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A Study of Psychological Effects of Pilots Depending on the Different Environments between Actual and Simulated Flights

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Objective: This study aims to examine the psychological effects of pilots caused by the environmental differences between actual and simulated flights by measuring biochemical stress level and subjective stress level.

Background: Currently, the flight system of the air force suffers from several problems including a limited training area, increase of complex and tangled missions and rise in oil prices. In order to overcome these problems an L-V-C (Live, Virtual, Constructive) training system has been proposed as a solution. However, to establish the effective L-V-C training system, it is required to figure out the characteristics of each system first. Also we have to solve the problems which could occur when these systems are connected together.

Method: In order to measure the biochemical stress level of pilots, we investigated the differences in cortisol responses after actual and simulated flight training separately. Meanwhile, we conducted the questionnaire survey of about 40 pilots to identify the subjective stress level of pilots.

Results: There was significant difference in cortisol level between actual and simulated flight tasks. However, we found that there was no significant difference in pilots' feelings about two flight tasks.

Conclusion: The results from this study can be used as basis for the further research on not only how to decrease linkage errors of the L system and the V system but also how to make the L-V training system more practical.

Application: The results of the analysis might help to develop the Live-Virtual-Constructive (LVC) pilot training system.

Keywords: L-V-C training system, Pilot's psychological effect, Stress, Cortisol level, Stress

1. Introduction

The virtual environment is used in various areas including medical, industrial fields and pilot flight training, because the virtual environment offers very similar environment as the actual environment, and thus, has an advantage that it provides indirect experience to users (Han, 2011). Especially, an airplane simulator is a device embodying the same situation or manipulation as the actual airplane flight on the ground. The simulator is effectively used for pilot training, due to low flight accident risk, low cost and time saving (Hwang, 2000).

The air force also has been building a pilot training and evaluation system using the merits of such a simulator. A variety of researches are carried out to build a connected training environment (L-V-C training system) by using the Live, Virtual and Constructive system in which the air force has to actively cope with various combat environments in the 21st century's future warfare, as well as to develop individual training system recently. Figure 1 shows a diagram of the L-V-C training system: building a connected training environment through network technology and linkage technology in terms of individual L-V-C training system.

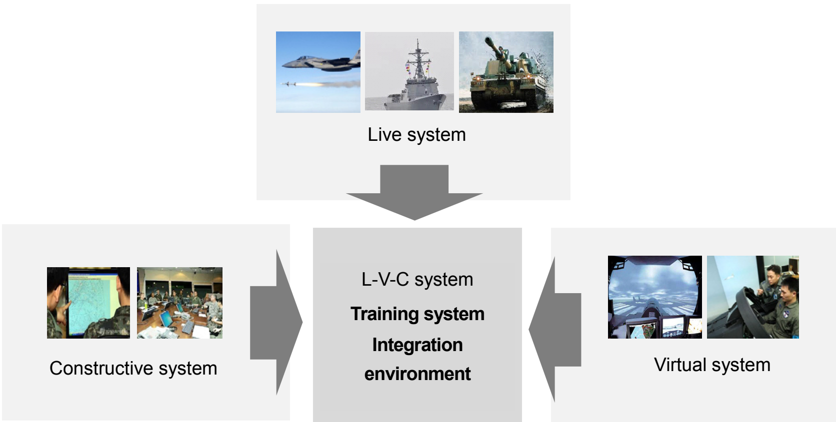

Figure 1. Live-Virtual-Constructive training system

In Figure 1, Live means training with actual military strengths like real fighters, vessels and tanks, which can conduct maneuvers. Virtual means training under the virtual situation of actual troops using the equipment composing of the same environment as the real environment like a simulator. Constructive is training with virtual troops under the virtual environment, and the Changgong and the Chunghae systems are included here (Kim, 2009; Kim et al., 2010). If one system is composed by linking systems with different environments, various linkage errors, such as the problem of embodiment completeness, physical and psychological differences depending on environmental differences and information delay, occur. Therefore, a study on analysis of errors that may occur upon identification of and linkage with different characteristics is essentially necessary. Through such a study, if linkage errors are reduced, and joint combat training, in which actual and fair training is possible, is operated, it is expected to acquire low cost and high efficiency under the actually connected training environment with merits and complemented demerits of each system (Kim et al., 2010).

