The changes of corneal bio-mechanical properties after parachute opening shock

Lu-Yu Wu[1], Kaung-Jen Chien[2,3,#], Choa-Wen Pan[4], Chi-Ting Horng[3,5], Shu-Zhang Lin[5,*]

[1]Department of Nursing, Kaohsiung Armed Force General Hospital. Kaohsiung, Taiwan, R.O.C.
[2]Department of Pediatrics, Kaohsiung Veteran General Hospital, Kaohsiung, Taiwan, R.O.C.
[3]Department of Pharmacy, Tajen University, Pingtung, Taiwan, R.O.C.
[4]Department of Surgery, Zouing branch of Kaohsiung Armed Force General Hospital. Kaohsiung, Taiwan, R.O.C.
[5]Department of Ophthalmology, Kaohsiung Armed Force General Hospital. Kaohsiung, Taiwan, ROC
[*]Corresponding author: Shu-Zhang Lin, E-mail: h56041@gmail.com
[#] This author contributed equally to the first author

Abstract: Parachute opening shock (POS) in high acceleration force may result in several physiologic responses and injuries However, little is known about the effects of shock on corneal rigidity and elasticity when parachutists jumping out from the airplane and deployed after high + Gz acceleration. The aim of this study was to determine the changes of corneal biomechanical properties after POS. Sixty subjects were enrolled in the study. They jumped out the C-130 airplane at 1350-1500 fts above the ground in Pintung. The parachute of shock may simulate at least 5 times of gravitational force in head to toe Z-axis direction (+ 5 Gz force). The ocular Response Analysis was applied to detect the dynamic bi-directional changes of cornea in the subjects who underwent parachuting. The related parameters were evaluated before ejection such as corneal hysteresis (CH), corneal resistance factor (CRF), and central corneal thickness (CCT). The bare visual acuity and refraction were also recorded. At instant, 15mins and 30mins after ejection, the parameters were detected as well. All the bare visual acuity and refractive errors remain unchanged during the study. There were no significant change of CH and CRF before and after POS. However, the CCT increased significantly immediately and 15 min after compared with the values before study. When landing, the main corneal biomechanical properties did no show remarkable change. Besides, the refraction and bare visual acuity remained stable. We concluded that the rigidity and elasticity of the cornea were not apparently affected by high G-force. During real high altitude ejection, true environmental factors such as windblast, low temperature, and hypoxia remained challenger to parachutists. We need further studies in the future.

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1. Introduction

Since its inaugural world championship in 1951, the sport of skydiving has grown and diversified considerably. Skydiving, sport parachuting from aircraft, is becoming a popular air sport in the world now. Sport parachuting (civil parachuting) from aircraft engages > 675000 participants in 118 countries. Furthermore, approximately 5.5 million jumps made worldwide by almost 1 million jumpers in 40 countries [1]. More than 5.77 million jumps were made worldwide during 2002. To date, 4.7 million skydives made by 222,000 skydives operating their own equipment were reported to the Internal Parachuting Commission (IPC) of the World Air Sports Federation (FAI) in 2009 [2]. During the 1990s, speeds in skydiving increase dramatically because of the transition from round parachutes to wing parachutes. Moreover, new free-fall events evolved with skydivers falling at faster rates (regularly > 100 km/h), and faster wing parachutes popularized radical parachute flying. It is not uncommon for an active athlete to make 10 skydivers a day and several hundred skydives per day. To reduce deceleration forces, skydiving parachutes are fitted with a reefing device force, skydiving parachutes are fitted with a reefing device to retard the parachute opening, during which a skydiver in terminal velocity decreases from higher speed to lower speed 20 km/h within a few second for safe consideration.

