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Effects of Low Visual Acuity Simulations on Eye-Hand Coordination and Brainwaves in Healthy Adults

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Objective: In general, macular degeneration, cataracts and glaucoma generally cause visual injury in clinical settings. This study aimed to examine the effects of low visual acuity simulations on hand manual dexterity function and brainwaves in healthy young adults.

Design: Cross-sectional study design

Methods: This study was an observational, cross-sectional study. Seventy healthy young adults participated in this study. To evaluate the effects of low visual acuity simulations on hand function and brain waves, this study involved four different visual conditions including (1) normal vision, (2) simulated cataracts, (3) simulated glaucoma, and (4) simulated macular degeneration. The hand function was measured to use the Minnesota manual dexterity test (MMDT), and the brainwaves was also measured to use the electroencephalography.

Results: In hand function, placing and turning performance on the MMDT in the normal visual condition was significantly different than that in the cataract and macular degeneration conditions ($p < 0.05$), and the placing performance was significantly differred in the normal condition than that in the simulated glaucoma. However, turning was not significantly different in the normal condition than that in the simulated glaucoma. The alpha, beta, and gamma waves did not significantly differ among the four visual conditions ($p > 0.05$).

Conclusions: The results suggest that limited visual information negatively affects the ability to perform tasks requiring arm-hand dexterity and eye-hand coordination. However, the effectiveness of low visual acuity on the brainwaves should be further studied for rehabilitative evidence of visual impairment.

Key Words: Brainwaves, Cataract, Glaucoma, Hand function, Macular degeneration, Visual acuity

Introduction

Visual impairment is one of the most common forms of sensory loss, resulting from degeneration, diabetic retinopathy, and infection [1]. It is a vision loss to see something and is not fixable by usual means, such as by wearing eyeglasses. The major causes of visual impairment globally are glaucoma, macular degeneration, and cataracts [2, 3]. Visual impairment may cause difficulties with daily activities, reading and cooking and if it is severe, causes difficulties in performing basic activities of daily living such as transferring, eating, bathing, and walking [4]. Ultimately, visual impairment can support to evasion of social interactions and engagement, resulting in social isolation or substantial physical decline, which may ultimately require a transition into a dependent daily living [1, 5, 6].

Many previous studies have reported the best suitable therapeutic interventions for visual impairments in children to gain optimal functional activities and behavior, to decrease participation restriction and to improve quality of life [7-9]. Wagner et al. [10] provided

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an empirical basis for instruction gross motor function for visual impairments' child. They reported that developing basic motor skills during childhood is a fundamental component of motor skill that can have permanent effects on physical function, activity and participation levels, and physical and mental health [10]. Other studies were conducted to investigate the strength of the association between depression and visual impairment in the older adults [1]. Popescu et al. [11] examined whether people with age-related eye diseases (Fuchs' corneal dystrophy, glaucoma, or macular degeneration) were more likely to show signs of depression than those of older persons with normal vision, and also assessed the association between aged-related eye diseases and physical mobility. They reported that eye disease limiting visual acuity was related with depression in the elderly [11].

While many previous studies have examined the visual impairment on the development of motor function in children, and the association between depression and visual impairment in the elderly [1, 10, 12], few have assessed whether low visual acuity from diseases such as cataracts, glaucoma, and macular degeneration cause limited motor function. Visual skills such as acuity, oculomotor control, and intact visuals fields can affect visual perception, attention, scanning, and pattern recognition. Therefore, visual skills are presumed to affect the development of motor skills as well as motor learning and the retention of functional activities. We were to investigate the effects of low visual acuity simulations on hand function and brainwaves in healthy young adults. We hypothesized that the low visual acuity simulations would limit hand function more than that in the normal visual condition. We also hypothesized that the brainwaves during the low visual acuity simulations would differ to those during the normal visual condition.

