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Original Article

Effects of the optimal flexor/extensor ratio on G-tolerance

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Abstract. [Purpose] The aim of this study was to examine the flexor/extensor ratio of the knee joints and compare it with the results of Korean Air Force students in G-tolerance test. [Subjects and Methods] The body composition of Korea Air Force students (n=77) was measured by an impedance method. A muscular function test was performed using a Humac Norm (USA) at angular speeds of 60°/sec and 240°/sec and an isokinetic muscular function test was also conducted. [Results] In the failed C and passing groups, muscle mass and fat percentages were significantly higher than those of students in the failed A group. The BMI of the failed C and passing groups were significantly higher than that of the failed A group. The group that passed had a significantly higher value of left knee 60°/sec flexion peak torque than the failed B group. Moreover, the total work of left knee extension of the failed C group and the passing group was significantly higher than that of the failed A group. The C group and the passing group had significantly higher values of the trunk 60°/sec flexor/extensor ratio than the failed A group, and the total work flexor/extensor ratio of the passing group was significantly higher than that of the failed A group. [Conclusions] Based on these results, balance the right and left knee flexor/extensor ratio, and a high flexor/extensor ratio of the trunk are required to endure a high G-tolerance test (+6G/30 sec). Moreover, an improvement in the maximum muscular strength is necessary to endure a situation of rapidly increasing acceleration in the early stage.

Key words: G-tolerance, Acceleration, Isokinetic

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INTRODUCTION

Recent developments in aircraft technology have significantly contributed to the development of high performance fighter aircraft, and fighter pilots are placed under a lot of stress in extreme gravity acceleration when performing a lot of tasks[1)]. Continuous stress on pilots can result in a decreased sense of the static organ and spatial disorientation due to a maladjusted condition of the vestibular organ, caused by an illusion phenomenon. Furthermore, a situation of rapidly increasing gravity (+6–9G) causes excessive inflammation in the human body, which lacks immediate reactions and coping mechanisms against psychological and emotional situations[2)]. Exposure to a high gravity condition can lead to a decreased blood flow and G-induced loss of consciousness (G-LOC), causing temporary loss of brain function, due to declined peripheral vision. Even though the timing of exposure in 3-dimensional space movement and positive or negative acceleration stress during flight varies according to each person, the role of physical strength in preventing G-LOC during flight is very significant.

In general, pilots perform the L1 maneuver, which maximizes the human response, to tolerate temporary disruption of cerebral blood flow[3)]. Moreover, as a method for maximizing the L1 maneuver, pilots always perform weight training to improve their muscle strength[4, 5)].

It is known that using isokinetic equipment is the most effective method of measuring maximum strength to determine the

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efficiency of training with respect to muscular function within the 60–240°/sec or 30–300°/sec range[6, 7]. That is, with use of isokinetic movement devices, peak torque, muscle power, and muscular endurance can be measured and improved at 60°/sec, 180°/sec, and 240°/sec angular velocity, respectively. However, when trainers don't consider the muscular ratio between the antagonistic muscle and the agonist muscle and only focus on improvement in muscle power and endurance, it can cause an injury. Especially, when the muscular ratio of knee extension and flexion is lower than 60%, there is the possibility of causing pain or rupturing nearby ligaments and cartilage. In general, athletes can achieve approximately 80% of the muscular ratio, which is necessary for peak torque, muscle power, and muscular endurance[8]. An appropriate and well-balanced muscular ratio of the right and left sides for pilots experiencing extreme gravity is considered to be a muscle ratio of 80%.

In particular, exerting maximum muscular strength can be a factor that reduces G-LOC in situations of rapidly increasing acceleration. Therefore, this research examined muscular ratios of the knee and trunk and explored the influence on the success of Korea Air Force Academy students in gravity acceleration (+6G/30 sec) tolerance tests.

