G-LOC Warning Algorithms Based on EMG Features of the Gastrocnemius Muscle

Sungho Kim; Taehwan Cho; Yongkyun Lee; Hyojin Koo; Booyong Choi; Dongsoo Kim

BACKGROUND: G-induced loss of consciousness (G-LOC) is mainly caused by failure to sustain an oxygenated blood supply to the pilot's brain because of the sudden acceleration in the direction of the $+G_z$ axis, and is considered a critical safety issue. The purpose of this study was to develop G-LOC warning algorithms based on monitoring electromyograms (EMG) of the gastrocnemius muscle on the calf.

METHODS: EMG data was retrieved from a total of 67 pilots and pilot trainees of the Korean Air Force during high-G training on a human centrifugal simulator. Seven EMG features were obtained from root mean square (RMS), integrated absolute value (IAV), and mean absolute value (MAV) for muscle contraction, slope sign changes (SSC), waveform length (WL), zero crossing (ZC), and median frequency (MF) for muscle contraction and fatigue.

RESULTS: Out of seven EMG features, IAV and WL showed a rapid decay before G-LOC. Based on these findings, this study developed two algorithms which can detect G-LOC during flight and provide warning signals to the pilots. The probability of G-LOC occurrence was detected through monitoring the decay trend for representing muscle endurance and climb rate of the IAV and WL value during sudden acceleration above 6 G, representing muscle power. The sensitivity of the algorithms using IAV and WL features was 100% and the specificity was 66.7%.

DISCUSSION: This study suggests that a G-LOC detecting and warning system may be a customized, real-time countermeasure by improving the accuracy of detecting G-LOC.

KEYWORDS: G-LOC bio-signal, anti-G straining maneuver, EMG features, G-LOC warning algorithms.

Kim S, Cho T, Lee Y, Koo H, Choi B, Kim D. *G-LOC warning algorithms based on EMG features of the gastrocnemius muscle.* Aerosp Med Hum Perform. 2017; 88(8):737–742.

G-LOC (G-induced loss of consciousness) and A-LOC (acceleration-induced near-loss of consciousness) refer to losing consciousness from failure to sustain blood supply to the fighter pilot's brain. This is caused by sudden acceleration during flight and may lead to fatal accidents in high-performance aircrafts.[3,9,20] Acceleration during flight is classified into $+G_z$, $-G_z$, $+G_y$, $-G_y$, $+G_x$, and $-G_x$ based on directions from which the pilot is seated, and the main cause of G-LOC is $+G_z$ acceleration, which is applied vertically downward.[18,22,23] The primary reason for loss of vision, cardiac arrhythmia, myoclonic convulsions, and loss of consciousness during acceleration is the loss of sustainability of venous blood flow to the heart, as well as the loss of sustainability of brain blood pressure and cerebral blood flow.[17,22,25] On average, an increase of $+1\ G_z$ induces the average cerebral artery blood pressure to drop by ∼22–25 mmHg. Hence, if the cerebral artery blood pressure was 78 mmHg in a normal state of $+1\ G_z$, it would drop to −10 mmHg when exposed to $+5\ G_z$ acceleration, which is the main cause of G-LOC.[16] Blood pressure on the feet will be increased up to 1165 mmHg and up to ∼450–520 mmHg even when seated. This is a result of the blood congestion in the lower part of the body and reduced venous blood to the heart due to the acceleration. From this, a decrease in cardiac output will be triggered. When exposed to acceleration, heart rate will increase sharply in response to the decreased arterial blood pressure and cardiac output.[3,4,19] A normal person will face changes in vision such as gray out or black out at ∼4.1–4.8 G_z and, without any equipment or techniques to

---

From the Air Force Academy, Cheongju, Chungbuk, Republic of Korea.

This manuscript was received for review in September 2016. It was accepted for publication in May 2017.

Address correspondence to: Dongsoo Kim, Department of Basic Science, Republic of Korea Air Force Academy, 635 Danjaero, Cheongju, Chungbuk 28187, Republic of Korea; dongsookim04@gmail.com.

