Gravitational Acceleration Test Results by Lifestyle and Physical Fitness of Air Force Cadets

Jun-Young Sung; In-Ki Kim; Deok-Hwa Jeong

BACKGROUND: The purpose of this study was to analyze G test results according to the Three-Factor Eating Questionnaire (TFEQ), body composition, and physical fitness of fourth-grade air force cadets. This was done to identify the relationship between the TFEQ, body composition, and G resistance, in order to provide basic data for pilots and air force cadets to strengthen G tolerance.

METHODS: From the Republic of Korea Air Force Academy (ROKAFA), 138 fourth-year cadets were assessed using the TFEQ and for body composition and physical fitness. Based on these measurement results, a G test result analysis and a correlation analysis were conducted.

RESULT: The TFEQ showed statistically significant differences in several areas when comparing the G test pass group (GP group) to the G test fail group (GF group). Three-km running time was significantly faster in the GP group than in the GF group. Physical activity levels were higher in the GP group compared to the GF group.

CONCLUSION: The TFEQ demonstrated utility in predicting whether cadets will pass or fail G-LOC testing. G test success for any cadet will require improvement in continuous eating behavior and physical fitness management. If variables affecting the G test are analyzed and applied to physical education and training through continuous research over the next two to three years, it is expected to have a greater effect on the success of the G test for every cadet.

KEYWORDS: G-LOC, physical activity, G tolerance, eating behavior, Korean Air Force.

Sung J-Y, Kim I-K, Jeong D-H. *Gravitational acceleration test results by lifestyle and physical fitness of air force cadets*. Aerosp Med Hum Perform. 2023; 94(5):384–388.

Air Force pilots must be able to overcome various physiological changes experienced when in the flight environment. These physiological changes include gravity-induced loss of consciousness (G-LOC), hypoxia, cognitive dissonance, hearing loss, and flight illusion.[13]

G-LOC occurs when acceleration forces produce a situation in which the cardiovascular system is unable to supply oxygenated blood to the regions of the nervous system that support consciousness.[19] According to research, approximately 8–20% of military aircrews have experienced G-LOC.[6] The Royal Air Force conducted two surveys on G-LOC within their military aircrew in 1987[21] and 2005,[9] with 19.3% and 20.1%, respectively, of aircrew reporting such an event at some point in their careers. In addition, deaths resulting from this condition have been reported.[23]

The Republic of Korea Air Force Academy (ROKAFA) has a special purpose educational institution that trains Republic of Korea Air Force (ROKAF) pilots for suitable physical fitness in order to prevent G-LOC. It is important for pilots to maintain a high muscle mass and low body fat composition.[4] Increasing muscle mass heightens peripheral resistance, which helps with preventing G-LOC.[7] Low body fat mass is also known to have a positive effect on G-force ($+G_z$) resistance. Also, according to the cyclical model of obesity and cognitive function, high body fat causes physiological changes that negatively affect cognitive function.[10] These cognitive deficits contribute to poor self-regulation, leading to unhealthy eating behavior and low physical activity.[2]

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This manuscript was received for review in July 2022. It was accepted for publication in January 2023.

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DOI: https://doi.org/10.3357/AMHP.6155.2023

Consequently, low body fat composition is an important factor for pilots to have $+G_z$ tolerance, accurate situational judgment during flight, and health. Therefore, it is important to maintain proper nutritional management practices that directly impact body fat mass, including eating habits and physical activity. Nutrition management practices are influenced by many factors, such as culture, beliefs, self-efficacy, nutrition knowledge, and eating behavior.[3] Nutritional knowledge is used in other various fields as well, such as in the army[16] or athletics.[11]

Nutrition is a key component of operational preparation that must be maintained by military personnel.[15] It is an important factor for all branches of the military, including air forces and particularly for pilots, who consume a lot of energy. Eating behavior must be evaluated and for this, the Three-Factor Eating Questionnaire (TFEQ: Questionnaire for comparison of eating behavior[24]) can be used. We expected that ROKAF cadets with a lower TFEQ score, higher physical activity, and higher physical strength would perform better on G-LOC testing. However, no studies have investigated the relationship between G-LOC, physical activity, body composition, and the TFEQ on pilots and cadets. Therefore, the current study aimed to evaluate TFEQ, body composition, physical activity, and physical strength surveys as being new predictors of success or failure in G-LOC tolerance; through this, we also examined the TFEQ of ROKAF cadets and assessed the relationships between eating behavior, body composition, physical activity, physical strength, and G-LOC.