SUBJECTS AND METHODS

In this study, through a muscular function test, the muscular ratio between flexion and extension was examined, after obtaining the informed consent and voluntary participation of 80 Korea Air Force Academy male students who were preparing for air missions. All subjects underwent an acceleration test (+6G/30 sec) and were classified as the passing and fail groups. The fail group was further divided into 3 groups according to the failure time: within 10 seconds (A group), 20 seconds (B group), and 30 seconds (C group). Three out of the 80 subjects were excluded from the study because of personal issues and incomplete consent; ultimately, 77 subjects participated in this study. All experimental procedures were explained in detail to all of the subjects, who then signed a written informed consent statement. The study was approved by the Korea Air Force Medical Center Institutional Review Board, and it was conducted in accordance with the Declaration of Helsinki.

Height and weight were measured %fat, BMI, and body composition of the left and right leg muscle amounts were determined using a body composition analyzer Inbody 729 (Bio space, Korea). For muscle function evaluation, the subjects were tightly fastened in a Humac, and isokinetic testing of left and right knee flexion and extension was performed at angular velocities of 60 and 240°/sec. The test items were peak torque, body weight to peak torque ratio and body weight to total work ratio.

A G-tolerance test is performed as one of the eligibility criteria for entry into the flight training program at the Air Force Aerospace Medical Center. The subjects were exposed to +6G at a rapid acceleration of +1G per second, for a maximum of 30 seconds. While they were exposed to the acceleration, the subjects performed the L1 maneuver, a tolerance promotion method of positive acceleration and they were fully skilled at a certain level of the L1 maneuver. When they were exposed to the acceleration, the subjects were not wearing an Anti-G suit. Subjects were classified into the failed group and the successful group based on whether they had loss of consciousness or not while they were exposed to acceleration. In the case of the failed group, once the subjects failed the test, the time (sec) of their failure was recorded.

The mean and SD (standard deviation) of all the outcome measures were calculated using SPSS version 20.0. One-way ANOVA was conducted on the body composition, muscle function test, and acceleration test results, and Duncan's post-hoc test was also conducted. A statistical significance level of α=0.05 was used.

RESULTS

All physical characteristics of the subjects in this study are listed in Table 1. The muscle mass and fat percentage of the failed C group and passing group were significantly higher than those of the failed A group ($p<0.05$). Moreover, the failed C group and the passing group had higher BMI values than the failed A group ($p<0.05$). Knee 60°/sec peak torque is displayed in Table 2. Knee 60°/sec left flexion peak torque of the failed C group was significantly higher than that of the failed B group ($p<0.05$).

The results of knee 240°/sec peak torque of the subjects are presented in Table 3. the failed C group and the passing group showed higher 240°/sec left knee extension peak torque values than the failed A group ($p<0.05$). The total work of left knee extension in the failed C group and the passing group was significantly higher than that of the failed A group ($p<0.05$), and the total work of right knee flexion of the failed C group was significantly higher than that of the failed A group ($p<0.05$).

The knee 240°/sec left flexor/extensor ratio of the passing group was significantly lower than that of the failed A group ($p<0.05$), and the right extensor/flexor ratio of the failed B group was significantly lower than that of the failed A group ($p<0.05$) in Table 4.

The passing group showed a significantly higher trunk 60°/sec extensor/flexor ratio than the failed A group ($p<0.05$), and the total work extensor/flexor ratio of the failed B group was significantly higher than that of the failed A group. The trunk 120°/sec extensor/flexor ratio of the failed C group and the passing group was significantly higher than that of the failed A group, and the total work extensor/flexor ratio of the failed C group was significantly higher than that of the failed A group (Tables 5–7).

