The effects of total body vibration on visual acuity and stereopsis during military exercise

Kuo-Yuan Chuang[1] and Chi-Ting Horng [2,*]

[1]Department of Rehabilitation, Kaohsiung Veteran General Hospital, Kaohsiung, Taiwan
[2]Department of Ophthalmology, Zuoying branch of Kaohsiung Armed Forces General Hospital, Kaohsiung, Taiwan
Tell phone: 886-7-5834845; Email: h56041@gmail.tw

Abstract: **Objective**: To investigate the impacting effects of on human visual acuity and stereopsis during military exercise. **Methods**: In our experiment, total 60 healthy male soldiers (mean age 22.6 Y/O) were enrolled. The whole body vibration exercise was induced in Taiwan High Speed Rail Laboratory. We created the Gx and Gy force (< and > 0.1G) in one moving vibrating platform. We checked the visual acuity of right eye and stereopsis of every subject before and during the vibration. The vision was checked by Rosenbaum pocket vision screener. The stereopsis was tested by the stereotest-circles. **Results**: In our experiment, all the BCVA of the 60 participates revealed 20/20 on the ground and the stereopsis all reached 40 seconds of arc. When whole body vibration occurred lower than 0.1G (X-or Y-axis), the BCVA and stereopsis remained unchanged. That is to say that the static and dynamic visual acuity and stereopsis are equal when vibration less than 0.1G. If the Gx or Gy greater than 0.1G, dramatic changes were found. When 0.1G from lateral direction (Gx) happened, the dynamic BCVA of 50% subjects showed one line letter drop (to 20/25) and also dynamic stereopsis of 50% subjects changed to 60 sec of arc. If Gy force greater than 0.1G (A-P direction), the dynamic BCVA of 40% subjects dropped 2 lines (to 20/30). Moreover, the dynamic stereopsis of 40% of volunteers reduced to 50 sec of arc. Besides, all the subjects complained about different levels of discomfort (ocular strain or headache) in reading. **Conclusion**: To the best of our knowledge, no exact data showed the degree and level of vibration induce the decrease of visual acuity and stereopsis in the past. Our scientific evidence shows that the visual acuity and stereopsis of the human being may mildly deceased when the Gx (or Gy) greater than 0.1G in acceleration and deceleration of any vehicles in the ground.

[Kuo-Yuan Chuang and Chi-Ting Horng. **The effects of total body vibration on visual acuity and stereopsis during military exercise.** *Life Sci J* 2017;14(10):108-116]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 16. doi:10.7537/marslsj141017.16.

Keywords: Whole body vibration exercise, Visual acuity, Stereopsis

Introduction

Nystagmus is defined as repetitive, to-and-fro involuntary eye movements that are initiated by slow drifts of the eye. It has a prevalence of approximately 24 per 10000. Sometimes, dissociated eye movement were also found〔1〕. The patho-physiology and mechanisms of nystagmus involved visual system, extra-ocular muscles, central nervous system, the inner ear, semicircular canals and labyrinth pathway〔2〕. Other literature mentioned that the relationship between nystagmus, cortical pursuit pathways and subcortical optokinetic pathways〔3〕. The majority of nystagmus was caused by various diseases and traumatic injury. For example, the ocular manifestation of patients with acute attack of multiple sclerosis may be the primary position of upbeat nystagmus〔4〕. In addition, if suddenly downbeat nystgmus happened, the lesions in midbrain or cerebellum should be taken into the first consideration〔5,6〕.

Nystagumus is characterized by different speeds and directions of the eye including the fast and slow phase. In clinical, the repeated horizontal motion was found in most of the patients with nystagmus, however, vertical, rotatory, oblique and the mixed types of mobility were found at times. The causes may be due to congenital (congenital cataract, strabismus or amblyopia), acquired (inflammation, head injury, macular degeneration, brain tumors, or vascular disease), or the lesions affecting the vestibular and cerebellar system. The eye movements of patients with nystagmus are accompanied by motion in the retinal image which resulted in decreased visual acuity, ocular strain, diplopia, and head tilt (compensation effect)〔7〕. Acute onset of nystagmus may also be accompanied with unrest, anxious mood, dizziness, nausea vomiting, and even acute oscillopia〔8〕. Some congenital nystagmus were emergent and can be easily controlled by some medical treatment (for example, the cataract and strabismus surgery and spectacles and prism lens correction)〔9〕. But if acquired nystagmus occurred recently, the patient must seek for medical intervention immediately because the underlying etiologies may be serious and induce the unexpected life threat (e.g.; brain tumor, intracranial hemorrhage and even CNS infection)〔10〕.