This study focuses on the linkage of the two L system and V system among the L-V-C connected training environments. Also, this study conducts analysis on the differences of psychological burden felt by pilots, when the real combat plane (Live) and combat plane simulator (Virtual) environments are connected. Although, the simulator offers the environment similar to actual flight, pilots can experience environmental factors that the virtual environment has (lacking embodiment completeness, virtual motion sickness), and in the actual flight, they also experience various environmental factors (change in weather, instability on danger) that cannot be embodied in the virtual environment. This study identifies whether environmental differences between the two systems cause significant differences in psychological burden to pilots. The research on the analysis on such differences will provide a direction through which training with smaller errors between the systems can be conducted, although different systems are used, when actual training is conducted using the connected training system.

Stress is defined as non-specific responses that may occur within human body concerning external stimuli (Selye, 1979; Park and Kim, 2007), and is used in many fields as a tool to measure psychological responses according to external environmental factors. Stress includes extensive, abstract and subjective content in essence, and thus, measuring of stress is difficult. However, various methods to evaluate stress level are used (Park and Kim, 2007).

The method to measure stress level can be divided into two methods: First, a subjective method using interviews or questionnaires. This method can acquire relatively candid information, but there are some demerits like long measuring time and much reflection of individual subjectivity (Andre and Wickens, 1995; Quick, 1998; Park and Kim, 2007). Second, a method to actually measure physical signals like cardiac impulse, blood pressure, breath, temperature, movement of pupil and cortisol. The physiological method actually measuring physical signals can be divided into the physiological index looking into human body's physical change on stress, and biochemical index looking into chemical change like hormone secretion. To use the physiological index, a specific device is necessary, and measuring sensors are attached to human body. Therefore, there is a demerit in that the method gives restrictions to behaviors, but it is a relatively consistent and reliable method (Kamer, 1991; Tsang and Wilson, 1997; Park and Kim, 2007). The biochemical index is to measure the amount of neural transmitter like serum, saliva, urine and hormone secretion. This method is easier to measure than other methods, because the burden to experiment subjects is small during the experiment, and thus, the effect such as tentative stress increase on the experiment is small. With all these, the biochemical index is greatly used as the neuroendocrine reaction index on work stress in various recent studies (Kang et al., 2003). Especially, cortisol hormone has been used as a reliable bioindex indicating human's stress level (Levine et al., 2007). When a human is exposed to stress situation, CRF (corticotropin releasing factor) is released in the hypothalamic paraventricular nucleus, and the CRF stimulates anterior pituitary gland, and adrenal cortical stimulating hormone is secreted (Levine et al., 2007; Hellhammer et al., 2009). When stress continues, cortisol hormone is secreted, because hypothalamus-pituitary gland-adrenal axis is stimulated. The cortisol hormone can be sampled through saliva, blood and urine, and the method to sample the hormone through urine or saliva than the one through blood is used more in researches. The method to sample hormone within saliva does not need any special device or expert, and is easy not giving burden to experiment subjects. Therefore, the method has small effects on tentative stress on experiment, does not disturb work and reflects actual situation well, which can be the merits.

This study collected the saliva of pilots who finished flight training by each flight environment for the analysis of pilot stress, according to environmental differences between actual and simulated flights, analyzed cortisol, which is stress hormone, and judged the difference of stress level. This study identified the factors affecting psychological burden and conducted the questionnaire survey together for pilot's subjective opinion analysis.

Although the experiment is easy and has smaller burden to experiment subjects in terms of the cortisol analysis, there are several things to consider: First, cortisol level has daily cycle. Figure 2 shows the daily cycle of cortisol level. At 7:00 am, the highest level is shown, and the lowest level is exhibited at midnight. Therefore, there needs some control of the saliva sampling time.

Actually, pilot's flight training starts after the sunrise and finishes before sunset. In a special case, there are night flights conducted after the sunset. This experiment analyzed targeting actual flight training, and sampled pilots' saliva at the training conducted between 13:00 and 17:00 in consideration of the daily cycle of cortisol concentration. As demonstrated in Figure 2, the cortisol concentration change in the time slot is gentle and the time can match the actual flight training time.

Another condition to consider in sampling saliva for cortisol analysis is to decide sampling time, that is, when the saliva will be sampled, after a stress condition is given. To examine preceding studies, there is a study that the highest cortisol concentration level within saliva reaches within 30 min since stress condition is given (Kirschbaum and Hellhammer, 2000). Also, there are studies that the highest level is distributed between 10 to 40 min (Bremner, Vythilingam and Vermetten, 2003; Gordis et al., 2006). In this way, various studies can be found. There is a preceding study that such a difference may vary according to the study participants' properties and period exposed to stress (Furlan et al., 2001). Figure 3 shows the peak cortisol concentration distribution, when children are exposed to a fear condition (When a child approaches a glass box covered with cloth in a dark room, a false snake suddenly sticks out) (Lopez-Duran et al., 2009). This can be an example showing that reaching time to the peak cortisol concentration level varies depending on experiment subject and stress type.