Table 1. Characteristics of the participants

Variable	FG (n=40)			PG (n=37)	post hoc
	A (n=18)	B (n=10)	C (n=12)		
Age (years)	21.6 ± 0.7	21.5 ± 1.0	21.8 ± 0.8	21.7 ± 0.9	
Height (cm)	176.3 ± 5.2	175.1 ± 4.5	176.4 ± 6.0	174.1 ± 4.5	
Weight (kg)	67.3 ± 9.4	71.3 ± 8.5	73.5 ± 8.4	70.7 ± 8.1	
Muscle mass (kg)	33.1 ± 4.2	34.6 ± 4.1	36.0 ± 3.7	34.3 ± 3.6	A<C
Fat mass (kg)	9.0 ± 3.4	10.6 ± 3.1	10.5 ± 4.0	10.7 ± 3.8	
BMI (kg/m^2)	21.2 ± 2.4	23.2 ± 2.4	23.6 ± 1.9	23.3 ± 2.2	A<C,D
%fat (%)	13.2 ± 3.5	14.8 ± 3.2	14.0 ± 4.1	14.9 ± 3.9	
%fat Visceral (%)	0.8 ± 0.0	0.8 ± 0.0	0.8 ± 0.0	0.8 ± 0.0	A<C,D

Mean ± SD, FG: fail group, PG: pass group.
p<0.05. A; 10 sec, B; 20 sec, C; 30 sec, D; PG

Table 2. Change of knee 60°/sec peak torque

Variable			Extensors		Flexors	
			left	right	left	right
PT (N/m)	FG	A	159.4 ± 38.0	175.0 ± 34.1	114.2 ± 21.6	119.8 ± 24.9
		B	160.3 ± 19.5	168.8 ± 25.2	109.5 ± 17.8	115.9 ± 15.1
		C	180.3 ± 37.4	180.9 ± 34.5	128.3 ± 25.5	128.8 ± 19.7
	PG		169.2 ± 26.5	176.8 ± 23.7	122.4 ± 21.8	124.7 ± 19.0
	post hoc		NS	NS	B<C	NS
PTBW (%)	FG	A	235.2 ± 30.9	259.0 ± 27.5	169.3 ± 21.3	177.8 ± 25.3
		B	226.8 ± 32.4	237.8 ± 32.6	155.9 ± 32.2	164.0 ± 23.7
		C	248.1 ± 42.4	248.6 ± 28.5	176.4 ± 27.0	177.5 ± 16.9
	PG		240.8 ± 34.4	251.2 ± 29.0	193.9 ± 26.7	176.9 ± 20.4
	post hoc		NS	NS	NS	NS
WR (N/m)	FG	A	157.7 ± 44.2	174.1 ± 37.7	126.3 ± 24.0	133.9 ± 27.3
		B	162.7 ± 17.0	173.1 ± 30.2	121.8 ± 20.5	130.2 ± 15.0
		C	185.7 ± 38.9	186.7 ± 29.2	140.3 ± 27.0	144.4 ± 22.8
	PG		173.0 ± 28.7	180.2 ± 27.1	133.2 ± 23.8	138.9 ± 21.2
	post hoc		A<C	NS	NS	NS
WRBW (%)	FG	A	231.9 ± 38.2	257.2 ± 31.3	187.8 ± 26.2	198.6 ± 29.8
		B	230.3 ± 30.8	244.1 ± 40.5	173.3 ± 37.2	184.4 ± 26.6
		C	256.3 ± 45.4	256.3 ± 27.6	192.3 ± 28.4	198.8 ± 22.6
	PG		245.8 ± 35.7	255.7 ± 31.0	189.1 ± 27.7	197.0 ± 22.1
	post hoc		NS	NS	NS	NS

Mean ± SD; PT: peak torque; PTBW: peak torque per body weight; WR: work per repetition; WRBW: work per repetition body weight
post hoc test: p<0.05 A, 10sec; B, 20sec; C, 30sec; D; PG

DISCUSSION

This research studied the effect of body composition and muscular function (knee extensor/flexor ratio) on the G-tolerance (+6G/30 sec) of 77 male students of the Korea Air Force Academy. When the endurance time against gravity was prolonged or subjects successfully endured high gravity, lean body mass-related factors of body composition were significantly high. Moreover, in the muscular function test, the right and left difference between the knees at 240°/sec, one of the factors of muscle endurance was low, and the maximum muscular ratio of the trunk was high and significant.