METHODS

Subjects

This study was carried out on 138 fourth-year cadets from ROKAFA, who conducted the G test in 2021. Subjects voluntarily signed the consent form after hearing the explanation of the study. Study subjects were classified into non-LOC (G test pass group: GP) and LOC (G test fail group: GF) groups according to G test results.

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the 21st–22nd Institutional Bioethics Committee (ASMC-21-IRB-006) of the Air Force Aerospace Medical Center.

Equipment and Materials

The G test was performed using high-speed centrifugal gondolas (ETC, USA), located at the Air Force Aerospace Medical Center. Subjects sat in cockpit-shaped seats and performed a G test for 30 s at 5 G acceleration. Immediately after the start, the gondola started rotating at a speed of 0.8 G and accelerated to 5 G as soon as the participant pulled the lever directly. The measurement ended 30 s after the start, or when the subject pushed the lever himself or lost consciousness due to G-LOC. The criteria for G-LOC were met when the participant's upper body was bent forward, eyes were closed, jaw muscles were relaxed, and mouth was open. Prior to the start of the G test, instructors with more than 20 yr of pilot experience conducted training on postures, breathing methods (anti-G training maneuvers), and precautions required for the G test.

Eating behavior was investigated using the TFEQ.[22,24] This is a 51-item questionnaire composed of three subscales measuring "restraint" (i.e., cognitive control of eating behavior, 21 items), "disinhibition" (i.e., the susceptibility to eating in response to emotional factors and sensory cues, 16 items), and "hunger" (i.e., the susceptibility to eating in response to feelings of hunger, 14 items).

The questions on physical activity (International Physical Activity Questionnaires–Short Form) were modified for this study. Survey questions were based on a short questionnaire on physical activity.[1] The reliability of the questionnaire was evaluated through a pre-experimental run conducted by researchers. The pre-experimental data indicated that the test reliability coefficient of the survey was suitable ($r = 0.84 – 0.96$).

Body composition measurements were conducted for one week before the G test. Body composition was measured at 07:00 to ensure an empty stomach. Weight (kg), skeletal muscle mass (%), body fat mass (kg), and body mass index (kg/m^2) were measured using an Inbody 720 (Biospace Cop, Seoul, Republic of Korea) ($r = 0.87 – 0.99$). A physical fitness test, based on the physical fitness test events of the Ministry of National Defense of Korea, was conducted in the afternoon of the same day. The test included 3 km of running, push-ups, and sit-ups.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (version 25.0, Windows). All data are expressed as the mean ±SD value. Independent *t*-tests were used to compare the differences between the G test pass and fail groups. Spearman's statistical calculation of the ranking correlation coefficient was used to analyze the correlation between the TFEQ (restraint, disinhibition, hunger), G test, body composition, and physical activity. Statistical significance was set at $P \leq 0.05$.

RESULTS

During the study, 79 people passed the G test (GP), and 59 people failed (GF). In terms of body composition, cadets in the GP group had higher body weight, skeleton mass, and body mass index when compared to those in the GF group. GF cadets also had higher body fat mass, but the differences were not significant (**Table I**).

The GF group scored statistically higher in the TFEQ when compared to the GP group. With regard to restraint, the scores were 5.16 ± 4.78 for GP and 8.34 ± 5.51 for GF ($P < 0.001$). Regarding disinhibition, the scores were 5.94 ± 3.46 for GP and 7.92 ± 5.05 for GF ($P < 0.001$). Regarding hunger, the scores were 4.86 ± 3.62 for GP and 7.25 ± 5.06 for GF ($P < 0.001$) (**Table II**).