Typical the practitioner jumps out of an air-plane at 4000 m (13000 ft) above ground level (mAGL) and a terminal vertical velocity accelerates in free fall, reaching terminal speeds of > 200 km/h (reached in 10-15 sec) [3]. The parachute is deployed at approximately 1000 mAGL and then, the ram-air parachute is deployed, reducing the falling speed to circa 20 km/h in a few sec, causing an abrupt deceleration called parachute opening shock (POS). The military free-fall parachute system is a type of high altitude training (3500 – 35000 fts) which belongs to the special forces jumps. However, we will not discuss this type of parachute in this article. A parachute is first and foremost an aerodynamic decelerator. During deployment, it causes an abrupt deceleration that carries an intrinsic risk of deceleration injury on multiple organs such as musculoskeletal system [4]. Military parachutes differs from skydiving including demography, training, environmental condition for jumping and parachutes flight characteristics. In Taiwan, the Army paratroopers are required to jump out the airplane at the altitude of 1350-1500 fts and reached the ground after 240 seconds during deployment (low altitude combat parachute jump). The abrupt deceleration is referred to as parachute opening shock and may reach average magnitude of 3-6 times the Earth's gravitational forces (so called 3-6 G), meaning that the skydiver experiences a pressure from the parachute straps equal to 3-5 folds greater than that of hanging stationary on the ground [5]. Furthermore, Potvin and his co-workers even demonstrated the higher G from the POS may elevate to 9-12 G [6]. When exposed to these higher G forces, the air force pilots may experience many discomfortable symptoms and abnormal physiological responses [11,12].

In the previous studies, POS may impact on the emotion of human being and induce the anxiety disorders and tachycardia [7,8], different types of injuries partially due to higher G (gravitation) forces [9], higher sympathetic nervous system activation (the cardiovascular risk factor) [10], and even death (severe trauma, acute myocardial infarction or water landing) [13].

It is well known that higher acceleration force (G force) from ejection and parachuting may result in several physiologic responses from the military aircrews [14,15]. However, the cornea has been a subject of interest to ophthalmologist and other eye careers because it playa a critical role in human undergoing high-acceleration movement. To our knowledge, there were no related articles to evaluate the effects of POS on human corneal rigidity and elasticity (so called biomechanical properties) during skydives. Therefore, the goal of this study was to investigate the influence of POS-induced substantial G-loads on corneal biomechanical characteristics. Moreover, the figure 1 shows the acceleration of gravitational force in head-to-toe Z-axis direction of (+3-5 Gz force) (eyeballs down) [16]. In our experiment, the ORA (Ocular Response Analyzer) was applied to evaluate the changes of corneal biomechanical properties after POS exposure.

2. Materials and Methods

Because civilian and armed forces parachuting differ in important aspects, we only discussed the military parachuting (lower altitude jumping) (round parachute size). In other articles, many research all focused on other physiological factors about POS [17,18,19]. Now we pay attention to the corneal biomechanical factors. Therefore, 60 military healthy subjects (55 males and 5 females) who ever experienced POS were enrolled in the study. Mean (SD) age, weight, and height were 22(1.5) years, 70(5.6) kg, and 1.68(0.65)m, respectively. All army paratroopers are required to jump out the C-130 airplanes and the automatic deployment were performed at the altitude of 1350-1500 fts above the ground level in Pintung. After POS deceleration, the skydivers reached a steady descent speed of 29 km/h. The participants only wore helmet (mean weight 0.52 Kg) without face cover and any equipment including weapon. The experiment was performed on October last year (2016).

Informed consent was obtained from each volunteer before participation in the studies began. All experimental protocols were conducted in accordance with the Declaration of Helsinki. Ethical approval for this study in advance was obtained from the institution review board (Kaohsiung Armed Forced General Hospital). Criteria for inclusion were age of 18-25 yr and the paratroopers in ROC who has ever experience of 3- 4 combat jumping. Criteria for exclusion were history of ocular or systemic diseases, such as hypertension, diabetes, cataracts, glaucoma, refractive error or uveitis were excluded from the study. All the 60 subjects were 6/6 in bare visual acuity in both eyes.