High acceleration of gravity can cause negative effects on the human body, not only on the cardiovascular and central nervous system, but also on the functioning of the pulmonary circulation. These negative influences can lead to fatal accidents among fighter pilots[9]. Fundamentally, fighter pilots perform anti-G straining L1 maneuvers, which is one of the methods of anti-G straining maneuvers (AGSM). This method is known to be optimal, and using it, pilots can endure acceleration of

Table 3. Change of knee 240°/sec peak torque

Variable			Extensors		Flexors	
			left	right	left	right
PT (N/m)	FG	A	88.2 ± 18.1	94.1 ± 20.0	79.6 ± 13.4	80.4 ± 16.3
		B	96.8 ± 17.6	97.7 ± 12.5	76.8 ± 8.9	77.3 ± 7.4
		C	103.8 ± 22.1	105.0 ± 23.4	84.4 ± 12.5	87.4 ± 11.8
	PG		100.2 ± 16.1	98.2 ± 18.5	81.2 ± 15.3	83.1 ± 15.3
	post hoc		A<C, D			
PTBW (%)	FG	A	130.7 ± 20.1	139.3 ± 18.5	118.7 ± 17.7	119.2 ± 17.6
		B	136.4 ± 28.3	138.2 ± 23.2	109.4 ± 20.3	109.4 ± 19.1
		C	143.5 ± 29.3	145.0 ± 31.3	116.8 ± 16.3	121.0 ± 15.6
	PG		141.9 ± 17.1	139.0 ± 20.9	115.1 ± 16.8	117.8 ± 17.6
	post hoc					
TWD (N/m)	FG	A	1,961.1 ± 349.0	2,053.5 ± 331.6	1,881.9 ± 310.3	1,834.9 ± 354.4
		B	2,216.0 ± 340.9	2,220.7 ± 257.4	1,852.7 ± 132.1	1,831.5 ± 223.6
		C	2,259.5 ± 375.4	2,299.6 ± 302.5	2,096.4 ± 251.5	2,083.2 ± 240.2
	PG		2,192.0 ± 318.4	2,241.3 ± 363.2	1,971.5 ± 353.5	1,974.9 ± 305.4
	post hoc		A<C, D			A<C
TWDBW (%)	FG	A	2,913.8 ± 371.3	3,017.0 ± 411.1	2,807.9 ± 433.5	2,724.8 ± 410.0
		B	3,129.5 ± 491.4	3,134.5 ± 357.5	2,634.9 ± 385.7	2,614.2 ± 525.4
		C	3,126.4 ± 498.0	3,183.2 ± 424.4	2,903.2 ± 358.1	2,895.3 ± 433.7
	PG		3,111.1 ± 337.3	3,176.4 ± 370.9	2,795.2 ± 397.4	2,800.8 ± 318.2
	post hoc					

Mean ± SD; PT: peak torque; PTBW: peak torque per body weight; TWD: total work done; TWDBW: total work done per body weight
post hoc test: $p<0.05$; A, 10sec; B, 20sec; C, 30sec; D, PG

gravity without loss of consciousness[10].

Gravity acceleration training is particularly difficult because pilots can experience G-LOC due to inexperience with the L1 maneuver against instantaneously increasing gravity. Therefore, for successful gravity acceleration training (+6G/30 sec), the role of AGSM is highlighted more than the physical ability. However, other studies have emphasized that physical features and strength are very important and even essential. Epperson et al. reported that 12 weeks of weight training could intensify endurance of gravity acceleration, but until now, there has been little research on this issue[11]. In particular, as AGSM is performed, based on the basic physical strength, physical and muscular strength are necessary for people working in the air. The results of the present research show that the subjects withstanding prolonged gravity acceleration, or those belonging to the passing group, had relatively higher muscle mass and BMI than the other subjects. These results indicate that pilots need a relatively higher muscle mass and BMI to endure rapidly increasing acceleration of gravity (an increase of +1G per second).