DOI: https://doi.org/10.3357/AMHP.4781.2017

handle rapid acceleration from 1 G_z to 6 G_z, or constant exposure to over 6 G_z, he will go into a G-LOC state within 5 s.[2,17,25]

Fighter pilots need to increase their G tolerance (level of tolerance against G-LOC) with the help of equipment such as the angle of the seat or an anti-G suit or through an anti-G straining maneuver (AGSM) technique, which includes L-1 respiration maneuvering and muscular contraction of the venous capacitance spaces.[22,23] AGSM consists of muscular contraction of the bottom part of the body, e.g., the abdomen and leg muscles, and a respiration maneuvering called L-1 maneuvering. This is the most effective method to enhance G tolerance and is essential during exposure to acceleration. The reason behind going into a G-LOC state, despite using the AGSM technique, is due to exhaustion from inefficient or inattentive muscle contraction or excessively rapid respiration rate. Hence, monitoring the flight trainees in performing the AGSM technique during ground training based on their changes in muscle contractility and endurance through electromyogram (EMG) monitoring is a useful method.[5]

Our studies have researched possibilities of prognosis detection and warning generation of G-LOC through EMG monitoring by undergoing human centrifugal simulator experimentation and have reported the rapid changes in muscle contractility and endurance features in EMG around the time of G-LOC.[8] From this, we proposed G-LOC warning algorithms and suggested that creating a G-LOC alarm prior to G-LOC based on alteration of patterns in EMG features is feasible. It would be effective if there were a way to prevent G-LOC through a defining individual manner with bio-signals. This study shows the result of objectification and application of a real-time method for validating G-LOC prognosis by using EMG features.[1,21,24] We already introduced concepts developed in a regular conference.[6,7] Then we proposed G-LOC warning algorithms in detail.

METHODS

Subjects

A group that consisted of 67 volunteers who were healthy Korean Air Force subjects (63 pilots and 4 pilot trainees), with ages between 22 and 40, participated in this study. EMGs were obtained while volunteers consisting of pilots were taking the centrifugal simulator training for pilots. The participation number of the centrifugal simulator training of the pilot trainees was less than five as compared to that of the pilots. A total of 60 EMGs were obtained from 56 pilots and 4 trainees who successfully completed the G-LOC training, and 7 EMGs were obtained from 6 pilots and 1 trainee who experienced G-LOC. All experimental procedures involving human subjects were approved by the Research Ethical Review Board at the Korean Air Force Academy. All volunteers agreed to bio-signal collection such as EMG, electrocardiogram (ECG), and body temperature. However, ECG and body temperature data were excluded from the analysis due to lack of significance. Collected data were coded and then analyzed for privacy protection.

Materials

G-LOC training is a mandatory course air force fighter pilots take once every 3 yr and air force pilot trainees have to complete G-LOC training before participating in flight training. G training pass/fail criterion is to determine whether or not loss of consciousness during the G profiles is a result of the type of pilot aircraft. G-LOC training was performed in the high-performance human centrifugal simulator (ATF400, ETC, Southampton, PA). EMG raw data was obtained from an embedded bio-signal collection system (MP-150, Biopac, Goleta, CA) on the simulator. Surface EMG sensors were attached to the pilots' gastrocnemius muscles in the calves and 67 EMGs were obtained and used for analysis.

Procedures

The experiment for this study was carried out in four stages: 1) preparation, 2) EMG sensor attachment, 3) the main experiment, and 4) debriefing. First, researchers introduced the main experimental contents such as purpose and procedure, and participants were asked to sign the experiment agreement form. Secondly, pilots participating in the research had active and reference electrodes attached to their gastrocnemius muscle with 5 cm in between and the ground electrode attached to the end point of the soleus muscle on the ankle prior to entering the simulator, as shown in **Fig. 1**. Thirdly, air force F-15 and F-16 fighter pilots have to endure 9 G for 15 s with a full coverage anti-G suit (CSU-13B/P); air force F-4 and F-5 fighter pilots have to endure 7.3 G for 20 s with a full coverage anti-G suit; and pilot trainees have to endure 6 G for 30 s without an anti-G suit. All pilots participating in the training performed L-1 maneuvering during $+G_z$ and EMG raw data was collected from pilot and pilot trainees while they took G-LOC training. Lastly, researchers requested significant things to report or opinions on the experimental results.