Before jump, each volunteer underwent a series of examinations including corneal biochemical properties, refraction and bare visual acuity. The Ocular Response Analyzer (ORA, Reichert, Buffalo, NY, USA) are the new instrument that measures the main corneal biomechanical properties including cornea hysteresis (CH), cornea resistance factor (CRF) and central corneal thickness (CCT). Bare visual acuity was tested were at 4 meter distance and recoded by EDTRS (Early Treatment of Diabetes Retinopathy) logMAR chart. Refractive errors were gained by Auto-refractometer (AR310, Nidek, Tokyo, Japan). Due to the limitations of time, only the left eyes of all subjects were enrolled. After the investigation, they took the C-130 ROC Air forces and jumped & deployed at the previous altitude on the ground. After they landed safely, we checked the above parameters immediately, 15 minutes, and 30 minutes after landing. All results are corrected and analyzed.

All results are expressed as the mean ± standard deviation (SD). Bare visual acuity is indicated as LogMAR (The chart has five letters per low ranging in size from + 1.0 to -0.3 log MAR). The data was assessed by SPSS 22.0, IBM (Armonk, NY, USA). A paired t-test was used to compare the physiological parameters before and after POS exposure associated with higher + Gz. $P < 0.005$ was accepted as significant.

3. Results

In the 60 skydivers, there were no incorrect procedures, midair collision, incorrect gear (incorrect wearing or configuration), and medical problems (including any trauma) after landing.

All the data were collected for 60 eyes. In Table 1, there were no significant changes of CH and CRF before and after POS exposure (immediate after, landing after 15 min and 30 min) associated with higher Gz. However, in Table 2, the CCT increased significantly immediately after (546.5 ± 14.7 vs 591.8 ± 12.8, $p < 0.005$) and 15 min after (546.5 ± 14.7 vs 585.5 ± 14.2, $p < 0.005$) compared with the values before POS. Remarkable central corneal thickness increase was observed and persisted at least for 15 mins after POS exposure in our experiment.

The bare visual acuity of all the pilots were 0.05 ± 0.03 (logMAR) and the mean refraction of subjects were – 0.50 ± 0.25 diopters (D) before study on the ground. In Table 3, bare visual acuity and the refractive error status remained un-change after POS at the same time. According to the above results, we concluded that the skydivers remained their initial visual acuity even exposed to shock from parachuting, however, only a little amount central corneal thickness increasing.

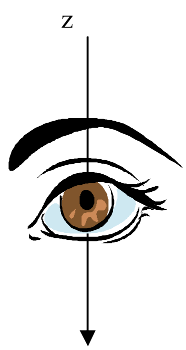

Fig 1：The direction of gravitational force is from head to toe in Z-axis direction (+ Gz force) after landing during the most time of parachute opening shock.

4. Discussion

Skydiving is a major air sport in which almost 200000 participant in 40 countries do not more than 5 million jumps annually (IPC Technical and Safe Committee, 2012). Individual jump frequency typically ranges from one to 300 jumps per year, but highly experienced competing or professionally working skydivers may performed more that 500 jump per person. However, the above numbers did not enroll in the military parachuting about soldiers in many countries in the world. Besides, military pilots sometimes may experience the danger and be ejected from the fighter. They were free-falling with the parachute at first (horizontal plane of parachute) (fig 2). After several seconds, the deployment of parachute developed and the pilots endured under POS (vertical plane of parachute). Finally they were landing on the ground and then relieved and rescued by their companies (fig 3).

According to the previous reports, the POS exposure may result in neck pain (major problem), head and face abrasion or laceration, rib fraction, knee dislocation, ankle stain, foot contusion, pelvic fracture, pneumothorax, shoulder dislocation, upper arm, wrist and forearm fracture, finger contusion, spine associated problems, back strain, whole musculoskeletal pain and even psychophysiological response [9,20,21,22]. Furthermore, autonomic nervous system activity that instantiates novelty and risk from POS was also reported. Heart rate has been used extensively in previous research quantifying the sympathetic nervous system. Increases in heart rate facilitate acute psychological and physical changes that provide the individual with the ability to flight or flee during parachuting [23]. Besides, we found that decrease in blood oxygen saturation and parasympathetic modulation, increase blood lactate and blood pressure (BP), decreased level of glucose, elevated salivary cortisol and blood creatinkinase (CK) [24,25]. However, the topics about POS impacting on human eyeball were not ever well discussed.