Methods

Seventy healthy young adults without a history of visual field defects participated in this research between December 01, 2019 and February 23, 2020 (Figure 1). Participants were those who had a sufficient understanding of the purpose of the research and voluntarily involved in the experiment. The inclusion criteria included individuals (1) without any cognitive impairment or psychological diseases, (2) without any visual acuity or visual field deficits, (3) without any physical impairments, and (4) who voluntarily agreed to participate in the study [13]. This study excluded the persons who involved similar experiments in the previous 6 months, who had a diagnosis of depression, or who took any medicine

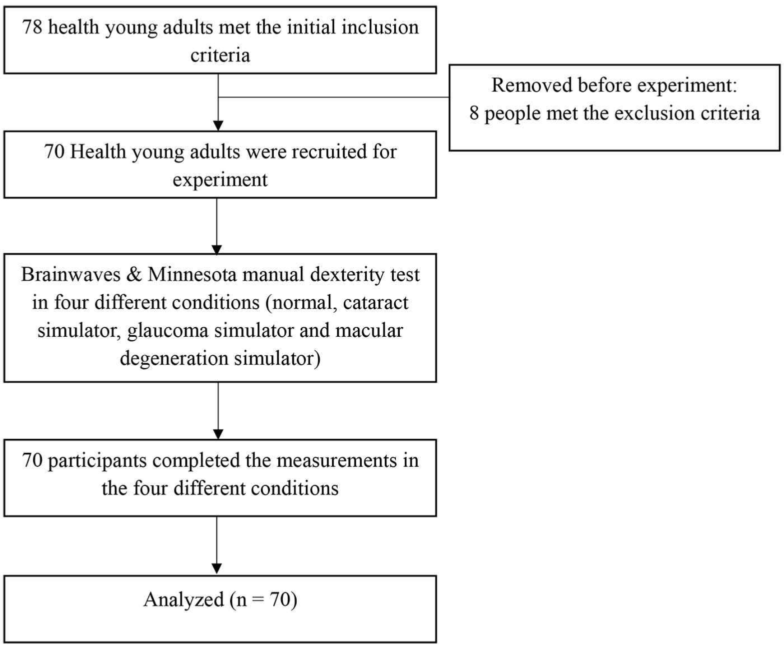

Figure 1. Flow diagram of the study

which could affect the results of experiments. The protocol of this study was approved by the Wonkwang University Institutional Review Board (Permit No. WKIRB-201905-HR-040), and all the participants voluntarily consented to contribute in this research.

Procedure

This study used an observational, cross-sectional study design to assess brainwaves and hand function in response to visual impairments. To determine the effects of visual field deficits on hand function and brain activation, four different visual conditions were created: (1) normal visual condition, (2) cataract condition, (3) glaucoma condition, and (4) macular degeneration condition. Assessing the brainwaves and hand-eye coordination were conducted in two different settings.

Prior to measuring the brainwaves, participants entered a well-organized measurement room that contained one chair (height of the chair = 45 cm) and a large monitor (27 inches) positioned 2 m in front of the chair. First, the participant randomly selected the measurement order by sortation. The participant was then asked to maintain the correct posture by pulling the chin-to-chest and attaching the trunk of their body to the back of the chair. The participant was careful not to move his/her head or body and maintain a stable position. The assessor removed all jewelry from the participant's head and tidied up his/her hair behind his/her ears. The participant put on the electroencephalography (EEG) headset and adjusted the straps to suit his/her head circumference. Ear clip sensors were inserted in the ear and the utility tool was used to ensure that the sensors were well attached to the participant's scalp. The assessor turned on the program and checked that all electrodes were well attached, using the utility tool to adjust until a green signal appeared indicating that the electrodes were well attached. The participant stared at a paragraph on the monitor located in front of him or her while the assessors measured the brainwaves, including alpha, beta, and gamma waves.