The isokinetic muscular function exercise test can accurately assess the muscle strength of diverse joints. The knee and trunk are most commonly used for maximum muscular measurement of the lower extremity and lumbar muscles[12], and these muscles are most commonly used when enduring high gravity acceleration.

In order to measure the muscular strength, isokinetic strength evaluation of the knee using an isokinetic strength evaluation device is important[12]. This is because while demonstrating great power, as one of the pivotal muscles for all movements, knees are surrounded by the largest muscle. Moreover, when experiencing gravity acceleration, the femoral muscle's isometric muscle power and L1 maneuver play a pivotal role. According to the results of the present study the imbalance between the left and right sides in the failed C group and the passing group was the lowest and the muscular ratio was the most stable. Furthermore, the differences between the left and right sides and changes in the muscular ratio, an indicator of muscle endurance at 240°/sec in the passing group indicated that this group had the best balance between the left and right sides and the most stable muscular ratio. These results indicate that the left and right femoral balance and an adequate ratio of flexion and extension are required to endure rapidly increasing gravity in the early stage. After that, an improvement in muscle endurance, which the pilots can maintain for a long time, is needed to tolerate high acceleration of gravity for 30 seconds.

The trunk also plays an important role in exposure to high acceleration. This is because acceleration of gravity occurring from head to toe rapidly transfers the blood flow into the chest, abdomen, and legs. Therefore, the blood flow decreases in the direction of the chest and upper body, circumferential orbital blood pressure significantly reduces and blood supply to the brain and optic nerves fail. In the end, pilots experience G-LOC[13]. It is believed that lumbar and femoral muscle strength

Table 4. Change of knee left/right for extensor/flexors ratio

Variable			Left	Right
Extensor/flexors 60°/sec	FG	A	72.3 ± 7.1	68.4 ± 8.0
		B	68.5 ± 9.5	69.1 ± 6.6
		C	71.8 ± 9.8	71.7 ± 8.0
	PG		72.8 ± 9.4	70.7 ± 7.5
	post hoc			
Extensor/flexors 240°/sec	FG	A	92.1 ± 15.3	97.1 ± 15.3
		B	81.5 ± 14.3	85.1 ± 11.6
		C	83.2 ± 12.9	94.5 ± 15.6
	PG		81.7 ± 12.8	90.5 ± 13.6
	post hoc		A>D	A>B

Mean ± SD, FG: fail group; PG: passing group
post hoc test: $p<0.05$; A, 10sec; B, 20sec; C, 30sec; D, PG

Table 5. Change of trunk 60°/sec peak torque

Variable			Extensors	Flexors
PT (N/m)	FG	A	286.3 ± 58.9	253.2 ± 58.3
		B	284.9 ± 36.9	247.5 ± 29.8
		C	297.9 ± 43.3	270.7 ± 43.0
	PG		286.7 ± 52.5	256.7 ± 50.3
	post hoc			
PTBW (%)	FG	A	425.2 ± 68.9	374.4 ± 65.2
		B	400.8 ± 38.9	347.7 ± 22.8
		C	413.8 ± 64.8	375.9 ± 64.2
	PG		406.8 ± 61.5	362.8 ± 52.4
	post hoc			
TWD (N/m)	FG	A	268.8 ± 58.9	222.1 ± 56.9
		B	265.4 ± 39.8	222.8 ± 36.6
		C	276.7 ± 62.6	243.2 ± 44.1
	PG		268.0 ± 46.3	229.2 ± 45.4
	post hoc			
TWDBW (%)	FG	A	398.7 ± 66.8	327.1 ± 58.0
		B	373.9 ± 54.5	312.4 ± 35.6
		C	383.8 ± 85.0	338.1 ± 60.4
	PG		380.7 ± 57.9	324.2 ± 47.6
	post hoc			

Mean ± SD; PT: peak torque, PTBW: peak torque per body weight; TWD: total work done; TWDBW: total work done per body weight