Mathematical Analysis

EMG raw data was acquired with a sampling frequency of 400 Hz and a high-pass filter was used to eliminate noise below 10 Hz. EMG features representing muscle contraction

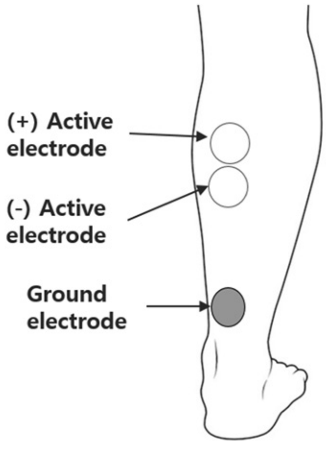


Fig. 1. EMG collection from the calf (gastrocnemius muscle).

and fatigue were obtained from rectification and digital smoothing of EMG raw data. Those were root mean square (RMS), integrated absolute value (IAV), and mean absolute value (MAV) for muscle contraction,[10,13,15] slope sign changes (SSC), waveform length (WL), zero crossing (ZC), and median frequency (MF) for muscle contraction and fatigue.[11,12,14] RMS can be used as an indicator of the level of activity about the mean of the signal. It is a square root of the average of the square of the EMG signal amplitude values. IAV is a summation of the absolute value of the EMG signal amplitude over the time segment, and MAV is an average of it. SSC is the number of times that the slope of the EMG waveform changes sign. WL is the cumulative length of the waveform over the time segment. WL is related to the waveform amplitude, frequency, and time. ZC is defined as the number of times the signal crosses the reference within a specified interval. This feature provides an approximate estimation of frequency domain properties. MF is a frequency at which the EMG power spectrum is divided into two areas with an equal total power. EMG features were calculated as below. In each, x_n is the n^{th} sample of surface EMG signal amplitude, N is the length of the analysis window for computing the features, P_i is the EMG power spectrum at a frequency bin i, and M is the length of the whole frequency bin.

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2} \qquad \text{Eq. 1}$$

$$\mathrm{IAV} = \sum_{n=1}^{N} \left| x_n \right| \qquad \text{Eq. 2}$$

$$\mathrm{MAV} = \frac{1}{N}\sum_{n=1}^{N} \left| x_n \right| \qquad \text{Eq. 3}$$

$$\mathrm{SSC} = \sum_{n=2}^{N-1} \left[\mathrm{f}\left[\left(\mathrm{x_n} - \mathrm{x_{n-1}} \right) \times \left(\mathrm{x_n} - \mathrm{x_{n+1}} \right) \right] \right] \qquad \text{Eq. 4}$$

$$\mathrm{f}(\mathrm{x}) = \begin{cases} 1, & \mathit{if}\ x \geq \mathit{threshold} \\ 0, & \mathit{otherwise} \end{cases}$$

$$\mathrm{WL} = \sum_{n=1}^{N-1} \left| x_{n+1} - x_n \right| \qquad \text{Eq. 5}$$

$$\mathrm{ZC} = \sum_{n=1}^{N-1} \left[sgn\left(x_n \times x_{n+1} \right) \bigcap \left| x_n - x_{n+1} \right| \geq \mathit{threshold} \right] \qquad \text{Eq. 6}$$

$$\mathrm{sgn}(\mathrm{x}) = \begin{cases} 1, & \mathit{if}\ x \geq \mathit{threshold} \\ 0, & \mathit{otherwise} \end{cases}$$

$$\mathrm{MF} = \sum_{i=1}^{\mathrm{MF}} P_i = \sum_{i=\mathrm{MF}}^{M} P_i = \frac{1}{2}\sum_{i=1}^{\mathrm{MF}} P_i \qquad \text{Eq. 7}$$

To analyze the EMG changes before and after G-LOC, EMG features over 6 G were divided into two phases: the normal phase (withstanding G-force from a 6 G or more start point to alarm phase start point) and the alarm phase (3 s before G-LOC). EMG features of 1-s units with 0.5-s overlap consecutive windows were analyzed for alteration in the EMG patterns.

RESULTS

This study investigated the possibility of detection of G-LOC onset and warnings generated through EMG monitoring. In the analysis on the characteristics of EMG features before and after G-LOC, the EMG pattern of the pilots entering G-LOC generally showed a low peak value. This trend was observed by calculating moving average values of EMG signals, which is a calculation to analyze data points by creating a series of averages based on the consecutive time domain of the full data set. On average, G-LOC occurred when the value reached below 0.5 mV. Pilots and trainees resisted G-LOC through AGSMs and muscle contractions. Most G-LOC occurrences were associated with irregular L-1 respiration maneuvering and reduced muscle tone. Irregularities of L-1 respiration maneuvering were observed not by bio-signals, but through monitoring of training situations. Pilots withstanding $+G_z$ force showed a regular and strong EMG pattern, whereas the ones going into G-LOC showed an irregular and weak EMG pattern, which fluctuated irregularly at the time of G-LOC occurrence (**Fig. 2**).[6]