Alpha waves are recorded primarily over the parietal and occipital lobes, and occur when you are in a relaxed state, close your eyes, are concentrating, or are thinking under the influence of visual stimulation. Beta waves are recorded primarily over the frontal lobe and are affected by auditory, tactile, and emotional stimulation. They occur when active, arousal, stressful, and mental activity focus attention. Gamma waves are recorded primarily over the frontal and parietal lobes, and are brain waves that occur frequently in a state of intense stress, such as anxiety and excitement, due to external consciousness. In this study, alpha waves were measured at parietal locations P3 (parietal 3) and P4 (parietal 4), beta waves at frontal locations F3 (frontal 3) and F4 (frontal 4), and gamma waves at locations P3, P4, F3, and F4. According to the measurement order selected by the participant, he or she set the visual condition and kept the correct posture while looking straight ahead for 1 minute. There was a 1-minute break between each trial. The test was performed three-time and the mean-value was used in the analysis for each condition (Figure 2).

In the second part of the experiment, eye-hand

a. Front view | b. Side view | c. Electrode sites

Figure 2. Electrode sites and electroencephalography

coordination and arm-hand dexterity were assessed using the Minnesota manual dexterity test (MMDT). The participant maintained a standing position in front of a table (height 71-76 cm and width 55 inches), with the assessor located on the other side of the table across from the participant. The assessor explained the task and confirmed the precautions for the participant before the evaluation. With setting in a chair 1.5 m from away the table, the participant performed the task of the MMDT according to the assessor's instruction.

Intervention equipment

Low-vision simulators, including cataract simulators, glaucoma simulators, and macular degeneration simulators, were used to simulate different visual field deficits. The cataract simulator showed visual acuity impairment across the entire visual field and resulted the glare vision. The simulator also offers a general understanding of the visual acuity and a visual limitation like as optic nerve hypoplasia, albinism, and achromatopsia. The glaucoma simulator impaired vision at 20 degrees in the visual field to simulate glaucoma. The macular degeneration simulator reproduced the effect of a central scotoma, which was a foggy visual periphery and a white and opaque blind spot.

Outcome measures

The main measures of the study were the alpha, beta, and gamma waves, all of which were collected at baseline and during the visual impairment conditions. The equipment to measure the brainwaves was a research-grade wireless dry electrode EEG headset (DSI-24, Wearable Sensing, USA). The EEG from the Pz (midline parietal) location was the default reference and the ground was Fpz (midline sagittal plane). The main feature of this device is that it included wireless transmission with sampling at 300 Hz, a 16-bit analog/digital converter, 0.003-150 Hz bandwidth, 8 bits digital trigger-input, and was adaptable to fit the head sizes from 52 cm to 62 cm in circumference.

The secondary measure was the MMDT, which it is a standardized test for the evaluation of a participant's upper extremity function to move small objects various distances (Lafeyette Instrument Company Co., Lafeyette, IN, USA). The MMDT is used to measure a participant's eye-hand coordination and arm-hand dexterity with a thin board with 60 holes that folds into three [14]. The MMDT is composed of two subtests: the placing and the turning tests. A higher score (i.e., longer time) indicates a lower performance [15]. The MMDT was reported the acceptable to high test-retest reliability (intraclass correlation coefficients, 0.79-0.87) and high validity with the Minnesota rate of manipulation test [16].

Statistical analysis

The independent variables were the simulated low visual acuity conditions, including the cataract, glaucoma, and macular degeneration simulators. Brainwaves and hand function were also assessed under a normal visual condition to be able to determine whether measures were impaired under the simulated conditions compared to normal vision. Therefore, there were four different conditions: (1) normal visual condition, (2) cataract simulator condition, (3) glaucoma simulator condition, and (4) macular degeneration simulator condition. This study collected demographic characteristics of the participants including sex, age, and corrected visual acuity. A paired t-test was used to analyze the differences in the dependent variables between each simulated condition and normal vision: (1) normal condition vs cataract simulator condition, (2) normal condition vs glaucoma simulator condition, (3) normal condition vs macular degeneration simulator condition. We also used a repeated measures general linear model to analyze whether there were significant differences in brainwaves and hand function among the four different visual conditions, and used the Scheffe post hoc test to determine exactly where differences occurred among the four different visual conditions. SPSS (version 25.0, IBM Inc., USA) was used for analyzing. A p-value less than 0.05 was statistically significant.