Therefore the ocular movement (nystagmus) itself may impact on the visual acuity and stereopsis. In the past, many literatures about the force (especially the gravity force) from the head to foot (downward) were respected and well discussed (so called +Z force). When the fighter elevated rapidly, the aircrews may endure the higher gravity (even up to + $9G_Z$). At emergent acceleration, most of the blood could not return back to the heart and accumulated in the lower limbs. Therefore, the brain and eyes could not gain enough oxygen and nutrition form blood flow. Therefore, military pilots will experience a series of trouble visual impairment such as gray out, blackout, loss of peripheral vision and even conscious loss after high gravitation force (G-force). For example, Whinney et al. had discovered that 5-9 G force is thought to be the maximum exposed for a human based on the tolerance of fighter pilots exposed to high G forces. Yet, this threshold is for sustained G's over many seconds (mean of 43 sec), which will cause unconsciousness from reduced blood flow to the brain 〔11,12〕. However, the exact changes of vision from the force of X-and Y-axis were rare well-studied. In the field of aerospace medicine, the force from the lateral (left-to-right) direction (Gx) and antero-posterior (A-P) direction (Gy) were always ignored. Only few reports were mentioned in motor vehicle impacts〔13〕. In fact, the impact from Gx or Gy was not the key-point to the aircrews during fly in the sky. Nevertheless, these two forces from vibration of the human body cannot be neglected on the ground.

In daily activities, various levels of vibration of body were usually seen in walking, running, driving and travelling or working in some vesicles (cars, high speed rail, rapid transit system, boats, railway, and airplane, especially helicopter)〔14〕. When human being such as sailors, aircrews and passengers were in the moving equipment, they may take up the challenge of some problems including motion sickness and spatial disorientation. Many workers may also experience the vibration in their environments and machines, such as construction machinery (bullozers, tow-motors, forklifts, and cranes), heavy equipment (grinders, jack hammer), and power hand tools. Besides, some dramatic activities such as riding a roller coaster may also induce the whole body vibration (WBV) exercise. In the past, only few researchers roughly mentioned that the effect of vision depends on many factors including the vibration level, vibration frequency, viewing distance and objective size and illumination. At the farthest, some research revealed that the human vision affected by WBV was the body (ex, head) position. Until now, the effect of total body vibration on human visual acuity and stereopsis remained unknown. In the study, we will explorer the shot and long term influence from the vibration. At the same time, the exact data and level of changes are also evaluated.

Materials and Methods

Informed consents were obtained from each subject before participation. All experiment protocols were conducted in accordance with the Declaration of Helsinki Ethical approval for this study was obtained from the institution. In this experiment, volunteers with any history of ocular disorders (except myopia) or systemic diseases such as hypertension, diabetes, cataract, glaucoma or uveitis, were excluded from the investigation. The refractive errors were measured by Ref-keratometer (Kowa, KW-2000) directly. If the astigmatism of each subject was greater than ± 1 D, they will be excluded.

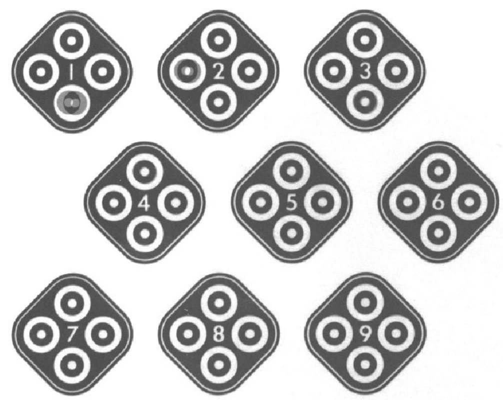

Fig. 1. The stereotest-circles picture card (total 9 square pictures and only one circle look " forward; in each square) (the subjects must need special glasses to find out the forward phenomenon)

The experiment was performed in the Taiwan High Speed Rail Laboratory in Yanchao District of Kaohsiung (Taiwan, ROC) in this year. Total 60 male participants were enrolled and the age of subjects were between 18 and 24 years old (mean age: 22.6 Y/O). The refractive error were between + 1.0D and – 3.0D (without dilated pupil) and they all could be corrected to 20/20 by glasses. The right eyes of all subjects were enrolled in the evaluation. Before study, they all understood the entire processes and methods. No any cranial nerve diseases such as vestibular problems were found. The common cold medication and alcohol drinking were prohibited before 3 days before this study. Besides, they all had no obvious symptoms of upper respiratory tract infection in order to avoid affecting the vestibular function. The subject stood on the platform and received the test of visual acuity and stereopsis one by one. At the beginning, regular vibration of the platform was created by machine and the speed and acceleration were monitoring by LMU system. In this study, we designed two types of acceleration (mild greater 0.1G and lower than 0.1 G) and two directions (X and Y axis). During the moving vehicle, every volunteer was asked to cover the left eye and read the letters on holding Rosenbaum pocket vision screener vision card (so we checked the visual acuity of right eye) (Fig 2). After completed the examination of the vision, the participant was again requested to test stereopsis by the stereotest-circles (Stereo Optical Co., INC, Ltd.) (Fig 1) (The subjects must put on the special glasses to check stereopsis in both eyes). All the results were recorded. After finished, the vibrated platform stopped. Then, another subject went up the quiet platform and repeated the previous procedures.