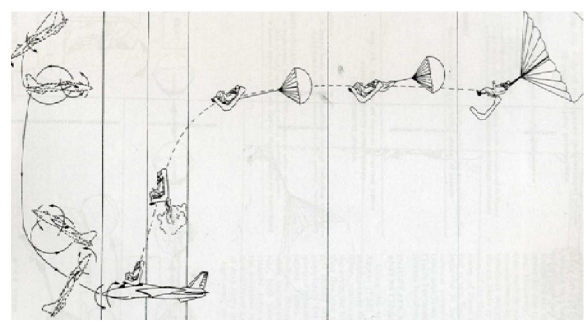

Fig 2：The military pilots was ejected from the fighter and he was free-falling with the parachute at first (horizontal plane of parachute) in real situation.

In the past, we only use the concept of central corneal thickness (CCT) to investigate the corneal rigidity/elasticity and its function. In the last few decades, corneal biomechanics received more attention to define the corneal hyper-elasticity, the effects and hydration. Until 2005, the ocular response analyzer (ORA) was introduced as devices capable of acquiring an IOP measurement by Luce [26]. The machine offers a new metric, corneal hystresis, it represents visoelastic properties. In addition, we can measure the corneal resistance factor and central corneal thickness (an ultrasound pachymetry attach to

ORA) together. Now the CH and CRF were widely used by the ophthalmologists to predict the probability of ecstatic cornea after LASIK as well as the early detection and difference diagnosis of glaucoma [27,28].

The ORA release a precisely metered air pulse that cause central 3mm of the cornea to move

Table 1: The corneal hystresis and corneal resistance factor before and after landing

	Before	***Immediate after***	***After 15 min***	***After 30 min***
CH (mmHg)	9.11 ± 1.75	10.22 ± 2.44	10.08 ± 1.32	9.15 ± 2.03
CRF (mmHg)	11.04 ± 1.98	12.32 ± 2.08	12.01 ± 1.43	11.12 ± 0.78

N= 60 eyes, * Statistically significant difference ($P < 0.005$).

inwards. Thus, the cornea passes through applanation- inward applanation (P_1), then the past applanation phase where its shape becomes slightly concave. Twenty milliseconds after applanation, the air puff shuts off resulting in pressure decrease in a symmetrical fashion. During this phase the cornea shape tries to gain its normal shape. During this process the cornea again passes through an applanation phase-outward applanation (P_2). Theoretically, these two pressures should be the same, but this is not the cause [29]. It is described as the bi-dynamic response that is the resistance to application manifested by the corneal tissue due to the viscoelastic properties. In Fig 3, the difference between the outward and inward pressure (P_1-P_2) is termed corneal hystresis and is measured in mmHg. The P_1 is normally higher than P_2 where P_1 and P_2 are arbitrary units. The conversion formula of CRF by Luce is that CRF = ｛0.1324〔(P_1 -0.7)〕P_2｝-7.46 (fig 4). In general, CH was refers to the viscosity of cornea. Luce, however, regards that CH is the absorbing and dispersing ability of cornea and CRF represents the elastic properties of cornea. Ortiz defined CRF as the sum of the corneal rigidity to resist the external force and the ability to prevent from deformation of the cornea [30].

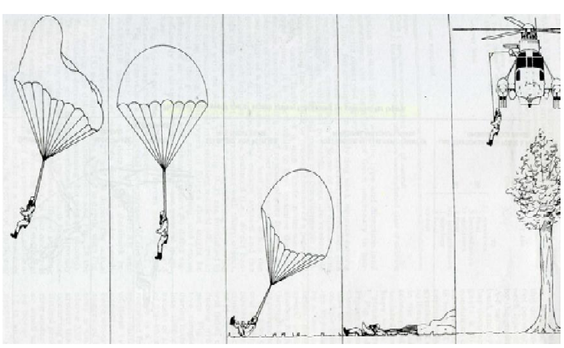

Fig 3：After several seconds, the deployment of parachute developed and the pilots endured under parachute opening shock. Finally he was landing on the ground and then relived by his companies (vertical plane of parachute).