Table I. Subjects Characteristics.

FACTOR	GP (n 79)	GF (n 59)	t	p
Age (years)	23.7 ± 0.7	23.4 ± 0.8	0.953	0.943
Height (cm)	175.5 ± 4.9	174.9 ± 4.9	0.684	0.954
Body weight (kg)	72.27 ± 7.32	70.29 ± 7.39	1.165	0.786
Skeletal muscle mass (kg)	35.23 ± 3.86	33.94 ± 3.59	1.992	0.718
Fat mass (kg)	10.44 ± 2.86	10.57 ± 2.99	−0.268	0.796
Body fat (%)	14.40 ± 3.46	14.92 ± 3.58	−0.863	0.614
Body mass index (kg/m^2)	23.43 ± 1.78	22.93 ± 1.92	1.560	0.677

Values expressed as mean ± *SD*.
* P < 0.05, † *P* < 0.001, ‡ P < 0.01 vs GP by t-test; GP, G test passed; GF, G test failed.

Table II. Results of Three-Factor Eating Questionnaire and Physical Fitness Measurements.

FACTOR	GP (n 79)	GF (n 59)	t	p
Restraint	5.16 ± 4.78	8.34 ± 5.51†	1.378	<0.001
Disinhibition	5.94 ± 3.46	7.92 ± 5.05†	2.581	<0.001
Hunger	4.86 ± 3.62	7.25 ± 5.06†	1.563	<0.001
3km running (min.sec)	10.52 ± 3.97†	11.59 ± 2.07	2.030	<0.001
Push up (rep)	95 ± 18	91 ± 19	1.162	0.770
Sit up (rep)	95 ± 21	90 ± 24	1.185	0.659

Values expressed as mean ± *SD*.
* P < 0.05, † *P* < 0.001, ‡ P < 0.01 vs GP by t-test; GP, G test passed; GF, G test failed; TFEQ, Three-factor-eating-questionnaire.

Running time was significantly faster ($P < 0.001$) in the GP group (10.52 ± 3.97) than in the GF group (11.59 ± 2.07). Push-ups and sit-ups were higher in GP cadets than in GF cadets, but the difference was not statistically significant (Table II). Physical activity levels were higher in the GP group compared to the GF group: vigorous activity (min/d), GP: 98.86 ± 47.50, GF: 70.84 ± 55.18 (P = 0.009). Moderate to light activity was higher in the GP group than the GF group. Lying down and sleeping levels were higher in the GP group, whereas sitting levels were higher in the GF group. Finally, for total number of meals, the GF group had higher levels than the GP group: lunch (d/wk), GP: 6.72 ± 0.79, GF: 6.27 ± 1.37 ($P < 0.001$). The rest of the factors showed no statistically significant differences (**Table III**).

In relation to the G test, correlation analysis was as follows: −0.216 (P = 0.011) for disinhibition, −0.168 ($P < 0.048$) for skeletal muscle mass, −0.173 (P = .044) for running, −0.252 (P = 0.003) for vigorous activity (raps/week), −0.263 (P = 0.002) for vigorous activity (mins/day), 0.157 (P = 0.040) for sitting, and −0.203 (P = 0.017) for lunch. Restraint showed a significant correlation with having eaten breakfast: 0.174 (P = 0.041). Hunger had no significant correlations. (**Table IV**).

DISCUSSION

Air force pilots are affected by six acceleration axes during flight.[5] The lower inertial force can be quantified by gravity (G-force). Hemodynamic variables are affected in hypergravity environments, in which the hydrostatic pressure generated by the G-force causes blood to flow toward the lower body.[17,25] For a pilot to withstand this gravitational acceleration requires high physical strength at an athletic level.