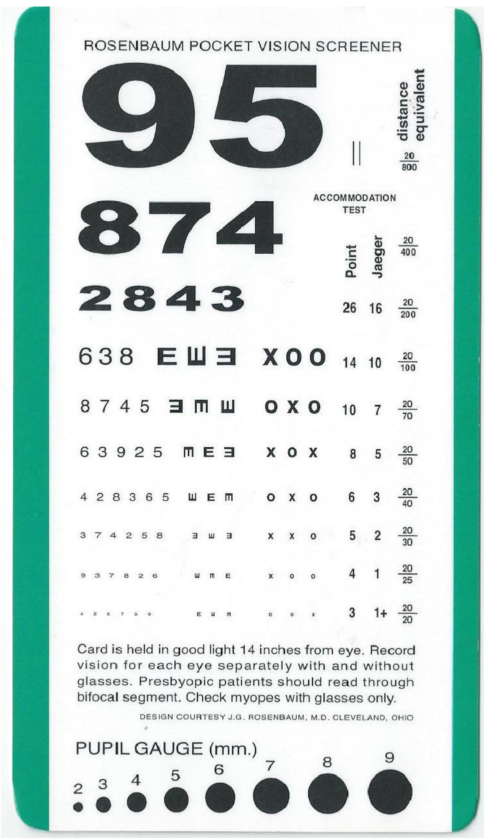

Fig. 2 The portable Rosenbaum pocket vision screener now are very popular in clinics to easily evaluate the vision in immobile or very sickly patients. In many studies, especially the measured distance is very short. This vision card had the many advantages such as cheap and simple to the researchers.

In our study, we made use of Rosenbaum pocket vision screener to measure the patients' vision. The advantage is convenient to carry, and the measure distance is very short (about 35 cm). In clinical, it can be easily used to examine the vision of the immobile patients in ICU or traumatic peoples. The results can be converted to the equivalent of the Snellen chart (measure distance about 6 m) and the results revealed 20/20, 20/25, 20/30, 20/40, 20/50, 20/70, 20/100, 20/200, 20/400 and 20/800. Before the test, we had already checked the vision on the ground, and it represented the static vision (so called static visual acuity; SVA). The visual acuity in the vibrated platform was called dynamic vision (dynamic visual acuity; DVA). Besides, the stereotest-circles picture now is well popular by many ophthalmologists to evaluate the ability of image fusion. In the test, the people may view nine square pictures with special glasses in both eyes. Each square picture contained four circles, respectively upper, lower, left and right. If the stereopsis of the subject is good, volunteer may find out the circular projection (forward) which can be measured 800, 400, 200, 140, 100, 80, 60, 50, and 40 second of arc. In excellent fighter pilots may search 40 seconds of arc, however, varying condition such as diseases or other condition may decrease stereopsis. The results of volunteers checked on the ground were defined as static stereopsis. At the same time, the findings on the shaking platform were considered as dynamic stereopsis. In this whole study, the results were recorded by other staffs in detail.

All data were collected and analyzed. The results are expressed as the mean ± SD. A pair t-test was used to compare the refractor error changes one year later. P value < 0.05 was accepted as statistically significant.

Results

All BCVA of the 60 male soldiers revealed 20/20 on the ground (so called static visual acuity was 20/20) and the static stereopsis all reached 40 seconds of arc in the same time. When whole body vibration occurred and the acceleration lower than 0.1G force (X-or Y-axis), the BCVA and stereopsis remained unchanged. That is to say that the static visual acuity and stereopsis are equal to dynamic visual acuity and stereopsis when vibration less than 0.1G. If the Gx or Gy greater than 0.1G, dramatic changes were found. When Gx force greater 0.1G (lateral direction) happened, the dynamic BCVA of 50% (10/20) subjects showed one line letter drop (from 20/20 to 20/25) and the dynamic stereopsis of 50% (10/20) subjects changed to 60 sec of arc. If Gy force greater than 0.1G (A-P direction), the dynamic BCVA of 40% (8/20) subjects dropped 2 line (from 20/20 to 20/30). In the same time, the dynamic stereopisis of 40% (8/20) of volunteers also reduced to 50 sec of arc. Besides, all the subjects complained about different levels of discomfort in reading whether G force greater than 0.1 G from X or Y axis. Thus, we supposed boldly that people in vibrating car, boat or airplane (acceleration near 0.1 G) may decrease their vision and stereopsis (1-2 lines depends on X or Y axis). To be more precisely, participates may feel ocular strain and even headache while reading the message from books or messages from the smartphone in vibrating platform.

Discussion

As is well-known patients with nystagmus and the impact of vibration likely to cause blurred vision 〔15,16〕, but the degree and type of vibration induce visual impairment is still a mystery to us. In the past, many researchers including the specialists in NASA had focused on the investigation of the Z-axis force (from head to foot) which pays an important role in various airplanes and space shuttle. The higher +Gz stress may affect the aircrews in the fly because a lot of blood will be accumulated in the lower part of the body. Visual acuity showed a transient reduction under rapid acceleration (about5G) immediately 〔17〕, however, if the higher sustained G force (8-9G) induced by the acceleration of the modern fighters still persisted over 43 seconds, their brain and eyes would lack enough blood supply and may cause serious and further ischemia and hypoxia. In this condition, military pilots may experience the series of physiological changes from the black image, peripheral vision loss, gray image, total blindness, conscious loss and suddenly involuntary coma. Thus, daily weight training to strength the muscle power and the use of anti-G suit will decrease the risk and threat from higher G force and promote fly safety effectively. It is a challenge to the aircrews during operation of fast jet military aircraft. In many air crash investigations, the Gz intolerance of aircrews is the very important factor. The lateral acceleration (especially Gy) in fly was rare discussed. The Gy force from 2.2 to 7.1 G in some studies, the clues provided some indication of likely tolerance to lateral acceleration〔18,19〕. Besides, anecdotal evidence gained from race car drivers, who require specific strength training regimes to tolerate the 4-5 Gy loading encountered during cornering〔20〕. Thus, the effect of X- and Y-axis is always omitted during fly or daily activity. However, neck is one of the area most vulnerable to G-related injury is also supported by Gx and Gy force during impact studies, as well as Gz exposure in flight〔21〕.