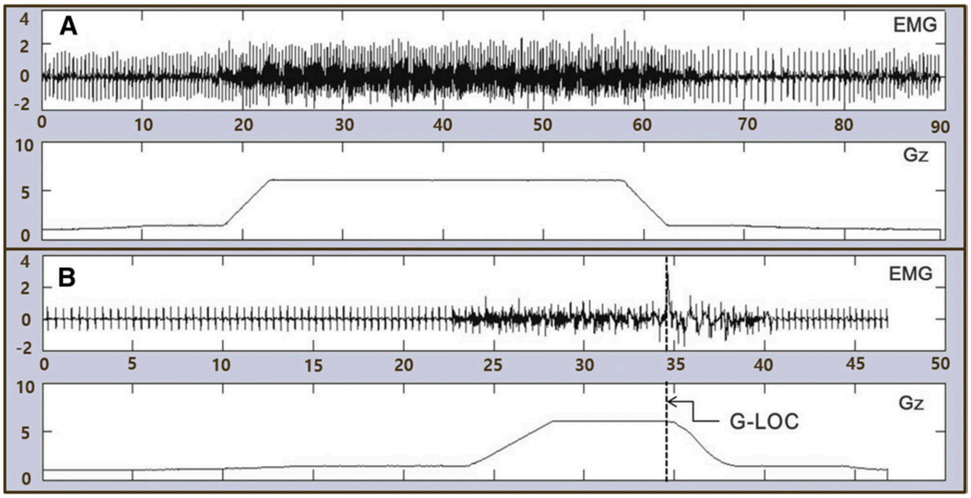


Fig. 2. Differential EMG patterns under exposure to $+G_z$ acceleration. A) EMG of the gastrocnemius muscle of a pilot who withstood the G force. B) EMG of the gastrocnemius muscle in a pilot who experienced G-LOC.

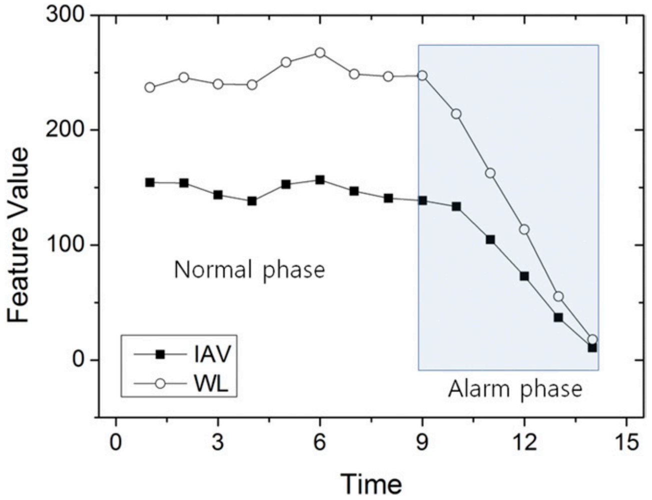
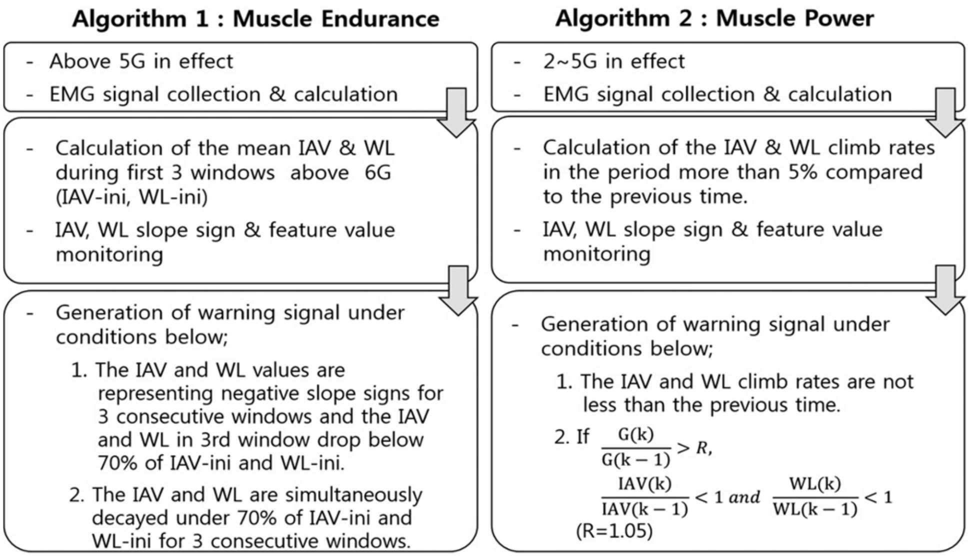


Fig. 3. Fluctuations of WL and IAV after 6 G_z exposure. The alarm phase is indicated by the grey box and was 3 s before onset of G-LOC. The normal phase is a time period from the 6-G start point to the beginning of the alarm phase.