Results

Common characteristics of the participants in this study

Table 2 shows the common characteristics of the participants in this study. The participants were thirty-five

Table 1. Characteristics of the participants (N = 70)

Variables		mean±SD/frequency(percent)
Sex (male/female)		35(50.0)/ 35(50.0)
Age (yr)		22.4±1.39
Rt. Corrected visual acuity	20/20 or below	60
	Above 20/20	10
Lt. Corrected visual acuity	20/20 or below	61
	Above 20/20	9

Lt, left; Rt, right; SD, standard deviation

Table 2. Comparisons among non-taping, rock-taping, compression, com-sil and com-mesh conditions in participants (N = 70)

Variables		mean±SD				F	p
		Normal vision	Cataract simulator	Glaucoma simulator	Macular degeneration simulator		
Brainwave	Alpha wave	0.22±0.13	0.24±0.14	0.23±0.13	0.22±0.13	.560	.618
	Beta wave	0.38±0.10	0.36±0.08	0.36±0.09	0.36±0.08	1.708	.174
	Gamma wave	0.29±0.02	0.33±0.14	0.30±0.12	0.34±0.13	0.207	.891
MMDT	Placing	117.69±12.95 ‡§	183.50±25.25*‡§	137.40±16.47*†	142.26±26.78*†	200.443	< .001
	Turning	94.84±14.90 †§	135.57±25.68*‡§	98.51±16.09 †§	103.79±21.71*†‡	115.179	< .001

*statistically significant difference with normal vision condition
†statistically significant difference with cataract simulator condition
‡statistically significant difference with glaucoma simulator condition
§statistically significant difference with macular degeneration simulator condition
MMDT, Minnesota manual dexterity test.

men and thirty-five women, and their mean age was 22.4 years old. Their right corrected visual acuity was 20/20 or below in sixty persons and above 20/20 in 10 persons. Their left corrected visual acuity was 20/20 or below in sixty-one persons and above 20/20 in nine persons (Table 2).

The sixty persons of them showed 20/20 or below of right corrected visual acuity

Comparisons of the brainwaves among four different visual conditions

Table 2 shows the comparison of the brainwaves between the normal visual condition and the other, impaired visual conditions. Although the amplitudes of the waves showed small differences among the four different visual conditions, the alpha, beta, and gamma waves did not differ significantly among the four visual conditions ($p > 0.05$).

Comparisons of the hand function among four different visual conditions

Table 2 shows the comparison of the hand functions between the normal visual condition and the other visual conditions. The time of placing was significantly different in normal vision compared with three other visual simulations. The time of placing was the greatest in cataract simulator condition and the lowest in normal vision. The time of placing was also significantly different among the three different visual simulators, such that the time in the cataract simulation was significantly different from that in the glaucoma and macular degeneration simulator conditions. However, the placing times were not significantly different between the glaucoma and macular degeneration simulator conditions.

The time of turning was significantly different in the normal vision condition compared with the cataract and macular degeneration simulator conditions. The time of turning was also significantly different among the three different visual simulators. Specifically, the turning time in the cataract simulation significantly different than that in the glaucoma and macular degeneration simulator conditions. Further, the time of turning in the glaucoma simulator condition was significantly different than that in the cataract and macular degeneration simulator conditions. The time of turning was the greatest in the cataract simulator condition and the lowest in the normal vision condition.