However, most of people indeed cannot experience the dramatic and stronger forces (especially + Gz force) on the ground in real life. Nevertheless, we also can experience the similar condition in roller coasters in the playground which greater vertical drops will generate 4-5 Gz forces. During the huge and emergent gravity acceleration, the tourists themselves may have the perception of being compressed on the seats. We also should be shocked by the various symptoms of shortness of breath (SOB), blurred vision accompanied by anxious mood. Besides, the incorrect and improper G force induced by roller coaster rides may also cause internal carotid artery or vertebral artery dissection〔22,23〕, brain injury〔24,25〕, stroke〔26〕, subdural hematoma〔27〕, neurological complications 〔28,29,30〕, retinal artery occlusion〔31〕, glaucoma〔32,33〕, lens dislocation〔33〕, IOL dislocation〔34〕, macular hemorrhage〔35〕, shunt malfunction〔36,37〕, acute soft tissue neck injury 〔38〕. Recently, many specialists pay more attention to roller coaster safety and legislation is being proposed to regulate G forces induced by roller coaster rides. Clearly, as new roller coaster designs incorporate greater vertical drops, the G's increase, as do the visceral sensations of the riders. The current upper range of G forces on the power rides is 4-6 G force, as listed on Rep. Markey's Amusement Park Ride Safety website and from the Roller Coaster DataBase in USA.

However, the force from the X or Y axis is always neglected by researchers. So far, the exact data of impaction from Gx and Gy on human vision is still unknown. In this study, we are the first medical team to discover the truth in the word. On the ground, vibration, especially whole body vibration exercise, was considered as the source of Gx or Gy forces which were very common in daily activities (WBV also involved Gz force in some situation). It is known that human being has many special receptors. The tactile receptors in human skin and deep tissues (eg. Pacinian corpuscle, free nerve endings, Meissnern disc) and the specialized structures in musculoskeletal systems (eg. muscle spindle, Golgi tendon organ) were found. In these two systems, their roles are to provide and transmit various information and peripheral sensory signs to central nervous system including the rate of change of muscle length, tension of muscle and other related findings. Once vibration of human body occurs, it will cause series of physiological effects, finally resulting in muscle contraction. When the length of muscle is stretched into longer or faster, the contraction will become more intense. Whole body vibration (WBV) (so called vibration therapy or biomechanical stimulation) is a generic term used where any vibration of any frequency is transferred to the human body. It can stimulate muscle spindles, then enhance the circulatory ability of blood flow, and finally improve muscle power, human explosive force and balance training. At first, some doctors used the method of WBV to treat patients with anxious status and muscle spasm. The physiologic effects were decrease the spasticity and rigidity. At the time, it may also increase muscle tone〔39〕. Lately, they proposed that except WBV, the method of artificial muscle vibration stimulation may also induce vibration reflex (so called tonic vibration reflex, TVR)〔40〕. Recently, TVR induced by WBV are considered to detect via the muscle spindles or other tactile receptors, initiate a single synapse or synaptic motor units reflex and muscle contraction. It is assumed that this vibration evokes muscle contractions, probably via the monosynaptic stretch reflex. This principle is now widely used by department of rehabilitation in many hospitals. The physical therapists may use mechanical strength training to recruit more motor units and increase the activities of various muscles. In other words, WBV may employ low amplitude, low frequency mechanical stimulation to enhance the musculoskeletal structures for improvement of the muscle strength, power, and flexibility〔41,42〕. Literature had reported that low frequency vibration could even increase the peripheral circulation, increase the muscle blood flow and reduce the resistance index〔43〕.

