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TITLE

INSTRUMENT FLYING PERFORMANCE AFTER G-INDUCED LOSS OF CONSCIOUSNESS

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ORIGINAL RESEARCH

Instrument Flying Performance After G-Induced Loss of Consciousness

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Introduction: While both the USAF and the USN have characterized the immediate sequelae of G-induced loss of consciousness (G-LOC) as resulting in approximately 24 s of incapacitation, very little is known about the effect of a G-LOC immediately after this incapacitation period. This study is an attempt to determine the effect of G-LOC on instrument flying performance immediately after G-LOC. ***Method:*** In order to establish their flying performance baselines, 29 Canadian Forces (CF) pilots attending the high sustained G (HSG) course flew 3 iterations of a 15-min instrument flying task on the day prior to their HSG course. All 29 pilots performed this same task the next day within 5 min of completing the centrifuge training. In addition, the pilots who experienced G-LOC flew the task again 45 min after G-LOC. Flying performance was assessed by calculating Root Mean Square (RMS) error on 11 flight parameters. These RMS values were submitted to a multivariate analysis of variance. ***Results:*** Of the 29 pilots, 12 experienced G-LOC during the centrifuge training. The flying performance of the 17 non-G-LOC pilots was not affected by their exposure to HSG. Of the 12 G-LOC pilots, 11 had no measurable performance decrement while 1 pilot, after a severe G-LOC, stalled and "spun-in" on take-off and then (after being re-established on the outbound radial) could not complete the task. This same pilot flew the task very well 45 min later. This study did not identify a degradation in flying performance after HSG nor after G-LOC except in the 1 pilot. ***Conclusions:*** Whether or not a pilot's flying performance is affected after G-LOC may be related to the severity of the G-LOC. Some pilots may experience seizure activity relating to the G-LOC with a resulting sustained performance decrement that appears to resolve by 45 min. It is possible that some of the other G-LOC pilots in the study might have had measurable performance decrements if we had been able to have them fly the task while they were still in the gondola (i.e., immediately after the G-LOC).

G-INDUCED LOSS of consciousness (G-LOC) was first recognized in combat aircraft of World War I (3), and has been an operational problem in military aviation ever since. By World War II, the relatively higher performance fighter aircraft of that era exacerbated the G-LOC problem to the extent that the allies had 6 operational human use centrifuges researching the effects of G_z (3).

Over the past 15 yr, coincident with the introduction of fighter aircraft capable of very rapid onset high sustained $+G_z$, there has been an increasing number of flying accidents attributable to G-LOC. Although some pilots survive an in-flight G-LOC, many of these incidents are fatal (11,14). This problem has led to G-training programs in many NATO Air Forces that have reduced but not eliminated the occurrence of G-LOC (8,11).

The seriousness of this issue is further emphasized in the comments of a CF-18 pilot who suffered a G-LOC; "As I was regaining consciousness, I had absolutely no fear of crashing. There was no thought of ejecting or keying the mike. Upon regaining my vision, had I been confronted with a windscreen full of green trees, I don't believe I would have been alert enough to eject. I was definitely along for the ride for another 10 to 15 seconds." Later in the mission, as the two plane element was returning to base; "As we returned, I discovered that I was still not back to 100%. Break altitude at Cold Lake is 3,200 ft MSL. In a gradual descent from 14,000 ft MSL to 3,200 ft MSL, I descended to 2,800 ft before realizing I was low. By the time I reacted, I was level at 2,650 ft, climbing back to 3,200 ft. It took a call from my wingman to get me to switch to tower frequency. We were already only 10 miles out—normally this call is made around 20 miles" (1).