The G test results by body composition did not show any significant differences in any of the factors. However, the GP group showed higher weight and skeletal muscle mass than the GF group, as well as lower body fat mass and body fat percentage. The fact that skeletal muscle mass is required for passing the G test[8,12,20] supports the results of this study. Increased muscle mass heightens peripheral resistance to loss of consciousness due to elevated blood pressure.[7] Muscle improves G resistance by facilitating better blood supply to the brain; it does this by increasing the ejection of blood in the left ventricle of the heart and decreasing blood flow to the lower extremity, thus contracting blood strongly, similarly to an anti-G suit. In addition, increased muscle contractile force and respiratory muscle development prevent loss of consciousness by strengthening the effectiveness of the anti-G training maneuver.[12,14] Consequently, Metzler[19] reported that it is important to design a program that considers the balance between muscle training and aerobic training to increase the G resistance of fighter pilots.

In addition, physical activity and proper eating behavior are essential for maintaining a body composition suitable for

Table III. The Result of Physical Activity Questionnaires and Diet.

FACTOR	GP (n 79)	GF (n 59)	t	p
Vigorous Activity (Raps/Week)	4.02 ± 2.25	2.79 ± 2.48	3.034	0.304
Vigorous Activity (Mins/Day)	98.86 ± 47.50‡	70.84 ± 55.18	3.179	0.009
Moderate Activity (Raps/Week)	1.49 ± 1.95	1.38 ± 1.88	0.314	0.727
Moderate Activity (Mins/Day)	40.25 ± 18.01	43.55 ± 28.03	−0.366	0.196
Light Activity (Raps/Week)	1.96 ± 1.54	2.01 ± 1.34	−0.130	0.605
Light Activity (Mins/Day)	25.48 ± 51.76	30.25 ± 52.84	−0.531	0.419
Sitting (Mins/Day)	327.21 ± 186.96	390.16 ± 162.03	−2.070	0.702
Lying (Mins/Day)	485.72 ± 150.06	455.08 ± 121.56	1.284	0.436
Sleeping (Mins/Day)	358.48 ± 66.54	340.17 ± 56.97	1.699	0.628
Breakfast (Days/Week)	6.26 ± 1.45	6.10 ± 1.56	0.635	0.576
Lunch (Days/Week)	6.72 ± 0.79†	6.27 ± 1.37	2.416	<0.001
Dinner (Days/Week)	6.68 ± 0.99	6.51 ± 1.19	0.939	0.939

Values expressed as mean ± *SD*.
* P < 0.05, † *P* < 0.001, ‡ P < 0.01 vs GP by t-test; GP, G test passed; GF, G test failed.

Table IV. Coefficients for Pearson's Correlation between G test and Factors.

FACTOR	G TEST	RESTRAINT	DISINHIBITION	HUNGER
G test	–	−0.117 (0.170)	−0.216* (0.011)	−0.133 (0.120)
Body weight(kg)	−0.133 (0.120)	−0.045 (0.596)	0.003 (969)	−0.033 (0.698)
Skeletal muscle mass (kg)	−0.168* (0.048)	−0.079 (0.356)	−0.063 (0.465)	−0.078 (0.365)
Fat mass(kg)	−0.095 (0.269)	−0.088 (0.307)	−0.156 (0.068)	−0.111 (0.194)
Body fat(%)	0.023 (0.789)	0.033 (0.698)	0.137 (0.110)	0.065 (0.449)
Body mass index (kg/m^2)	−0.133 (0.121)	−0.030 (0.724)	0.010 (0.909)	−0.005 (0.957)
3km running	−0.173* (0.044)	−0.025 (0.769)	−0.026 (0.761)	−0.021 (0.806)
Push up	−0.099 (0.247)	0.046 (0.591)	0.007 (0.938)	0.043 (0.614)
Sit up	−0.101 (0.238)	0.001 (0.989)	−0.034 (0.691)	0.039 (0.648)
Vigorous Activity (Raps/Week)	−0.252‡ (0.003)	0.120 (0.162)	−0.044 (0.966)	0.068 (0.426)
Vigorous Activity (Mins/Day)	−0.263‡ (0.002)	0.072 (0.402)	0.035 (0.683)	0.036 (0.678)
Moderate Activity (Raps/Week)	−0.027 (0.754)	0.021 (0.805)	−0.084 (0.329)	0.010 (0.904)
Moderate Activity (Mins/Day)	0.031 (0.715)	0.055 (0.519)	0.012 (0.891)	0.056 (0.516)
Light Activity (Raps/Week)	0.011 (0.897)	−0.016 (0.857)	0.008 (0.926)	−0.002 (0.981)
Light Activity (Mins/Day)	0.045 (0.596)	0.064 (0.456)	0.036 (0.677)	0.063 (0.460)
Sitting (Mins/Day)	0.157* (0.040)	−0.056 (0.514)	−0.039 (0.647)	−0.017 (0.846)
Lying (Mins/Day)	−0.109 (0.201)	−0.082 (0.339)	−0.073 (0.395)	−0.053 (538)
Sleeping (Mins/Day)	−0.144 (0.092)	0.058 (0.501)	0.012 (0.891)	0.072 (0.401)
Breakfast (Days/Week)	−0.054 (0.526)	0.174* (0.041)	0.109 (0.202)	0.157 (0.066)
Lunch (Days/Week)	−0.203* (0.017)	−0.004 (0.959)	0.063 (0.463)	0.022 (0.798)
Dinner (Days/Week)	−0.080 (0.35.)	−0.024 (0.780)	0.038 (0.662)	−0.002 (978)