Now whole body vibration exercise has been proven to elicit improvements in isometric/dynamic leg muscle strength and bone mineral density〔44,45,46〕. Therefore, it was used to the training of various athletes to enhance their performance in many countries〔47〕. For example, Delecuse et al. had claimed that women accepted WBV exercise for 12 weeks, and the strengthening of muscles increased by approximately 16.6%, while the strength of quadriceps muscles and the extensor muscle of knee of these women also increased by 9.0%. They also found that the height of vertical jump significantly increased by 7.6%〔48〕. Roelants et al. revealed that after 24 week training of WBV, the strength of extensor muscles of knee will be significantly enhanced. Cardinale et al. reported that after 5 minute of WBV, the height of squat jump of 15 healthy subjects increased by 3.9% under 4mm (amplitude) and 20 Hz (frequency)〔49〕. Spitzenfeil and his co-work found that the alpine skiing subjects had accepted a wide range of 24H_Z (frequency) and 2.5 mm (amplitude) of vibration training for 3 weeks, and a significant increase in serum creatinine and urea were found. In addition, in 14th day, the height of squat jump in subjects from 38.9 cm (beginning) to 47.8 cm〔50〕. As for training on athletes found to have more reports in the literature can be used to increase the arm flexor muscle power of the national team of boxers〔51〕, The vertical jump and flexibility performance in female field hockey players〔52〕, the isotonic siting bench-pull, leg, and flex-and-reach test of the sportsmen〔53〕. WBV also may improve the strength and postural control in young skiers〔54〕. Besides, whole body vibration exercise was also used in the elderly to strength their muscles, decrease the back pain, improve the health-related quality and decrease fall risk〔55,56,57〕. For example, Runge et al. had found that the old people aged 61-85 year-old engaged in two months of WBV (three time in one month) will allow the time of the elderly to stand up repeatedly five times on a chair (chair rising test) faster (18%) than ever〔58〕. Bruyere et al. found that the residents aged from 63 to 92 years old living in nursing home who received six weeks of WBV exercise had significantly improved the gait, balance, and the quality of life〔59〕. Sabine et al. also revealed that the postmenopausal women (58 to 74-year-old) may improve their muscle strength, sense of balance, and hip bone density. Thus, it apparently may prevent from osteoporosis and reduce the risk of fall and bone fracture. Therefore, WBV now is popular to use in the fitness industry, physical therapy, rehabilitation, professional sports, and beauty and wellness applications today.

Violent vibration may impact the dis-comfortable sensation on the human. For example, the shaking forces in central part (Nantou city in Middle Taiwan) of 921 earthquakes were measured as 1.5 G of the horizontal force (Gx or Gy) and 0.3 G of the vertical force (Gy). In this force, human may feel very severely dis-comfortable. Thus, this earthquake made the huge disaster to the residents in whole Taiwan in 1999. Beside, several transportation systems such as airplanes, trains, sea vessels, and cars induced the whole body vibration that may affect pilots and passengers. WBV exercise refers to the transfer of low-frequency vibrations to the whole body contact area such as the sea of the truck, tractor, bus, or other vesicles, or the floor of a workplace. Besides, WBV exercise may also refer to the vibration exposures found in many occupational setting such as heavy construction, forklift operation, vehicle operation, and farming. There are two types of occupation: segmental and whole body. Segmental vibration is transmitted through the hands and arms, and is known to cause specific health effects such as Raynaud's syndrome. Whole body vibration exercise is transmitted through the body's supporting surfaces such as the legs when standing and the back and buttocks when sitting. Along with musculoskeletal problems, exposure to occupational whole body vibration also presents a health risk to the psychomotor, physiological, and psychological systems of the body. The most known disorder is motion sickness which will bother the travelers and driver in fly, driving and public road transport

〔60,61,62〕. In addition, short term exposure to vibration in the 2-20Hz range at 1 m/sec^2, may induce abdomen pain, headache, chest pain, nausea, loss of equilibrium, muscle contraction with decreased performance in precise manipulation tasks, shortness of breath, and influence on speech〔63,64〕. However, long-term exposure can cause serious health problem, particularly with the spine (disc displacement, degenerative spinal changes, lumbar scoliosis, intervertebral disc disease, degenerative disorders of the spine, and herniated discs)〔65,66,67,68〕. Furthermore, disorders of the gastrointestinal system and uro-genital systems were also found〔69〕. Therefore, many researchers believed that vibration may be considered as a cause of an occupational disease〔70,71,72〕. Even the U.S. Army aeromedical research laboratory conducted a research program to develop a new methodology for health hazard assessment of tactical ground vesicle rides〔73〕.

According to the influence of vision in and stereopsis from G force (especially in the 3 D environment, for example in the sky), the Gz force was the predominantly impact factor, however, the effect on visual effect from Gx and Gy force is relative mild 〔74〕. In addition, whole body vibration induced the visual performance was found for a long time. Grether et al. had arrived at the conclusion that combined exposures to WBV, heat, and/or noise caused anatagonistic rather than synergistic effects on vision, compared with single exposures〔75〕. WBV exercise can induce detrimental effects on vision was also mentioned by Grezesik et al. They suggested that broad-band WBV with frequencies mainly above 20 Hz and 6 ms^{-2}rms combined with noise 〔76〕. As shown by Griffin and Lewis, the effect on vision remained an open question〔77〕. Glucharev et al first reported that a constant visual acuity during WBV exposure (frequency 3, 4.4 or 8 Hz; 1.5 ms^{-2})〔78〕. In addition, Seidel et al, supposed that isolated of prolonged exposure to noise and whole-body vibration on hearing vision and strain. They found that the influence of the duration of exposures on vision depend on the condition. Besides, the firs10 minute were the most pronounced〔79〕. In fact, the z-axis sometime has more amplitude than sideway (x) and back and down (z) in WBV. Besides, the result of fore-and-aft oscillation in motion sickness at an acceleration magnitude of 0.89 m/S^2 (0.01G) had no effect on vision is just compatible with our research 〔80〕. In ROC, the military aircrews in the advanced attack helicopters (AH-64E), the whole body vibration is about 0.1G while flying〔65〕. According to the rules of our studies, the vision and stereopsis only showed mild decrease in long endurance in high altitude. In our well-experience in flight surgeons and ophthalmologists in clinics, the short-term exposure of vibration of AH-64E may not apparently influence the performance of military duties in fly. Nevertheless, how to educate the pilots, and help to protect and promote their good vision for performance is the unshirkable responsibility of the flight surgeons.