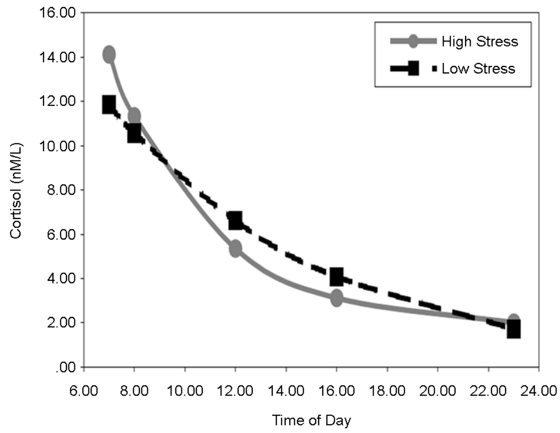

Figure 2. Line of best fit for high stress and low stress with mean cortisol level (Kav. Vedhara et al., 2002)

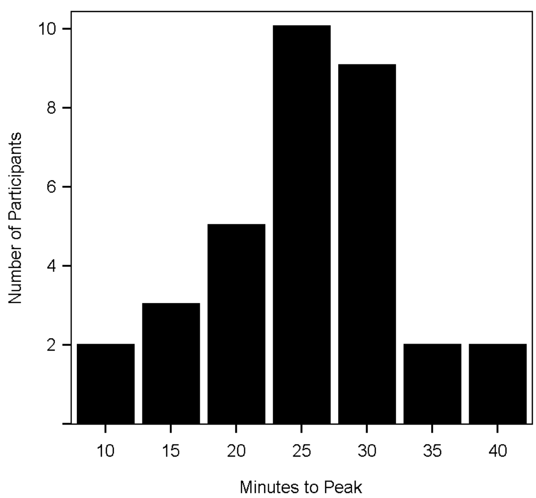

Figure 3. Number of participants reaching peak cortisol levels at specific time intervals after exposure to the fear condition (Lopez-Duran et al., 2009)

2. Experiment

2.1 1st phase experiment

2.1.1 Subjects of experiment

This study undertook experiments and questionnaire survey targeting student pilots in their flight training in the air force for the

1st phase experiment. For the pilots in their flight training, the courses are organized to train using a simulator and an actual trainer for the same mission, and also deviation of stress reaction caused by individual differences such as age, physical condition and the status of marriage can be minimized, which can be merits. This study conducted the experiment targeting 16 student pilots who received training for introductory and advanced courses of flight. The subjects of the experiment were all males, and their ages were 27.1±3.8 and average flight hours were 30.

2.1.2 Experimental procedure

In the 1st phase experiment, this study examines different stress levels in which the pilots feel psychologically on the different environments through cortisol hormone concentration change within saliva regarding each situation at normal time, after simulated flight and actual flight targeting 16 student pilots. The experiment was undertaken for 4 days, and the goal and procedure of the experiment were explained to the subjects on the previous day of the experiment. Because condition may vary depending on sleeping state, the subjects were advised to sleep for 7-8 hours at least. According to previous study result that hormone's daily change tends to be huge in the morning and in the afternoon, all experiments were controlled to be conducted between 13:00 and 17:00.

In comparison of cortisol change in groups, not that of individuals exposed to stress, the pilot's saliva sampling time was set as shown in Figure 4, based on the pre-research that pilots get much stress from the time when they arrive in the operation area and as they conduct operation mission to the landing in the case of actual flight training, as well as the research result of Lopez-Duran et al. (2009) that reaction differences between groups on stress can be examined through cortisol concentration comparison on the basis of the pre-set time.

