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Effectiveness of EMG in Development of G-induced Loss of Consciousness (G-LOC) Warning System

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***Abstract*−** G-Induced Loss of Consciousness (G-LOC) is caused by highly-sustained +Gz acceleration during an aviation and is considered as one of the most life-threatening problems to pilots. It would be effective if G-LOC could be prevented by personal based manner with bio-signals, thus the purpose of this study is to develop G-LOC warning system based on bio-signals. The electromyograms (EMGs) from trapezius, abdominal, or calf muscles of Korean Air Force pilots and pilot trainees are monitored during high G-training. EMG features, root mean square (RMS), integrated absolute value (IAV), mean absolute value (MAV) reflecting muscle contraction, slope sign changes (SSC), waveform length (WL), zero crossing (ZC), median frequency (MF) reflecting muscle contraction and fatigue were selected as candidates for G-LOC monitoring. WL, IAV, RMS, and MAV were rapidly decayed in alarm phase, which is 3 sec before G-LOC, compared to a normal phase withstanding G-force. This study suggests that EMG features can be useful for developing G-LOC warning system, and that WL, RMS, MAV, and IAV out of EMG features are candidates for creating G-LOC alarm algorism.

***Keywords*:** G-LOC, High-G training, Biomedical signals, G-LOC warning system.

1. Introduction

Gravity-induced loss of consciousness (G-LOC) is caused by +Gz acceleration stress exceeding pilot's tolerance threshold. Sustained +Gz acceleration takes blood away from the brain causing loss of vision, cardiac arrhythmia, myoclonic convulsions, and loss of consciousness (Zawadzka-Bartczak, et al., 2011; Whinnery et al., 1990). G-LOC is one of the primary concerns in air combat mission and aviation safety. G-LOC incidents have caused life-threatening accidents in high performance fighters, exposing high level of G-force for extended periods. Pilots and pilot trainees of high performance fighter must complete the ground human centrifugal training for enhancing their resistance to G-LOC.

Fighter pilots perform anti-G straining maneuvers (AGSMs), use positive pressure breathing for G protection (PBG), and wear anti-G suits (Fernandes et al., 2003; Whinnery et al., 1990) to resist G-LOC. Muscle contraction coordinated with breathing is important when pilots perform G protection maneuvers. EMG has been utilized to monitor muscle strain of pilots in ground and in-flight anti-G maneuvering (Oksa et al., 1996; Cornwall et al., 1992). Also Chen et al (2004) recommended EMG to replace subjective evaluation of trainee's AGSM performance. Up to date EMG has been used to characterize G-LOC and to monitor performance of G-protection procedure. However, EMG has not been used for predicting possibility of G-LOC. EMG may be a suitable tool for creating G-LOC warning alarm. Herein we investigate characteristics of EMG before and after G-LOC and possibility of creating a G-LOC alarm prior to G-LOC based on alteration of patterns in EMG features.

2. Materials and Methods

2. 1. Subjects

Forty-seven volunteers, who are healthy Korean Air Force pilots and pilot trainees in the ages between 27 and 40, participated in this study. Forty-two EMGs were obtained from pilot and pilot trainees who successfully completed the G-LOC training, and five EMGs were obtained from five pilot trainees who experienced G-LOC. All volunteers agreed on their bio-signal collection. Collected data were coded and then analysed for privacy protection.

2. 2. G-LOC Training

G-LOC training is a regular training course of Air Force pilots and pilot trainees. Air Force fighter pilots have to endure 9G for 30 sec, and pilot trainees have to endure 6G for 30 sec. G-LOC training was performed in the high performance human centrifugal simulator (ATF400, ETC, USA) on which a bio-signal collecting system (MP-150, Biopac, USA) is mounted.

2. 3. Features for EMG Analysis

EMG features representing muscle contraction and fatigue were obtained from rectification and digital smoothing of EMG raw data. Those were RMS, IAV, MAV for muscle contraction, SSC, WL, ZC, and MF for muscle contraction and fatigue (Oliveira et al., 2009; Merlettiet al., 1999a; 1999b).

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2} \qquad \mathrm{IAV} = \sum_{n=1}^{N} |x_n| \qquad \mathrm{MAV} = \frac{1}{N}\sum_{n=1}^{N} |x_n|$$

$$\mathrm{SSC} = \sum_{n=2}^{N-1} [f\{x_n - x_{n-1}\} \times \{x_n - x_{n-1}\}] \qquad \mathrm{WL} = \sum_{n=1}^{N-1} |x_{n+1} - x_n|$$

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

$$\mathrm{ZC} = \sum_{n=1}^{N-1} [sgn(x_n \times x_{n+1}) \cap |x_n - x_{n+1}| \geq threshold] \qquad \mathrm{sgn(x)} = \begin{cases} 1, & if\ x \geq threshold \\ 0, & otherwise \end{cases}$$

2. 4. EMG Analysis

Volunteers attached EMG sensors on trapezius, abdominal, or calf muscles before simulator flight. EMG records were collected from pilot and pilot trainees while they took the G-LOC training. An EMG over 6G was divided into two phase, the normal phase (withstanding G-force) and the alarm phase (3 sec before G-LOC), and then seven EMG features from these two phases were compared. EMG features of 1 sec unit with 0.5 sec overlap consecutive windows were monitored for alteration patterns of EMG features (Fig. 1).