However, it has never been reported in any studies about corneal biomechanics change after ejection in literatures review. In our experiment, we could not find the significant change of CH and CRF after higher G impaction. We know that the cornea has viscoelastic characteristics due to its numerous fibers thickness, hydration, and the crossed distribution of collagenous fibers [28]. The effect of high gravitational force on human including cardiovascular system was well-known. Meanwhile, the rigidity and elasticity of cornea may absorb and disperse the external G-force. Then the changes of CH and CRF were not significant after G-load. Therefore, we suggested that if the military aircrew jump out the airplane and deployed on the sky, the CF and CRF may remain unchanged under high G force exposure.

Our experiment also revealed that the thickness of central cornea (CCT) increased significantly immediate and 15 mins after higher G exposure. It means that the signs may persist at least for 15 mins after substantial G-loads [31]. However, the values returned to normal range 30 min after exposed to + 8 Gz. The minor changes may result from fiber arrangement or corneal edema after exposure to G-force, meanwhile because of the rebounding ability of the cornea, it returns to the value before ejection. In the past, we had ever observed a 10 % increase in CCT after + 9 Gz for exposure created by the human centrifugation. However, the sign of mild increase in CCT did not affect the vision. In this study, we gained the same results. According to the past articles, the transient hydrostatic pressure may explain that findings. When the subject exposed to high gravity, the hydrostatic pressure of the ocular anterior chamber may increase. Therefore, it may push the aqueous humor to flow across the corneal endothelium into the stroma, which may increase the corneal thickness [32]. Another mechanism was explained by LaStayo in 2003. He and his co-coworkers demonstrated that muscle have a protective function by absorbing shock and the associated kinetic energy when parachuting [33].

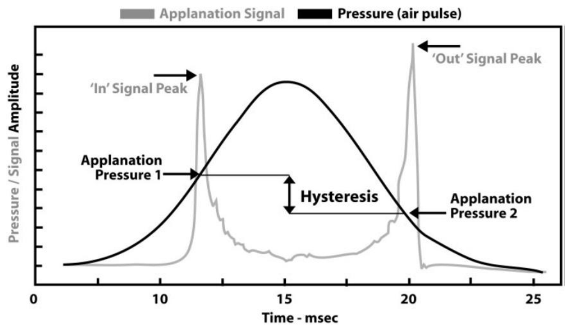

Fig 4: Explanation of corneal hystresis by the ocular response analyzer. By applying air-puff, a light reflex from the corneal surface changes and is detected by a sensitive sensor. There is a "delay time" in recovery from the convex condition, which is an indicator of absorbed energy during the deformation processes (corneal hystresis).

In this experiment, we also found that the bare visual acuity remain stable even just immediately after POS. Previous reports concerned with the occurrence of pathology in human during + Gz exposures have suggested some adverse effects including temporary vision, chest pain, dyspnea, motion sickness, nonpathological changes in the electrical activity of the brain, various cardiac arrhythmias, and unconscious [34]. Some reasons of that symptoms and signs may be due to the hemodynamics changes of the pilots. It is the tendency that massive peripheral blood stasis in the lower extremities and the difficulty in returning to the heart and brain were noted under high G-force (8-12G). However, that effect may be apparent during a longer time (always persisted for 8 to 15 seconds). The exposed time was only 1 to 3 seconds after jumping. When the parachute deployed, the visual acuity of the military pilots may remain unchanged. Paniabi et al. reported that muscle have the main role of maintaining neck stability [35]. Falla et al. found that the muscles of neck may protect the cervical spine and stabilize the visual and vesicular systems when POS developed [36]. However, the strong effects of the windblast from horizontal and vertical direction should be take into consideration. If the corneal biomechanics properties and visual function were affected by severe windblast or not, further studies are necessary in future.