The USAF and USN experiences with G-LOC on human centrifuges suggest that an individual suffering a G-LOC will experience an absolute incapacitation time (unconsciousness) of approximately 12 s and a relative incapacitation time (conscious but disoriented) for an additional 12 s resulting in a total incapacitation time of about 24 s (13–16). Given these data, it is not difficult to imagine the potential consequences of an in-flight G-LOC occurring at a relatively low altitude with either nose-down attitude or nose-down trim. During the 8 yr that DCIEM's (Defence and Civil Institute of Environmental Medicine) centrifuge has been operational, our own experience with G-LOC supports the USAF and USN characterizations of the immediate sequellae of G-LOC, but we are also seeing individuals whose higher order thinking appears to be impaired for up to several hours, or longer. During centrifuge work-ups, two of our in-house centrifuge subjects experienced G-LOC and felt "out of sorts" for the balance of the day. One of these individuals could not even perform routine operations on his computer for over 1 h.

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TABLE I. DEMOGRAPHICS OF G-LOC BY CURRENCY ON AIRCRAFT TYPE.

Aircraft Type	Number of Pilots by Currency on Type	Mean Age by Currency on Type	Mean Total Flying Time (h)	HSG Pilots	G-LOC Pilots	% G-LOC by Type
CF-18	5	34.6	3088	5	0	0%
CT-133	8	30.1	2533	5	3	37.5%
CT-114	15	25.5	972	7	8	53.3%

* 1 ex-test pilot took part in the study and experienced G-LOC but was several years removed from a cockpit and, therefore, not current on any A/C type.

Time to recovery of various aspects of performance has been studied by various authors (2,7,10). Burns et al. (2) used baboons trained in a shock avoidance performance task to demonstrate that post G-LOC performance recovery time increased with time of unconsciousness. Forster and Cammarota (7) found that time to recovery of the ability to de-activate warning signals in the centrifuge averaged about 12 s, while the ability to trim simulated aircraft power and acquire a target was about 60 s. Houghton et al. (10) determined that after G-LOC, two-dimensional tracking task performance recovered to baseline levels relatively quickly, while numerical computation and choice reaction time performance took 2–3 min to return to baseline. This may suggest that a pilot can still accomplish simple flying tasks after G-LOC, but that situational awareness and navigation ability might be compromised for much longer.

Although these studies (2,7,10) provide insight as to the recovery time course for several aspects of performance, so far there have been no studies that assess the ability of pilots to fly a complete flying task. This study is an attempt to fill that void by assessing the ability of military pilots to fly an instrument flying task on a flight simulator after experiencing G-LOC. The purpose of this study is two-fold: 1) to determine whether or not G-LOC causes a flying performance decrement; and 2) if there is a decrement, how long does it last?

METHODS

Subjects for this study were 29 Canadian Forces (CF) pilots (28 males and 1 female) who participated in the high sustained G (HSG) training program. Of these, 5 were current on the CF-18, 8 on the CT-133, and 15 on the CT-114 Tutor, the CF basic jet trainer. The average age, and average total flight time of the pilots (by currency on aircraft type) is shown in **Table I.** The Tutor pilots were mostly recent graduates to "wings standard" (similar to the USAF UGPT (undergraduate pilot training)) in that they had received approximately 250 h of military flight instruction and had been awarded their wings, but had not yet done any operational flying. However, several of them were on their first operational tour as instructors on Tutors. One pilot was an ex-test pilot who was a few years out of a cockpit and, therefore, not current on any aircraft type. All subjects provided written informed consent to participate in the study. The protocol was approved by the DCIEM Human Ethics Committee.

The pilots arrived at the DCIEM 1 d before their HSG course. This allowed assessment of their baseline flying performance on the day prior to the HSG course. The baseline flying performance assessment involved three practice sessions on a 15-min instrument flying task. The flying task was performed on an ATC-610 simulator, which is approved by both the Canadian Department of Transport and the FAA as a pilot training tool. Half of the total instrument flying time prerequisite for attaining an instrument rating can be done on this particular simulator.