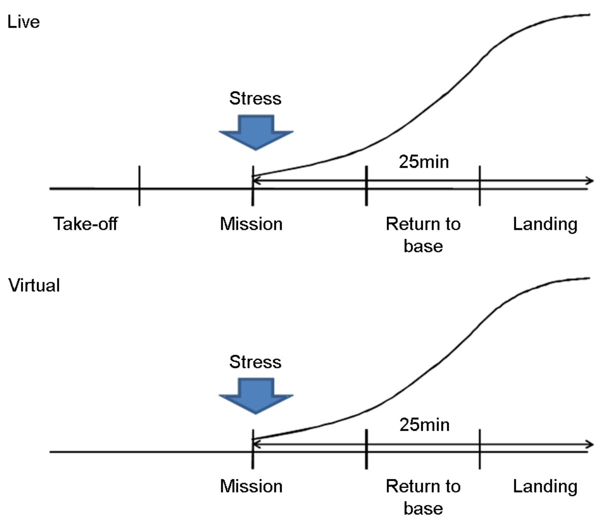

Figure 4. Saliva sampling time (actual & simulated flights)

In the actual flight training, the pilot's saliva was sampled upon after landing check, after a pilot landed in consideration of the stress hormone's activation time caused after the mission, while preventing danger situation that may be caused in saliva sampling. For simulator experiment, the same mission as a pilot conducted in the actual flight experiment was to be conducted 1-2 days after the actual flight experiment. From 25min after the time that a pilot carried out operation area mission after boarding, the saliva was sampled. Although, the same flight procedure that was conducted in the actual flight is carried out in the simulator, the simulator has actually shorter time to spend (taking off time, time to move to operation area), and 15-20min is spent to simply move to the operation area. Thus, difficulties exist to make simulated flight the same as the actual flight, despite the same mission. In this regard, the simulator time setting was made to sample saliva 25min after the operation mission undertaking, after a pilot arrived at the operation area, where stress is viewed to be caused, by referring to the previous study of Lopez-Duran et al., 2009 on the time when cortisol hormone is activated the most in the fear condition.

2.1.3 Questionnaire configuration

The questionnaire survey was carried out before and after the experiment. The questionnaire survey before the experiment was conducted in the fashion of self-inputting manner to identify age, weight, the status of smoking, status of marriage and flight time. For the questionnaire survey after the experiment, the questionnaire that we made ourselves was used, due to no available previous study. The questions consisted of the condition change that a pilot felt after actual and simulated flights, and whether there were environmental differences between the two systems, and if any, what factors affected.

2.1.4 Measurement of cortisol level

The measurement of cortisol level was analyzed through enzyme-linked immunoassay (EIA). The saliva was sampled by locating a cotton swab at the salivary gland area under the tongue by absorbing saliva for 2min. The saliva absorbed on the cotton swab was centrifugated, kept frozen at -20℃ and was analyzed following the procedure offered by Salimetrics.

2.1.5 Method of analysis

The SPSS analysis program was used for statistical analysis of the data collected through the experiment, and 0.05 significance level was applied. For three environmental stress differences at normal time, after actual flight and after simulated flight, this study used one-way ANOVA and Scheffe's post hoc tests were undertaken.

2.1.6 Results of experiment

The results of the 1st phase experiment that targeted 16 student pilots are shown in Table 1. As shown in Table 1, the cortisol levels within the saliva measured after actual flight were analyzed to be maximum 10.57ng/ml, minimum 4.4ng/ml and 7.05ng/ml on average. The cortisol levels within the saliva measured after simulated flight were analyzed to be maximum 8.1ng/ml, minimum 3.0ng/ml and 5.34ng/ml on average. The cortisol levels within the saliva measured at normal time were maximum 7.0ng/ml, minimum 2.7ng/ml and 4.33ng/ml on average.

Table 1. 1st phase experiment cortisol analyzed result (ng/ml)

Classification	Actual flight	Simulated flight	Normal
Max	10.57	8.10	7.00
Min	4.40	3.00	2.70
Mean	7.05	5.34	4.33
SD	1.86	1.56	1.06

To examine whether there is mean difference in cortisol concentration by each group after actual flight, after simulated flight and at normal time, this study conducted a variance analysis. Table 2 exhibits the analysis results. Here, significant differences in cortisol concentration between groups are indicated (p=0.00<0.01).

Table 2. 1st phase experiment analysis of variance result (ng/ml)

Classification	Sum of square	Level of freedom	Mean square	F value	Significance
Between groups	60.380	2	30.190	12.80	0.00
Within groups	106.129	45	2.358		