Table 2: The central corneal thickness before and after landing

	Before	*Immediate after*	*After 15 min*	*After 30 min*
CCT (μm)	*546.5 ± 14.7*	*591.8 ± 12.4**	*585.5 ± 14.2**	*551.5 ± 21.4*

N= 60 eyes,* Statistically significant difference ($P < 0.005$).

Table 3: The refraction and bare visual acuity before and after landing

	Before	*Immediate / after*	*After 15 min*	*After 30 min*
Refraction (D)	-0.50±0.25	-0.25±0.25	-0.25±0.25	-0.50±0.25
Bare visual acuity (LogMAR)	0.05±0.03	0.05±0.08	0.04±0.07	0.06±0.05

N=60 eyes,* Statistically significant difference ($P < 0.005$).

5. Conclusion

After jumping and parachute deployment, the main corneal biomechanical properties had no significant change. Furthermore, the refraction and bare visual acuity remained stable. We concluded that the rigidity and elasticity of the cornea were not apparently affected by high G-force. During real high altitude, true environmental factors such as severe windblast, low temperature, and hypoxia remained challenger to parachutists. We need further studies in the future.

References:

1. Technical and Safety Committee. IPC Safety Survey Report 2009. Lausanne, Switzland: FAI International Parachuting Commission; 2001.
2. International Parachuting Commission. Technical & Safety Committee, 2009 Safety Report; Retrieved 10 February 2013 from http // issu.com/delta 3x/ docs / safety-report-20091.y
3. Westman A. Dangers in sports parachuting [Ph.D Thesis]. Umea (Sweden): Print & Media, Umea University; 2009.
4. Gladh K, Martire RL, Ang BO, et al. Deceleration of parachute opening shock in skydivers. Aerosp Med Human Perform 2017; 88(2): 121-7.
5. Davis E, Jeffrey R, Jennifer A, et al. Aerospace medicine issues in unique aircraft types unique aircraft aspects of aerobatics flight. In: Davis JR, Johnson R, Stepanek J, editors. Fundamentals of aerospace medicine, 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2008; 653-82.
6. Potvin J, Peek G. Parachute opening shocking basics [Internet]. Outline of the presentation at the 2001 Parachute Industry Association Symposium. 2001 [Accessed 2015 June 18]. Available from: http://www.pcprg.com/sym01 out.htm.
7. Hare OA, Wetherell MA, Smith MA. State anxiety and cortisol reactivity to skydiving in novice versus experienced skydivers. Physiol Behav 2013; 118: 40-4.
8. Cavalade M, Papadopoulou V, Theunieesn S, et al.