Table 6. Change of trunk 120°/sec peak torque

Variable			Extensors	Flexors
PT (N/m)	FG	A	321.3 ± 83.1	270.0 ± 73.5
		B	317.0 ± 78.3	270.0 ± 58.3
		C	331.4 ± 56.1	318.9 ± 65.6
	PG		308.4 ± 76.7	285.9 ± 70.6
	post hoc			
PTBW (%)	FG	A	473.3 ± 84.9	399.7 ± 84.3
		B	444.7 ± 101.9	380.3 ± 79.4
		C	464.5 ± 106.4	445.8 ± 108.6
	PG		435.6 ± 86.8	402.7 ± 72.5
	post hoc			
TWD (N/m)	FG	A	3,017.0 ± 724.1	2,854.7 ± 768.8
		B	2,968.8 ± 732.0	2,858.6 ± 439.1
		C	3,158.5 ± 803.9	3,131.0 ± 507.1
	PG		3,065.7 ± 562.6	2,927.2 ± 608.2
	post hoc			
TWDBW (%)	FG	A	4,468.4 ± 842.4	4,208.6 ± 752.0
		B	4,163.0 ± 884.4	4,009.4 ± 418.6
		C	4,368.5 ± 1059.8	4,337.6 ± 682.5
	PG		4,348.0 ± 662.2	4,135.4 ± 639.0
	post hoc			

Mean ± SD; PT: peak torque; PTBW: peak torque per body weight; TWD: total work done; TWDBW: total work done per body weight

Table 7. Change of trunk for extensor/flexors ratio

Variable			PT	TWD
Extensor/flexors 60°/sec	FG	A	92.1 ± 15.3	97.1 ± 15.3
		B	81.5 ± 14.3	85.1 ± 11.6
		C	83.17 ± 12.9	94.5 ± 15.6
	PG		81.7 ± 12.8	90.5 ± 13.6
	post hoc		A>D	A>B
Extensor/flexors 120°/sec	FG	A	85.5 ± 17.4	82.6 ± 11.3
		B	87.2 ± 12.4	84.6 ± 14.0
		C	96.7 ± 16.4	89.3 ± 8.3
	PG		94.7 ± 19.5	86.7 ± 16.7
	post hoc		A<C, D	A<C

Mean ± SD; PT, peak torque; TWD, total work done
post hoc test: $p<0.05$; A, 10sec; B, 20sec; C, 30sec; D, PG

and a high level of muscular endurance are needed in order to endure a high acceleration of gravity, provide blood supply to the upper body through the L-1 maneuver, and prevent transfer of blood flow to the legs. Lumbar joints including the waist area and abdominal muscles are quite important for creating the ideal power needed for all physical activities, and to show performance in all items of sports. The results of this study didn't show significant differences among the lumbar joints of the groups. In the case of the muscular ratio, there was no statistically significant difference, but the failed C group and the passing group tended to show higher values than the other groups. Thus, when the muscular ratio was high after exposure to high acceleration, it was considered to be more effective. This is because the failed group showed lack of power in maintaining muscle strength and an inaccurate L-1 maneuver in the early stage when a relatively lower muscle ratio can rapidly increase the acceleration with passage of time. Therefore, it is necessary for Korean Air Force Academy students to endure situations of high acceleration not only for balanced muscles and improvement of muscular endurance, but also for improvement of the maximum muscular strength.

In this study, the body composition and muscular function tests of 77 male students of the Korea Air Force Academy was investigated and the effects of muscular ratios on the success or failure of a gravity acceleration test (+6G/30 sec) were investigated. The amount of muscle and BMI in the passing group were significantly higher than those in the failed group. In the muscle function test, the passing group showed that knee joint maximum muscle strength and balance of the muscular ratio are more effective indices of G tolerance than other parameters.

Considering these results, it is necessary to have balance between the left and right knee joints, muscular ratio, and raise the muscular ratio of the lumbar joints to successfully endure a high gravity acceleration test (+6G/30 sec). Furthermore, improving the maximum muscle strength is necessary to tolerate a rapidly increasing acceleration situation in the early stage; hence, training for improving the muscle strength is also needed.

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