***** $P < 0.05$, † $P < 0.001$, ‡ $P < 0.01$ vs G test by Pearson's correlation; TFEQ, Three-factor-eating-questionnaire.

pilots, meaning preventing obesity and keeping the body healthy.[18] According to Shiozawa et al.,[22] the most commonly studied aspects of eating behavior are: restraint, or the conscious restriction of food intake as a means of weight control; disinhibition, or the tendency to overeat in response to various stimuli; and hunger, or the tendency to eat in response to perceived physiological needs. Disinhibition and hunger are associated with obesity in both youths and adults.[24] Air force cadets must dedicate special attention to engaging in a high amount of physical activity and regulating their eating habits in order to maintain the necessary body composition. In this study, the GP group showed higher scores in the eating habit survey and had higher physical activity than the GF group. However, since this is only the result of using the eating habit questionnaire and the physical activity questionnaire, subsequence studies should involve calculation of the actual intake, activity, and energy metabolic rate of cadets using measurement equipment.

Through this study, we tried to find out the relationship between diet and G-LOC, which has not been attempted before. Based on this study, the TFEQ showed promise for utility in pilot selection for high-G aircraft. Further research is needed to validate and refine its utility in improving and maintaining pilot health and quality of life. The TFEQ may serve as a useful tool in aircraft selection for pilots-in-training and discrimination between high-G and low-G aircraft platforms. This would help reduce wash-out rates and save training dollars. Therefore, ROKAFA may apply systematic education, management of nutrition and eating habits, and physical training to the pilot training programs.

Eating behavior is a complex concept that involves much more than eating "healthy" foods. As human technology develops and the aerospace industry continues to expand, sports science will play a very important role in our understanding of health. Therefore, research on all aspects of health—including diet, sleep, and daily life—is very important and is not limited to the current study of pilots' muscular strength or fatigue. In this study, physical body composition and related body factors showed results similar to those of previous studies. In addition, it was found that an eating habit survey, such as the TFEQ, could also affect the G test. Therefore, proper nutrition education and prescription should be continued. Based on this study, further research is needed to preserve pilots' lives and improve their quality of life by investigating cadets and pilots' eating habits, nutritional knowledge, nutritional intake, activity, and energy metabolism. If the results of this study are applied to prospective pilots and further studies are carried out, it can be used as a discriminating material for selecting air force pilots and can provide more suitable options for specific aircraft training under high G vs. low G. These results could be a way to save both time and training costs. Therefore, ROKAFA feels that systematic education and management of nutrition and eating habits as well as the physical strength of air force cadets is necessary to train pilots.

ACKNOWLEDGMENTS

We would like to thank the officials of the Air Force Aerospace Medical Center for their help in the research. Also, we would like to thank Editage (www.editage.co.kr) for English language editing.

Financial Disclosure Statement: This research received no external funding. The authors declare no conflict of interest.

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