As a result of variance analysis, there was stress difference in a pair or more at least in comparison with stress by each environment. To look into whether there existed difference between which groups, a post hoc test was conducted. Table 3 shows the results, and the cortisol hormone level differences were significant after actual flight (live) and simulated flight (virtual) (p=0.011<0.05), and after actual flight (live) and at normal time (p=0.000<0.01). However, there was no significant difference in cortisol hormone level between after the simulated flight (virtual) and at normal time (p=0.190>0.01). Based on such a result, pilots receive more stress and more psychological effects in actual flight (live) than simulated flight (virtual). In the comparison of the stress levels after simulated flight and at normal time, there was no significant difference. The reason is that pilots are already adapted to stress situation of flight usually, and thus, no stress difference is shown in the simulated flight (virtual). No saliva concentration difference was shown during work period and holiday period, although concentration difference was observed during the two periods targeting the same people under the hypothesis that work load will increase stress and cause cortisol concentration within saliva to increase. The result matches the preceding study result that stress effects are difficult to observe, because no or small physiological change exists between the two periods, due to experiment subject's adaptation to stress condition in the experiment targeting the same people (Frankeneauser et al., 1989; Lundberg et al., 1989; Harenstam & Theorell, 1990; Pollard et al., 1996).

Table 3. 1st phase experiment post hoc comparison result (ng/ml)

Classification	Mean difference	P-value	95% confidence interval	
			LB	UB
Live-Virtual	1.711	0.011	0.335	3.084
Live-Normal	2.717	0.000	1.343	4.092
Virtual-Normal	1.008	0.190	-0.366	2.383

In the questionnaire survey conducted simultaneously with the experiment, all the subjects said "yes" to the question on whether they feel psychological difference upon actual flight and virtual flight. To the question on whether fair training is possible, if the two systems are connected, 15 subjects said "no" out of 16, and one said he did not know well. To the question on which system will be chosen among the connected two training systems, 7 subjects chose actual flight, 8 simulated flight and 1 did not answer. Concerning the reasons why those who chose the system were low sense of reality and narrow vision of the simulator display, and disadvantage of the simulated flight than the actual flight, due to the kinetic sense of the parts different form a real trainer. In the case of those who chose the simulator, they said there were many danger risks including burden on danger situation, the acceleration of gravity and spatial disorientation upon actual flight.

In conclusion, the experiment subjects received stress in actual flight, and said they had no significant differences, compared to the normal time from a biochemical perspective. As shown in the questionnaire survey results, the student pilots, who learn flying trainer based on actual flight, appear to think that the connected two systems training was not always advantageous to simulated flight, which is different from the reality.

2.2 2nd phase experiment

2.2.1 Subjects of experiment

Although actual flight receives higher level of stress than simulated flight through the 1st phase experiment and analysis, it was known that simulator environment also has some burden, compared to actual flight, according to the questionnaire survey. However, the 1st phase experiment targeted the student pilots whose mean flight hours were 30 hours or less, and thus, stress effects caused by no familiar actual flight need to be taken into account. In the second phase experiment, therefore, this study tried to find out whether the existing pilots received psychologically different stress between actual and simulated flight environments by expanding the subjects to the existing pilots with many flight experiences. The existing pilots need to complete some simulated flight training by airplane type like the student pilots, and therefore, comparative experiments were possible on after actual and simulated flights. The experiment subjects were 40 male pilots (the 1st phase experiment's subjects were also males) and their age was 30.5 ± 4.5. The pilots' mean flight hours were 286 hours (max: 800, min: 40).

2.2.2 Experimental procedure

Like the 1st phase experiment, the procedure and things to heed on the experiment were explained, and they were advised to have 7-8 hours of sleeping time before the experiment. This study conducted pre-research to identify basic information to affect the cortisol levels of the experiment subjects before the experiment and the difficulties of flight mission, and saliva sampling and the questionnaire survey were undertaken after actual and simulated flights. The experiment procedure was the same as the previous experiment procedure. The second phase experiment was conducted over a week in the manner that the simulator experiment was carried out on the next day of actual flight. All the experiment hours were controlled between 13:00 and 17:00.

2.2.3 Results of experiment

The 2nd phase experiment was carried out targeting 40 pilots, but 9 cases that data, through which hormone analysis was impossible, were caused, due to the lack of saliva amount sampled after flight training on each system and other causes (pollution). Therefore, an analysis based on the data for 31 pilots except for the 9 was undertaken. Table 4 shows the cortisol concentration within the saliva measured after actual and simulated flights on the 31 pilots. As demonstrated in Table 4, the cortisol level after actual flight was 5.58ng/ml on average (max: 10.57ng/ml, min: 1.40ng/ml), and the cortisol level after simulated flight was 4.50ng/ml on average (max: 9.67ng/ml, min: 1.88ng/ml). To find out whether significant difference exists between the

Table 4. 2nd phase experiment cortisol analyzed result (ng/ml)

Classification	Live flight	Simulated flight	*t*-test
Max	10.57	9.67	0.016
Min	1.40	1.88	
Mean	5.58	4.50	
SD	2.08	1.79	

two groups, a *t*-test was conducted, and significance probability was 0.016 ($p<0.05$), and thus, the stress levels of the pilots in the two systems were different. This means that the existing pilots with many airplane flying experiences also receive more psychological effects in actual flight than simulated flight.