Conclusion

Until recent years, the NASA began to note the vibrational effects on the reading and visual performance in outer space duties. Nevertheless, no report was revealed and the higher G exposure (4 Gx) was rare found in real daily activity in the ground. To the best of our knowledge, no exact data showed the degree and level of vibration induce the decrease of visual acuity and stereopsis in the past. Our scientific evidence shows that the visual acuity and stereopsis of the soldiers may deceased mildly when the Gx (or Gy) greater than 0.1G in acceleration and deceleration of any vehicles in the ground when they exposed. In summary, we strongly believed that it regular whole body vibration is a good exercise for the military duties.

Corresponding author:
Chi-Ting Horng, MD, Ph.D.
Department of Ophthalmology, Zuoying Branch of Kaohsiung Armed Forced General Hospital, No.553, Junxiao Rd., Zuoying Dist., Kaohsiung City 813, Taiwan.
Tell phone: 886-7-5834845
Email: h56041@gmail.tw

References

1. Brodsky MC, Tusa RJ. (2004). Latent nystagmus: vestibular nystagmus with a twist. *Arch Ophthalmol*. 122(2): 202-9.
2. Hertle RW. (2000). Examination and refractive management ofm patients with nystagmus. *Surv Ophthalmol*. 45(3): 215-22.
3. Bordsky MC. (2012). The accessary optic system: the fugitive visual control system in infantile strabismus. *Arch Ophthalmol.* 130(8): 1055-8.
4. Chen L, Gordon LK. (2005). Ocular manifestation of multiple sclerosis. *Curr Opin Ophthalmol* 16: 315-20.
5. Matsuzono K, Manabe Y, Takahashi Y, et al. (2014). Combined ipsilateral oculomotor nerve palsy and contralateral downbeat nystagmus in a case of cerebral infarction. *Case Rep Neurol*. 6(1): 134-8.

6. Cambi J, Astore S, Mandala M, et al. (2013). Nature course of positional down-beating nystdmus of peripheral origin. *J Neuro*. 260: 1489-96.
7. Kattah JC, Dagi TF. (1990). Compensatory head tilt in up-beating nystagmus. *J Clin Neuroophthalmol* 10: 27-31.
8. Kim JA, Jeong IH, Lim YM, et al. (2014). Primary position upbeat nystagmus during an acute attack of multiple sclerosis. *J Clin Neuro*. 10: 37-41.
9. Brodsky M, Dell'Osso LF. (2014). A unifying neurologic mechanism for infantile nystagmus. *JAMA Ophthalmol*. 132(6): 761-8.
10. Ehrhartdt D, Eggenberga E. (2012). Medical treatment of acquired nystagmus. *Curr Opin Ophthamol*. 23(6): 510-6.
11. Rickards CA, Newman DG. (2005). G-induced visual and cognitive disturbances in a survey of 65 operational fighter pilots. *Aviat Space Environ Med* 76(5): 496-500.
12. Whinnery JE, Whinnery AM. (1990). Acceleration-induced loss of consciousness. *Arch Neurol*. 47: 764-76.
13. Allen EM, Weir-Jones I, Motiuk DR, et al. (1994). Acceleration perturbations of daily living. *Spine* 19: 1285-90.
14. Seidel H. (1993). Selected health risks caused by long-term, whole-body vibration. *Am J Ind Med*. 23: 589-604.
15. Seidel H, Harazin B, Pavlas K, et al. (1988). Isolated and combined effects of prolonged exposures to noise and whole body vibration on hearing, vision and strain. *In Arch Occup Environ Health* 61: 95-106.
16. Dunn MJ, Margrain TH, Woodhouse M, et al. (2014). Grating visual acuity in infantile nystagmus in the absence of image motion. *Invest Ophthalmol Vis Sci*. 55(4): 2682-6.
17. Tsai ML, Liu CC, Wu YC, et al. (2009). Ocular response responses and visual performance after high-acceleration force exposure. *Invest Ophthalmol Vis Sci*. 50: 4836-9.
18. Girvan R, Wright RJ, Glaister DH (1977). Prediction of head stabilizing forces during sustained acceleration. Farmborough, UK: *RAF Institute of Aviation Medicine*. Scientific Memorandum No.128.
19. Petrovsky JS, Phillips CA. (1982). The strength-endurance relationship in skeletal muscle: its application to helmet design. *Aviat Space Environ Med* 53: 365-9.
20. Mertz HJ, Patrick LM. (1971). Strength and response of the human neck. *15th Stapp Car Crash Conference. Warrendale, PA: SEA*. Report N0.710855.
21. Burton RR. (1999). Acute neck injuries. Neuillysur Seine, France: *NATO/RTO technical report 4*; AC/323(HFM) TP/9.
22. Schneck M, Simionescu M, Bijari A. (2008). Bilateral vertebral dissection possible precipated in delay fashion as a result of roller coaster rides. *J Stroke Cerebrovasc Dis*.17: 39-41.
23. Stahlfeld KR, Roozrokh HC. (2002). Traumatic bilteral ECCA injury in a roller coaster enthusiast. *Ann Vasc Surg*. 16: 505-8.
24. Smith DH, Meaney DF. (2002). Roller coaster, G forces and brain trauma: on the wrong track? *J Neurotrauma*. 19(10): 1117-20.
25. Braksiek RJ, Roberts DJ. (2002). Amusement park injuries and deaths. *Ann Emerg Med*. 39: 65-72.
26. Scheer MS, Carlin DJ. (1979). Stroke after roller-coaster induced carotid compression. *JAMA*. 242: 1769.
27. Roldan-Valadez E, Facha MT, Martinez-Lopez M, et al. (2006). Subdural hematoma in a teenager related to roller-coaster ride. *Eur J Paediatr Neuro*. 10: 194-6.
28. Blacker DJ, Wijdicks EF. (2003). A ripping roller coaster ride. *Neurology*. 61:1255.
29. Lascelles K, Hewes D. Ganesan V. (2001). An unexpected consequence of a roller coaster ride. *J Neurol Neurosurg Psych* 71: 704-5.
30. Kettanech A, Biousse V, Bousser MG. (2000). Neurologic complications after roller coaster rides: an emerging new risk? *Press Med* 29: 175-80.
31. Arta YO, Volpi J, Arta A, et al. (2011). Bilateral internal artery and vertebral artery with retinal artery occlusion after a roller coaster ride – case report and a review. *Ulus Tranvma Acil Derg* 17(1): 75-8.
32. Jay Katz L, Meyers JS. (2009). Soothing the intraocular pressure roller coaster – a new goal? *Am J Ophthalmol*. 148(2): 177-8.
33. Andrews RM, Bell RW, Jayamanne DG, et al. (1994). Roller-coaster glaucoma.: An usual complication of Marfan's syndrome. *Eye (Lond)*. 8(Pt3): 558-60.
34. Asefzadeh B, Connell N. (2009). Macular haemorrhage after repetitive roller coaster riding. *ClinExpOptom*. 92(5): 447-8.
35. Bosch MM, Landau K, Thiel MA. (2003). Repositioning of a dislocated intraocular lens during a roller-coaster ride. *N Engl Med* 349(11): 1094-6.
36. Gegg C, Olavarria G, Pattisapu JV. (2009). Shunt malfunction after roller coaster ride. *Childs Nerv* 25: 509-10.
37. Sekhar LN, Moosy J, Guthkelch N. (1982). Malfunctioning ventriculo-peritoneal shunts. *J*