Alteration of the feature pattern may be useful for developing a G-LOC warning system to inform the pilot prior to G-LOC. EMG features were analyzed to elucidate the pattern of each feature. Out of the features, IAV and WL decayed rapidly in the alarm phase, but did not decay while the subject was withstanding $+G_z$ acceleration (**Fig. 3**). IAV, which represents muscle contractility, and WL, which represents both muscle contractility and fatigue, have shown a rapid, distinct change just prior to G-LOC, and thus were used as indices to detect G-LOC onset. These decay patterns represent the possibility of creating a G-LOC warning system. Six cases of G-LOC occurred in $+G_z$, where rapid acceleration has shown the same pattern, except in one case of G-LOC which occurred during delayed AGSM.

This study developed two G-LOC warning algorithms based on EMG features representing maintaining muscle power during $+G_z$ acceleration and delayed response to $+G_z$ acceleration. G-LOC warning algorithm 1 makes use of the characteristics in Fig. 3 and is tied to muscle endurance. G-LOC warning algorithm 2 complements the aforementioned algorithm 1. Associated with muscle flexibility, G-LOC warning algorithm 2 monitors EMG signals and generates warnings in the stage where G_z-force increases. While using both algorithms at the same time was efficient in detecting G-LOC, the rise in the frequency of false signals was a downside. First of all, G-LOC warning algorithm 1 through EMG was developed based on the fluctuation of WL and IAV after exposure to high $+G_z$ force (Fig. 3). To minimize interruptions to the pilot's focus during flight missions, the EMG monitoring system was activated when acceleration reached above 2 G. Once the system is activated, WL and IAV values are calculated with every 1-s window, of which 0.5 s would overlap. When the pilot is exposed to sudden $+G_z$ acceleration, one spontaneously runs through the AGSM. In sudden accelerations above 5 G, the EMG monitoring system calculates the means of IAV and WL captured during the first three windows as the initial reaction values. Initial reaction values of WL (WL-ini) and IAV (IAV-ini) are references which reflect the individual tolerance level of a pilot against $+G_z$ force during a sudden acceleration. If the WL and IAV values represent negative slope signs for three consecutive windows and the WL and IAV in the third window drop below 70% of WL-ini and IAV-ini, the system will generate a warning signal. A total of 70% of WL-ini and IAV-ini came from EMGs of subjects experiencing G-LOC, causing an alarm ~3–0.5 s prior to G-LOC. In addition, if the WL and IAV simultaneously are decayed under 70% of WL-ini and IAV-ini for three consecutive windows, the system will also generate a warning signal.

G-LOC warning algorithm 2 is based on EMG signals in the stage where G_z force is on the rise. The analysis of the EMG signals suggests that one experiences G-LOC unless IAV and WL do not go up simultaneously during this phase. This result was a foundation that led to the development of G-LOC warning algorithm 2. G-LOC warning algorithm 2 warns pilots by predicting that there is a high probability of experiencing G-LOC if the IAV or WL reading is less than that of a previous one when G_z force goes up beyond a certain extent. By recognizing the rise of G_z force in the early stage, this algorithm can secure enough time for pilots to cope with G-LOC. Summary of algorithm 1 and algorithm 2 are shown in **Fig. 4**.



Algorithm 1 : Muscle Endurance

- Above 5G in effect
- EMG signal collection & calculation

- Calculation of the mean IAV & WL during first 3 windows above 6G (IAV-ini, WL-ini)
- IAV, WL slope sign & feature value monitoring

- Generation of warning signal under conditions below;
  1. The IAV and WL values are representing negative slope signs for 3 consecutive windows and the IAV and WL in 3rd window drop below 70% of IAV-ini and WL-ini.
  2. The IAV and WL are simultaneously decayed under 70% of IAV-ini and WL-ini for 3 consecutive windows.