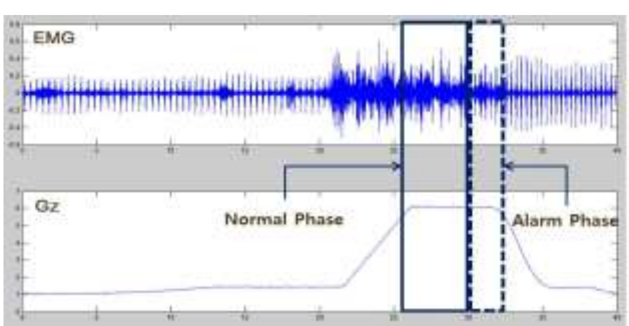

Fig. 1. EMG accompanied with G-force alteration.

3. Results

3. 1. Characteristic of EMG during G-LOC Training

Pilots and trainees prevent G-LOC through the AGSMs and muscle contraction. Most G-LOC came from irregular L1 respiration maneuvering and reduced muscle tone. Fig. 2 represents two EMGs of trainees. EMG of Subject A maintaining consciousness is regular and strong (Fig. 2, A); on other hand EMG of Subject B is irregular and weak, and is eventually shaking around G-LOC time point (Fig. 2, B).

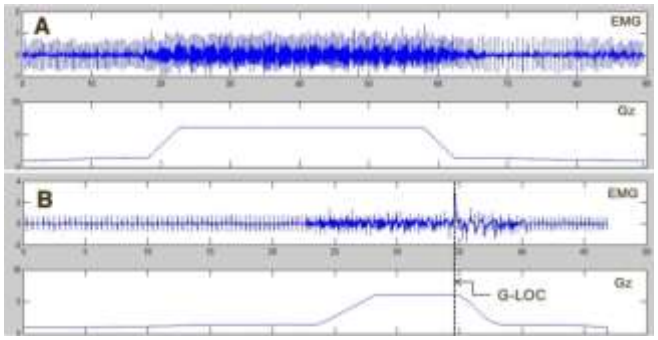

Fig. 2. Alteration of EMGs acquired from a subject under consciousness (A), and a subject under G-LOC (B).

3. 2. Fluctuation of EMG Features Before and After G-LOC

All EMG features of subjects were not equivalent. Five features, RMS, IAV, SSC, MAV, and ZC, except WL and MF in 3 sec window before G-LOC were significantly altered, compared to those in 3 sec window after G-LOC (not shown). Alteration pattern of features may be useful for developing G-LOC warning system to inform pilot prior to G-LOC.

3. 3. Candidate Features of EMG for Development of G-LOC Warning

EMG features were analysed to elucidate the pattern of each feature. WL, IAV, RMS, and MAV were rapidly decayed in alarm phase, which is 3 sec before G-LOC (Fig. 3). Decay pattern of MAV and RMS are not presented in Fig. 3 because these values are relatively small. These decay patterns represent the possibility of creating G-LOC warning system. Four cases of G-LOC occurred in +Gz where rapid acceleration has shown a same pattern, whereas in case of G-LOC occurred during deceleration after acceleration (6Gz) have shown a different pattern.

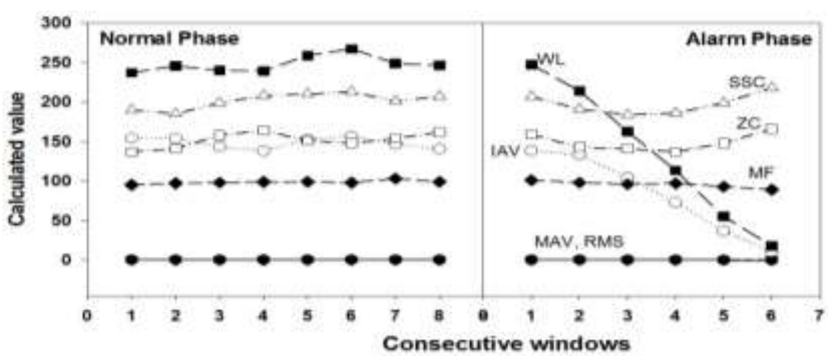

Fig. 3. Alteration of EMG features along with 0.5 sec consecutive time windows in normal phase and alarm phase (3 sec before G-LOC) in a subject.

4. Conclusion

G-LOC is one of the most serious threats to Air Force pilots. It would be effective if G-LOC could be prevented by personal based manner with bio-signals. This study suggests that EMG features can be utilized for developing G-LOC warning system, and that WL, RMS, MAV, and IAV out of EMG features are candidates for creating G-LOC alarm algorism.

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