Neurosurg 56: 411-6.
38. Green NDC. (2003). Acute soft tissue neck injury from unexpected acceleration. *Aviat Space Environ Med*. 74: 1085-90.
39. Bishop B. (1974). Vibration stimulation. *Physical therapy* 54(12): 1273-82.
40. Eklund G, Hagbarth AGBARTH KE. (1996). Normal variability of tonic vibration reflexes in men. *Exp Neurol* 16: 80-92.
41. Warman G, Humphries B, Purton J. (2002). The effects of timing and application of vibration on muscular contraction. *Aviat Space Environ Med* 37(2): 119-27.
42. David A, Gabriel JR, Basford KN, et al. (2002). Vibration facility of strength in fatigued muscle. *Arch Phys Med Rehabil* 83: 1202-5.
43. Kerschan-Schindl K, Grampp S, Henk C, et al. (2001). Whole-body vibration exercise leads to alterations in muscle blood volume. *Clin Physiol* 21(3): 377-82.
44. Roelannts MC, Delecluse C, Goris M, et al. (2004). Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained female. *Int J Sport Med* 25:1-5.
45. Rubin C, Turner AS, Bain S, et al. (2001). Anabolism low mechanical signals strengthen long bone. *Nature* 412: 603-4.
46. Verschueren SM, Roelants M, Delecluse C, et al. (2004). Effect of 6 month whole body vibration training on hip density, muscle strength, and postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res*.19: 352-9.
47. Issurin VB, Tenenbaum G. (1999). Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci* 17: 177-82.
48. Delecluse C, Roelants M, Verschueren S. (2003). Strength increase after whole body vibration compared with resistance training. *Med Sci Sports Exerc* 35(6): 1033-42.
49. Cardinale M, Lim J. (2003). Electromyograph activity of vastuslateralis muscle during whole body of different frequencies. *J Strength Cond Res* 20(2): 257-261.
50. Spitzenpfeil P, Schwarzer J, Fiala M, et al. (1999). Strength training with whole body vibration. Single case studies and time series analyses, In: Paris, P., Pigozzi, F., Prinai, G. (eds), *Sport Science in Europe. Proceedings of 4 th annual conference of the European College of Sport Science*, Rome, 613.
51. Bosco C, Cadinale M, Tsarpla O. (1999). Influence on vibration on mechanical power and electromyogram activity in human arm flexor muscles. *European J Appl Physiol* 79: 306-11.
52. Cochrane DJ, Stannard SR. (2005). Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *Br J Sport Med.*39: 860-9.
53. Issurin VB, Liebermann DG, Tenenbaum G. (1994). Effect of vibratory stimulating training on maximal force and flexibility. *J Sports Sci* 12:561-6.
54. Mahieu NN, Witvrouw E, De Voorde DV, et al. (2006). Improving strength and postural control in young skiers: Whole body vibration versus equivalent resistance training. *J Athletic Training*. 41(3): 286-93.
55. Iwamoto J, Takeda T, Sato Y, et al. (2005). Effect of whole body vibration on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. *Aging ClinExp Res* 17: 157-63.
56. Laeortune MA, Lake MJ, Henning EM. (1996). Differential shock transmission response of the human body to impact severity and lower limb posture. *J Biomech* 29: 1531-7.
57. Rittweger J, Just K, Kautzsch K, et al. (2002). Treatment of chronic lower back pain with lumbar extension and whole body vibration exercise: a randomized controlled trial. *Spine* 27: 1829-34.
58. Runge M, Rehfeld G, Resnicek E. (2000). Balance training and exercise in geriatric patients. *J Musculoskelet Neuronal Interact* 1(1): 61-5.
59. Bruyere O, Wuidart MA, Di PE, et al. (2005). Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil* 86: 303-7.
60. Butler CA, Griffin MJ. (2006). Motion sickness during fore-and-aft oscillation: effect of the visual scene. *Avait Space Environ Med*. 77(12): 1236-43.
61. Perrin P, Lion A, Bosser G, et al. (2013). Motion sickness in rally car co-drivers. *Aviat Space Environ Med* 84: 473-7.
62. Turner M, Griffin MJ. (1999). Motion sickness in public road transport: The relative importance of motion, vision and individual differences. *British J Psychol*. 90, 519-30.
63. Klosterhalfen S, Muth ER, Kellermann S, et al. (2008). Nausea induced by vection drum: contributions of body position, visual pattern, and gender. *Avait Space Environ Med* 79(4): 384-9.
64. Ramos RT, De Mattos DA, Reboucas JTS, et al. (2012). Space and motion perception and discomfort in air travel. *Avait Space Environ*