Algorithm 2 : Muscle Power

- 2~5G in effect
- EMG signal collection & calculation

- Calculation of the IAV & WL climb rates in the period more than 5% compared to the previous time.
- IAV, WL slope sign & feature value monitoring

- Generation of warning signal under conditions below;
  1. The IAV and WL climb rates are not less than the previous time.
  2. If $\frac{G(k)}{G(k-1)} > R$, $\frac{IAV(k)}{IAV(k-1)} < 1$ *and* $\frac{WL(k)}{WL(k-1)} < 1$ (R=1.05)

Fig. 4. Summary of algorithms 1 and 2.

Examples that apply algorithm 1 and algorithm 2 are shown in **Fig. 5**. The x-axis is elapsed time

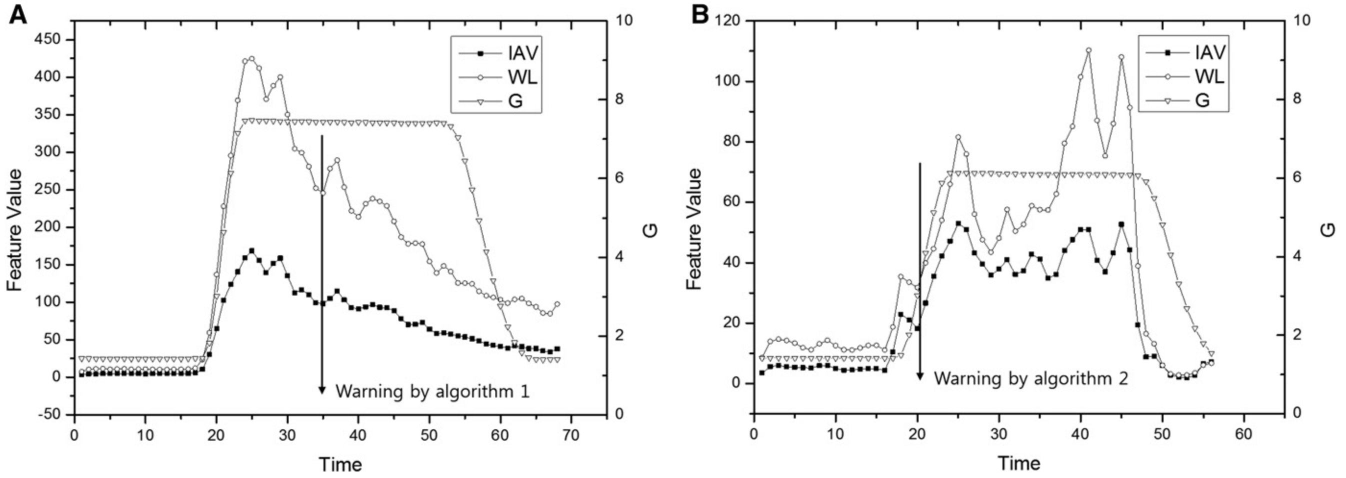


Fig. 5. Application for generation of G-LOC warning by implementing algorithm 1 and 2. Vertical arrows represent the time points at which G-LOC warning is generated.

and the y-axis is feature values. Figs. 5A and B represent a case in which warnings are created by algorithm 1 and 2, respectively.

For validating the performance of two developed G-LOC warning algorithms, we have obtained results as shown in **Table I** by applying the algorithms introduced in the prior paragraphs through using EMG data of 67 cases retrieved from the human centrifugal simulator. In all seven cases who have experienced G-LOC, true warning signals have been shown between 0.5 s and 3 s prior to G-LOC. However, data from 28 out of 60 participants who did not experience G-LOC suggested G-LOC warnings which could be interpreted as false warning signals. False warning signals were not generated for the other 32 subjects. After the training, we interviewed all subjects and found that out of 28 volunteers who were issued warning signals, 86% or 24 of them experienced blackout and grayout, which are considered an early sign prior to G-LOC. Thus, it can be concluded that the generation of G-LOC warning signals to those 24 participants who experienced a blackout and grayout is a desirable result. Ultimately, only 4 out of 67 subjects, approximately 6%, were actually issued false warning signals and the sensitivity of the algorithms using IAV and WL features was 100% and the specificity was 66.7%.

