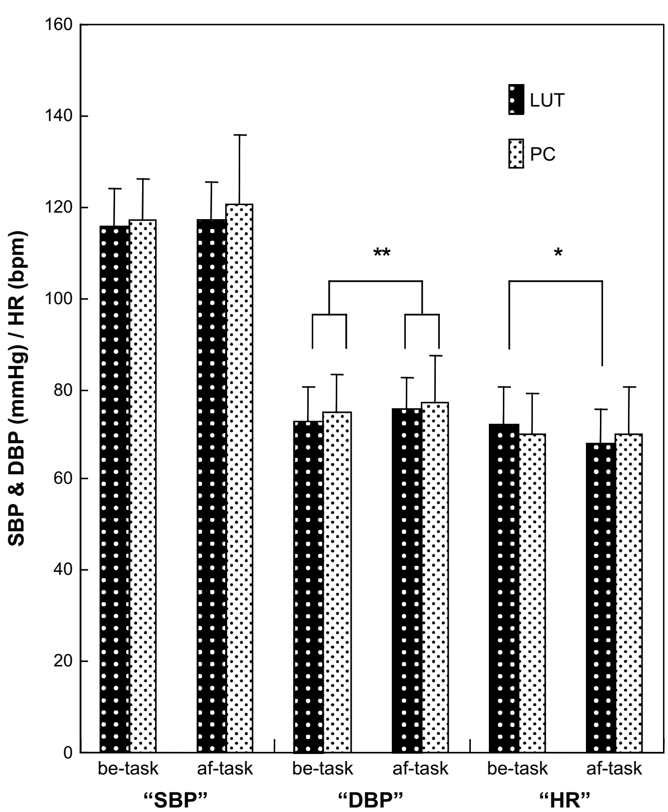

Fig. 6. Mean systolic (SBP) and diastolic (DBP) blood pressure, and mean heart rate (HR) (before and after the proof reading task) in the lutein (LUT) and placebo conditions (PC). SBP and DBP (mmHg), HR (beat/min; bpm).

diastolic blood pressure after the task was still higher than before the task. Heart rate typically changes more quickly than blood pressure, which changes with heart rate and peripheral blood vessel activities according to the alpha effect of the autonomic nervous system. Blood pressure changes due to LUT supplementation may therefore come about later than changes in heart rate. It does appear that LUT supplementation has a beneficial effect on another psychophysiological parameter, heart rate, after a strenuous visual task.

Muscle potentials at the forehead and neck showed large interindividual differences and no consistent variation as a function of visual strain or LUT supplementation. Nor did eye blinking during the proof reading task show any systematic changes. These data also suggest that participant posture was not constant during the proof reading task or across subjects.

We should conclude by noting that we did not obtain systematic differences in the control conditions.

5. Conclusion and remarks

Subjective participant ratings suggested that our difficult proof reading task was quite fatiguing for our participants. Many of our participants had to discontinue the study, while others only had their blood samples taken.

EFRP during a saccade test after the proof reading task increased in the LUT condition, compared to during a saccade test before the task. Typically, EFRP amplitude decreases after a difficult visual task. The participants had known that the proof reading task was very long and difficult, even before each testing session began (they experienced four testing sessions). The mind and bodily states evoked would have been rather unwelcome even at the beginning of the experiment. Participants would have been rather relieved upon completing the task.

After the task, LUT supplementation appeared to help participants to recover from the effects of visual fatigue and/or anticipatory stress, such that EFRP amplitude was larger after the proof reading task than before it, relative to placebo. Heart rate findings also support this assumption. EFRP could be applicable as an index for the assessment of visual fatigue and relevant effects of supplements.

Previous studies have shown that a supplement containing lutein, zeaxanthin, and blackcurrant extract has beneficial effects on visual functioning (Berendschot et al., 2000; Bone et al., 2000; Nakaishi et al., 2000; Gale et al., 2003; Richer et al., 2004). The increased serum concentrations of lutein and zeaxanthin that we observed in the LUT condition indicate good supplement bioavailability, and could help to maintain good macular pigment density. Overall, our results suggest that a combination of lutein, zeaxanthin and blackcurrant extract can aid recovery from visual fatigue.

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