Med 83: 1162-6.
65. Salmon DM, Harrison MF, Neary JP. (2011). Neck pain in military helicopter aircrew and the role of exercise therapy. *Aviat Space Environ Med*. 82: 978-87.
66. Byeon JH, Kim JW, Jeong HJ, et al. (2013). Degenerative changes of spine in helicopter pilots. *Ann Rehabil Med*. 37(5):706-12.
67. Srinivasan J, Balasubramanian V. (2007). Low back pain and muscle fatigue due to road cycling-ans EMG study. *J Bodywork Movement Ther* 11(3): 260-6.
68. Boshuizen HC, Bongers PM, Hulshof CT. (1992). Self-reported back pain in fork-lift truck and freight-container tractor drivers exposed to whole body vibration. *Spine* 17(1): 59-65.
69. Sidel H. (1993). Selected health risks caused by long-term, whole body vibration. *Am JInd Med*. 23: 589-604.
70. Hulshof CTJ. (2002). The fate of MRD Robinson: Criteria for recognition of whole body vibration injury as an occupational disease. *J Sound Vibration* 253(1): 185-94.
71. Bovenzi M, Zadini A. (1992). Self-reported low back symptoms in urban bus drivers exposed to whole body vibration. *Spine*. 17(9):1048-59.
72. Wasserman DE, Wilder DG, Pope MH, et al. (1997). Whole body vibration exposure and occupation work-hardening. *J Occup Environ Med*. 39(5): 403-7.
73. Alem N. (2005). Application of the new ISO 2631-5 to health hazard assessment of repeated shocks in U.S. Army vehicles. *Ind Health* 43: 403-12.
74. Horng CT, Liu CC, Kuo DI, et al. (2009). Changes n visual function during the coriolis illusion. *Avat Space Environ* 80: 360-3.
75. Grether WF, Harris CS, Ohlbaum M, et al. (1972). Further study of combined heat, noise and vibration stress. Aerospace Med 43: 641-5.
76. Grzesik J, Harazin B, Piekarski M. (1981). Behavior of selected parameters of vision during exposure to noise (Polish). *Pamjatnik III krajowegozjazdu Polskiego Towarzystwa Medycyny Pracy. Lodz 9-11.* November 198, T.1, pp 259-61. (Conference proceedings 3rd National Meeting of the Polish Society of Occupational Medicine).
77. Griffin MJ, Lewis CH. (1987). A review of the effects of vibration on visual acuity and continuous manual control, part I: visual acuity. *J Sound Vibration*. 56: 383-413.
78. Glucharev KK, Potemkin BA, Safronov JE, et al. (1972). Experimental analysis of the functional stat of the human operation during prolonged exposure to bibration (In Russian). *Maschinovedenie* 2: 3-8.
79. Siedel H, Harazin B, Pavlas K, et al. (1988). Isolated and combined effects of prolonged exposures to noise and whole body vibration on hearing, vision and strain. *Int Arch Occp Environ Health* 6: 96-106.
80. Butter CA, Griffin MJ. (2006). Motion sickness during fore-and-aft oscillation: effect of the visual scene. *Aviat Space Environ Med* 77: 1236-43.

10/25/2017