In the questionnaire survey conducted simultaneously, to a question on whether any condition change existed before and after actual flight, 23 pilots out of 31 answered there was a change, and 8 said there was no change. To a question asking whether there was any condition change before and after simulated flight, 14 out of 31 answered there was a change, and 14 said no change. To a question on whether fair training will be possible upon connecting the two systems, 23 out of 30, except one pilot, answered there would be no fair training, and 6 said they did not know well, and one said there would be fair training. To a question to choose one system out of the two training systems, 16 out of 31, except for 1 pilot, said actual flight would be advantageous, and 14 said simulated flight would be advantageous. The reasons why simulated flight would be advantageous were the burden of mission (16) with the most answers, followed by the effects of acceleration of gravity (10), weather (5), effects of the colleagues (4), difference in atmospheric pressure (2), other_briefing and grade (2), fear of danger (1), noise (1) and wearing gears (1). Concerning the reasons why actual flight was advantageous were difficulty in mission performance due to the absence of simulator equipment existence (10), followed by other_tension (2) and dizziness (1).

In wrapping up the 2nd phase experiment results, the existing pilots had difference in stress level, according to the flight environment between Live-Virtual (actual-stimulated flights) systems in the same manner as the student pilots. According to the hormone result analysis, the subjects significantly received more stress in the actual (live) flight than simulated flight (virtual), but, they did not think simulated flight was always advantageous, although they received more stress in actual flight. Through this, it is known that not only the factors on the danger or mission that can be received from actual flight, but the limitations of virtual environment that a simulator has function as psychological burden to the pilots.

3. Conclusion

This study aims to examine whether environmental differences of the two systems upon connecting the live and virtual (L-V) systems affect trainees' psychological characteristics. To this end, this study carried out a biochemical analyses through hormones to analyze stress level differences between live (actual) and virtual (stimulated) flights targeting pilots via comparative experiments.

As a result of hormone analysis, significant hormone level differences were demonstrated after the live (actual) and virtual (simulated) flights. In comparison with hormone level at normal time, there was significant difference in hormone level between actual flight and at normal time. Concerning the hormone level between virtual (stimulated) flight and at normal time, there was no significant difference in hormone level.

As a result of subjective questionnaire survey, most pilots answered that they felt environmental differences between the two systems, and that such differences would function as a cause of no fair training, when the connected training environment was built. To a question asking which system would be advantageous, the simulated and actual flight environments were evaluated to be at similar level. The pilots who thought the simulator environment was more advantageous said the reasons were burden on mission, the effects of acceleration of gravity and weather upon actual flight. The pilots said simulated and actual flight environments were at similar level to the question on which system would be more advantageous. The pilots, who thought the simulator environment was more advantageous, said the reasons were the burden on mission and the effects of acceleration of gravity caused by actual flight and weather. The pilots, who thought actual flight environment was more advantageous, said the reasons were the lack of reality of the simulator environment and thus, difficulty in performing mission and the dizziness in the virtual environment.

To analyze comprehensively, the stress that a pilot receives is bigger in actual (live) flight than simulated (virtual) flight, but the advantages by system subjectively felt by pilots are at the similar level for both live and virtual flights. Although, burden on mission existing, acceleration of gravity and weather effects that exist in actual (live) flight do not exist in virtual (simulated) environment, there are some factors like kinetic attributes of parts like stick and rudder and the lacking reality sense of display exist in virtual (simulated) flight. And these factors operate as those felt by the subjects, who learned flying airplane techniques in actual flight, which are difficult to be embodied in the simulator. These factors may provide difficulties to the pilots, which are different ones from the actual flight environment, although the simulated flight environment has smaller stress level than the actual flight environment.

Consequently, an effort to reduce the errors from connection the two systems caused by each system's characteristics is required, given that each system's environmental characteristics (live system and virtual system) may offer psychological effects to the pilots upon connecting the L-V systems.

In the further study, the process to draw the factors causing psychological differences on pilots concerning the two flight systems and to identify each factor's effects is necessary, based on this study. Such a further study is expected to contribute to building the environment enabling more fair training possible upon connecting the two flight systems.

Acknowledgements

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