Heat rate variability and critical flicker fusion frequency changes during and after parachute jumping in experienced skydivers. Eur J Appl Physiol 2015; 115(7): 1533-45.
9. Westman A, BjÖrnsting U. Injuries in Swedish skydiving. Br J Sport Med 2007; 41: 356-64.
10. Curtis BM, O'Keefe JH. Autonomic tone as a cardiovascular risk factor: the danger of chronic fight or flight. Mayo Clin Proc 2002; 77: 45-54.
11. Ang B, Harms-Ringdahl K. Neck pain and related disability in helicopter pilots: a survey of prevalence and risk factors. Aviat Space Environ Med 2006; 77: 713-9.
12. Coakwell MR, Bloswick DS, Moser RJ. High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviat Space Environ Med 2004; 75: 68-80.
13. Westman A, BjÖrnsting U. Fatalities in Swedish skydiving. Accid Anal Pre 2005; 37: 1040-8.
14. Guill FC. Ascertaining the causal factors for ejection-associated injuries. Aviat Space Environ Med 1989; 60(10, suppl.): 44-71.
15. Ang BO, Kristoffersson M. Neck-muscle activity in fighter pilots wearing night-vision equipment during simulated flight. Aviat Space Environ Med 2013; 84: 125-33.
16. Reid DH, Doerr JE, Doshier HD, et al. Acceleration and opening shock forces during free-fall parachuting: physiological studies of military parachutists via FM/FM telemetry-III. Aerospace Med 1971; 11: 1207-10.
17. Amoroso PJ, Bell NS, Jones BH. Injury among female and male army parachutes. Aviat Space Environ Med 1997; 68(11): 1006-1101.
18. Bricknell MC, Craig SC. Military parachuting injuries: a literature review. Occup Med (Lond.) 1999; 49(1): 1177-83.
19. Knapik JJ, Craig SC, Hauret KG, et al. Risk factors for injuries during military parachuting. Aviat Space Environ Med 2003; 74(7): 768-74.
20. Nilsson J, Friden C, Buren V, et al. Musculoskeletal pain and related risks in skydivers: a population-based survey. Aviat Space Environ Med 2013; 84(10): 1034-40.
21. Clemente-Suarez VJ, Robles-Perez JJ, Fernandaz-Lucas J. Psychophysiological response in parachute jumps, the effect of experience and type of jump. Physiol Behav 2017; 179: 178-83.
22. Westman A, Sjoling M, Lingberg A, et al. The Skynet data: demography and injury reporting in Swedish skydiving. Accid Anal Pre 2010; 42: 778-83.
23. Allison AL, Peres JC, Boettger C, et al. Fight, flight or fall: autonomic nervous system during skydiving. Personal Individu Differ 2012; 53: 218-23.
24. Sanchez-Monila J, Robles-Perez JJ, Clemente-Suarez VJ. Effect of parachute jump in the psychophysiogical response of soldiers in urban combat. J Med Syst 2017; 41:99. DOI 10.1007/s10916-017-0749-9.
25. Clemente-Suarez VJ. De la Vega R, Roble-Perez JJ, et al. Experience modulates the psychophysiological response of airborne warfighters during a tactical combat parachute jump. Int J Psychophysiol 2016; 110: 212-216.
26. Oh JH, Yoo C, Kim YY, et al. The effect of contact lens-induced edema on Goldmann applanation tonometry and dynamic contour tonometry. Graves Arch Clin Exp Ophthalmol 2009; 247(3): 371-5.
27. Ann GS, Bochmann F, Townend J, et al. Corneal biomechanical properties in primary open angle glaucoma and normal tension glaucoma. J Glaucoma 2008; 17(4): 259-62.
28. Boote C, Hayes S, Abahassin M, et al. Mapping collagen organization in the human cornea: left and right eyes are statically distinct. Invest Ophthalmol Vis Sci 2006; 47: 901-8.
29. Kirwan C, O'Malley D, O'Keefe M. Corneal hysteresis and corneal resistance factor in keratoectasia: Finding using the Reichert Ocular Analyzer. Ophthalmologica. 2008; 225(5): 334-7.
30. Ortiz D, Pinero D, Shabayek MH, et al. Corneal biomechanical properties in normal post-laser in situ keratomileusis and keratoconic eyes. J Cataract Refract Surg 2007; 33(8): 1371-5.\
31. Tsai ML, Liu CC, Wu YC, et al. Ocular response and visual performance after high-acceleration force exposure. Invest Ophtahlmol Vis Sci 2009; 50: 4836-9.
32. Muir KW, Jin J, Freedman SF. Central corneal thickness and its relationship to intraocular pressure in children. Ophtahlmology 2004; 111: 2220-3.
33. LaStayo PC, Woolf JM, Lewek MD, et al. Eccentric muscle contractions: their contribution to injury, prevention rehabilitation, and sport. J Orthop Sport Phys Ther 2003; 33: 557-71.
34. Burton RR, Leverett SD, Michaelson ED. Man at high sustained + Gz acceleration: a review. Aerospace Med 1974; 45(10): 1115-36.
35. Panjabi MM. The stability system of the spine. Part II. Neutral zone and instability hypothesis. J Spine Disord 1992; 5: 390-6.
36. Falla D, Rainoldi A, Merletti R, et al. Feedforward activity of the cervical flexor muscles during voluntary arm movement is delayed in chronic neck pain. Exp Brain Res 2004a: 157: 43-8.

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