Discussion

This study investigated the effects of low visual acuity simulations on hand function and brainwaves in healthy young adults. The main findings of the results were as follows: First, the three different visually impaired conditions, including cataract, glaucoma, and macular degeneration, did not affect qEEG, alpha waves, beta waves, and gamma waves. Second, eye-hand coordination was most affected in the cataract simulator condition and least in the glaucoma simulator condition. Third, arm-hand dexterity was most affected in the cataract simulator condition and least in the glaucoma simulator condition.

qEEG is most often used to diagnose epilepsy, sleep disorders, anesthesia, consciousness's level, encephalopathies, and brain injuries used the brain's electrical activities [17]. Despite not providing high-resolution anatomical imaging, qEEG is a valuable research tool due being noninvasive and easy to use, particularly in clinical settings. This study measured alpha, beta, and gamma waves of the qEEG [18]. The alpha wave is present during a relaxed mental state. Beta wave is associated with active concentration and nervous, hard or active thinking, so the wave is reinforced by sensory feedback in static movement and is decreased during dynamic movement. Gamma waves are associated with cognitive phenomena such as working memory, attention, and perceptual grouping, and has been observed in cognitive disorders such as Alzheimer's disease and epilepsy [17, 19]. The brainwaves in the normal visual condition and the three different simulator conditions were not significantly different from one another in this study. The diseases simulated here–cataracts, glaucoma, and macular degeneration–affect the eye and the eye's ability to detect and transmit the visible information to the visual cortex [20]. After detecting the visual information on the eye, the visual cortex perceives the information [21]. Therefore, those diseases do not directly damage the visual regions of the brain. The results of this study demonstrate that the diseases do not directly affect the visual centers, because the brainwaves did not significantly differ among the visual simulation conditions. Therefore, this suggests that appropriate treatment can prevent and alleviate those diseases from causing changes in the brain that result in difficulties in performing daily activities.

The secondary outcome measure was the MMDT, which is a simple task to measure arm-hand dexterity and rapid eye-hand coordination [14]. Eye-hand coordination is the processing of visual input to guide reaching, grasping, and manipulating of an object along with the use of visual proprioception [21, 22]. Generally, eye-hand coordination is evaluated by diversiform activities such as moving a solid object, and the MMDT is the most common method by which to assess this. This study examined the placing of objects under four different visual conditions, normal visual condition, cataract simulator condition, glaucoma simulator condition, and macular degeneration simulator condition. This was to assess differences in eye-hand coordination when the brain cannot properly process visual sensory information. According to the results, there was significantly difference in the time it took participants to place the objects depending on the visual information entering the brain. The placing of objects was the slowest in the cataract simulators condition, followed by the macular degeneration and glaucoma conditions.

The MMDT also measures arm-hand dexterity, which is the ability to use the hands and arms in a task, and thereby can determine the quality and skill level in performing activities in daily living as well as social functioning [14]. The interaction of sensory and motor components is reflected in the arms and hands. Therefore, arm-hand dexterity would be affected by the visual information from the eyes [23]. According to the results from the turning test, the time to perform the task in the normal visual condition was significantly different than that in the cataract simulator and macular degeneration conditions. Therefore, the glaucoma simulation did not affect arm-hand dexterity in the ability to quickly turn the objects.

In summary, the results suggest that decreased visual information negatively affects eye-hand coordination and arm-hand dexterity, but decreased visual information due to glaucoma does not affect arm-hand dexterity. The brainwaves were not affected by simulated limited visual information due to eye diseases such as cataracts, glaucoma, and macular degeneration. The results of this study suggest that the limited visual information would negatively affect the ability to perform tasks requiring eye-hand coordination and arm-hand dexterity. This study has some limitations. Namely, we only measured the immediate effect of low visual acuity simulations on hand function and brainwaves. Further studies will be needed to investigate the effectiveness of low visual acuity on more variable functional activities such as eating, walking, and dressing. Further, this study was conducted only in healthy young adults, not individuals with low visual acuity diseases. Future studies will need to be conducted on patients with diseases resulting in low visual acuity.

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