DISCUSSION

G-LOC is considered one of the most critical conditions to air force fighter pilots. In addition to the importance of creating a system to increase G tolerance, it came to our attention that the effectiveness of the system can be attained if G-LOC could be prevented in a customized manner during flight. Pilots wear G-suits and perform AGSM to resist a rapidly increasing $+G_z$ force. However, physical reactions to $+G_z$ force may differ depending on an individual's physical state or operational condition. Hence, even the expert pilots consider G-LOC a critical condition.

Table I. Summary of Algorithm Validation.

SYMPTOMS OF EXPOSURE TO HIGH G FORCE	WARNING	NO WARNING
G-LOC	7 (1) (100.0%)	0 (0.0%)
Blackout & Gray-Out	24 (3) (50.0%)	24 (50.0%)
No Symptoms	4 (33.3%)	8 (66.7%)
Total	67 cases	

* The numbers in parentheses are those of pilot trainees included in the displayed number.

Surface EMG data was obtained from pilots' gastrocnemius muscles of the calves. Before collecting this data from their calves, EMG data signals were measured in the neck and abdomen. The data from these two areas, however, were unreliable due to excessive noise caused by the differences in pilots' behavioral patterns and perspiration. On the other hand, the gastrocnemius muscle provided stable EMG data because of its wide area that helped reduce the noise level during flight. Meanwhile, two of the EMG features, WL and IAV, showed a sharp decay prior to onset of G-LOC, and thus were considered key variables for creating G-LOC warning algorithms. As a result of analyzing the decay pattern of EMG features, not all EMG features of the subjects were equivalent. WL, IAV, RMS, and MAV, out of seven features, were rapidly decayed in the alarm phase, which was 3 s before G-LOC. The decay patterns of MAV and RMS are relatively small.

This study suggests that G-LOC onset could be detected through real-time monitoring with EMG features and that warning signals could be generated during flight. G-LOC warning algorithm 1 uses the initial value of WL and IAV obtained from a state of high $+G_z$ force above 6 G as a reference, and is generated upon the simultaneous decay of WL and IAV to a certain degree by monitoring the two features during every 1-s window, of which 0.5 s would overlap. The calculation interval, of course, must be adjusted and optimized during the practical stage. Based on EMG signals in the stage where G_z force increases, G-LOC warning algorithm 2 issues G-LOC warnings if IAV and WL do not go up simultaneously during the phase in which G_z force is on the rise. This system is turned on/off repetitively depending on the $+G_z$ force and the reference for detection of G-LOC onset and generation of warnings varies depending on the individual manner and situation changes during flights. In conclusion, as far as the authors are aware, this system may be the first customized and adaptable G-LOC warning system depending on EMG monitoring.

This system will be improved further by finding ways to ramp up the accuracy of G-LOC detection and minimizing the generation of false warning signals through sensing from other sites of the body such as the quadriceps, multiple sensors such as the electroencephalogram, and change of activating point from above 2 G to above 3.5 G, etc. Also, in order to apply this to aircraft capable of rapid onset and reduce the false positive rate, this system should be refined and stabilized by adjusting the time windows of the EMG features and analyzing more cumulative data.

ACKNOWLEDGMENTS

This research was supported by the Civil Military Technology Cooperation Center, Republic of Korea. We would like to present our appreciation to the Aerospace Medical Training Centre of the Republic of Korea Air Force for supporting our research by allowing the use of their G-induced loss of consciousness training facilities.

Authors and affiliations: Sungho Kim, B.S., M.S., Department of Systems Engineering, Taehwan Cho, B.S., Ph.D., Department of Electronics and Communications Engineering, and Yongkyun Lee, B.S., M.S., Hyojin Koo, B.S., M.A., Booyong Choi, M.S., Ph.D., and Dongsoo Kim, M.S., Ph.D., Department of Basic Science, Republic of Korea Air Force Academy, Chungbuk, Republic of Korea.

REFERENCES

1. Bagshaw RJ, Whinnery JE. Contribution of skeletal muscle activity to the natural history of acceleration-induced loss of consciousness (G-LOC). Med Hypotheses. 1989 Oct; 30(2):123–128.
2. Buick F, Wood EH, Pecaric M, Maloan J. Methods for measuring physiological responses and protection in man exposed to high +Gz. Neuilly-sur-Seine, France: NATO; 1995. AGARD-LS-202.
3. Burns JW. G-protection basis/acceleration physiology. Neuilly-sur-Seine, France: NATO; 1995. AGARD-LS-202.
4. Cammarota JP. Integrated systems for detecting and managing acceleration-induced loss of consciousness. IEEE Eng Med Biol Soc. 1991; 10(1): 52–55.
5. Chen HH, Wu YC, Kuo MD. An electromyographic assessment of the anti-G straining maneuver. Aviat Space Environ Med. 2004; 75(2):162–167.
6. Choi B, Kim D, Kim M, Hwang S. Effectiveness of EMG in development of G-induced loss of consciousness (G-LOC) warning system. 1st International Conference on Biomedical Engineering and Systems; Aug. 14–15, 2014; Prague, Czech Republic. Ottawa (Canada): International ASET Inc., ICBES; 2014(129):1–4.
7. Choi B, Lee Y, Cho T, Koo H, Kim D. Detection of G-induced loss of consciousness (G-LOC) prognosis through EMG monitoring on gastrocnemius muscle in flight. 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society; Aug. 25–29, 2015; Milan, Italy. Piscataway (NJ): IEEE-EMBS; 2015:7007–7010.
8. Cornwall MW, Krock LP. Electromyographic activity while performing the anti-G straining maneuver during high sustained acceleration. Aviat Space Environ Med. 1992; 63(11):971–975.
9. Davis JR, Johnson R, Stepanek J, Fogarty JA. Fundamental of aerospace medicine, 4th ed. Philadelphia (PA): Lippincott Williams & Wilkins; 2008: 83–109.
10. Fernandes L, Linder J, Krock LP, Baldin UI, Harms Ringdahl K. Muscle Activity in Pilots With and Without Pressure Breathing During Acceleration. Aviat Space Environ Med. 2003; 74(6, Pt. 1):626–632.
11. Merletti R, Lo Conte L, Avignone E, Guglielminotti P. Modeling of surface myoelectric signals–Part I: Model implementation. IEEE Trans Biomed Eng. 1999a; 46(7):810–820.
12. Merletti R, Roy SH, Kupa E, Roatta S, Granata A. Modeling of surface myoelectric signals–Part II: Model-based signal interpretation. IEEE Trans Biomed Eng. 1999b; 46(7):821–829.
13. Oksa J, Hämäläinen O, Rissanen S, Myllyniemi J, Kuronen P. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med. 1996; 67(12):1138–1143.
14. Oliveira AS, Gonçalves M. EMG amplitude and frequency parameters of muscular activity: effect of resistance training based on electromyographic fatigue threshold. J Electromyogr Kinesiol. 2009; 19(2):295–303.
15. Phinyomark A, Limskaul C, Phukpattaranont P. A novel feature extraction for robust EMG pattern recognition. J Comput. 2009; 1(1):71–80.
16. Rainford DJ, Gradwell DP. Ernsting's aviation medicine, 4th ed. London: CRC Press; 2006.
17. Rangayyan RM. Biomedical signal analysis. a case-study approach. Chichester, UK: Wiley InterScience; 2002.
18. Rudnjanin S, Arsic-Komljenovic G, Pavlovic M, Vujnovic J. Loss of consciousness as criterion of +Gz tolerance at Institute of Aviation Medicine MMA during +Gz acceleration selective test. Acta Physiol Hung. 2006; 93(4):371–376.
19. Russomano T, Rizzatti MR, Coelho RP, Scolari D, Souza D, Pra-Veleda P. Effects of simulated hypergravity on biomedical experiments. IEEE Eng Med Biol Mag. 2007 May 26(3):66–71.
20. Shender BS, Forster EM, Hrebien L, Ryoo HC, Cammarota JP, Jr. Acceleration-induced near-loss of consciousness: the "A-LOC" syndrome. Aviat Space Environ Med. 2003; 74(10):1021–1028.
21. Stevenson AT, Scott JP. +Gz tolerance, with and without muscle tensing, following loss of anti-G trouser pressure. Aviat Space Environ Med. 2014; 85(4):426–432.
22. Whinnery JE. Theoretical analysis of acceleration-induced central nervous system ischemia. IEEE Eng Med Biol Mag. 1991 Mar 10(1): 41–45.
23. Whinnery JE, Whinnery AM. Acceleration-induced loss of consciousness. A review of 500 episodes. Arch Neurol. 1990; 47(7):764–776.
24. Winter DA. Biomechanics and motor control of human movement, 2nd ed. New York: John Wiley & Sons. Inc.; 1990:191–212.
25. Zawadzka-Bartczak EK, Kopka LH. Cardiac arrhythmias during aerobatic flight and its simulation on a centrifuge. Aviat Space Environ Med. 2011; 82(6):599–603.