The flying task incorporated three phases: 1) an instrument departure/climb while tracking a VOR (vector omni-directional radio range, calibrated to an accuracy

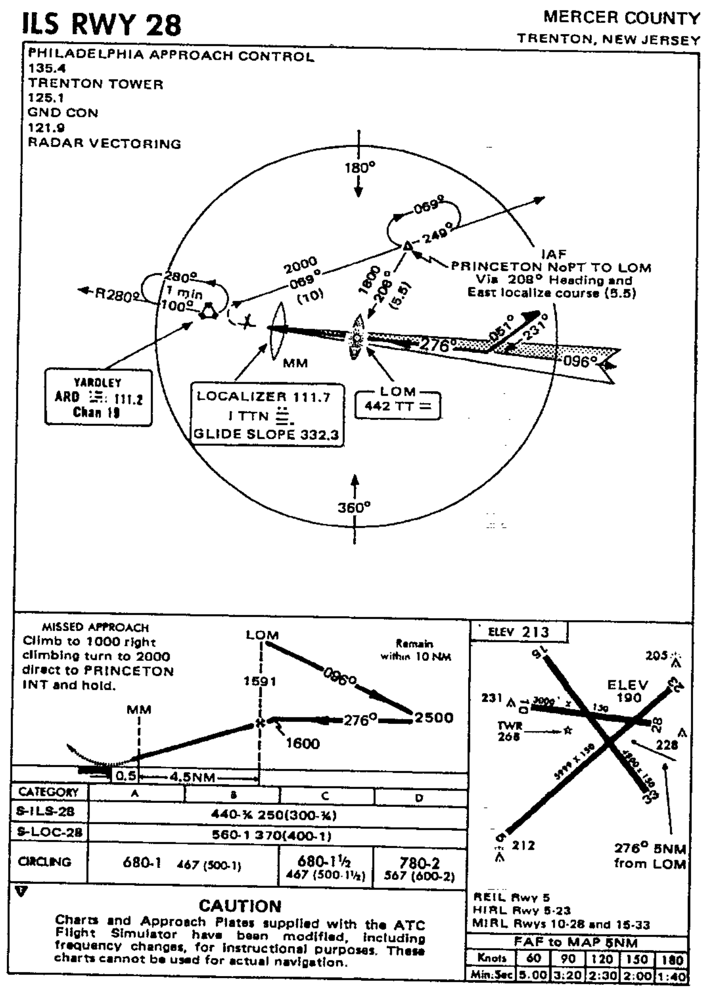

Fig. 1. Task approach plate.

TABLE II. MONITORED FLIGHT PARAMETERS AND TARGET VALUES FOR THE THREE PHASES OF THE ILS FLYING TASK.

Phase	Parameter	Target Value
Take off & climb-out	Manifold pressure	25 in
	Propeller speed	2500 RPM
	Departure airspeed	100 kn
	VOR tracking (096°)	0° error
Procedure turn	Outbound heading	051°
	Altitude during turn	2500 ft
	Turn rate	3° s
	Inbound heading	231°
ILS approach	Localizer deflection	0°
	Glideslope deflection	0°
	Approach airspeed	90 kn

of ±3°) radial to 10 m DME (distance measuring equipment) from the departure airfield; followed by 2) a procedure turn (in this case a left turn from the 096° radial to the 1-min outbound leg (051°) followed by a right turn (at a turn rate of $3° \cdot s^{-1}$) to the inbound leg of the procedure turn (the reciprocal heading of the outbound leg or 231°); and 3) an ILS (instrument landing system, which is a very precise progressively narrowing electronic beam with a localizer component to line up with the runway heading and a glidepath component to provide the correct approach angle, both calibrated to an accuracy of ±0.25°) approach returning to the departure airfield. The task approach plate is illustrated in **Fig. 1** and the flight parameters including their target values are presented in **Table II.** With respect to the flight parameter target values, all pilots were briefed to attempt to fly to "zero error."

The CF HSG course is 1 d long and involves instruction in high-G physiology followed by exposure to several acceleration profiles on the centrifuge. This series of acceleration profiles includes both gradual onset and rapid onset runs either with or without a G-suit, depending on whether or not the pilot's current operational aircraft is equipped with a G-valve. All pilots are monitored by videotape and electrocardiograph during their centrifuge runs. Standard centrifuge profiles (ASCC 61/51) are used. The pilots self-selected into one of two experimental groups (either the HSG stress group or the G-LOC group) depending on whether or not they experienced a G-LOC. Once a pilot experienced G-LOC, centrifuge

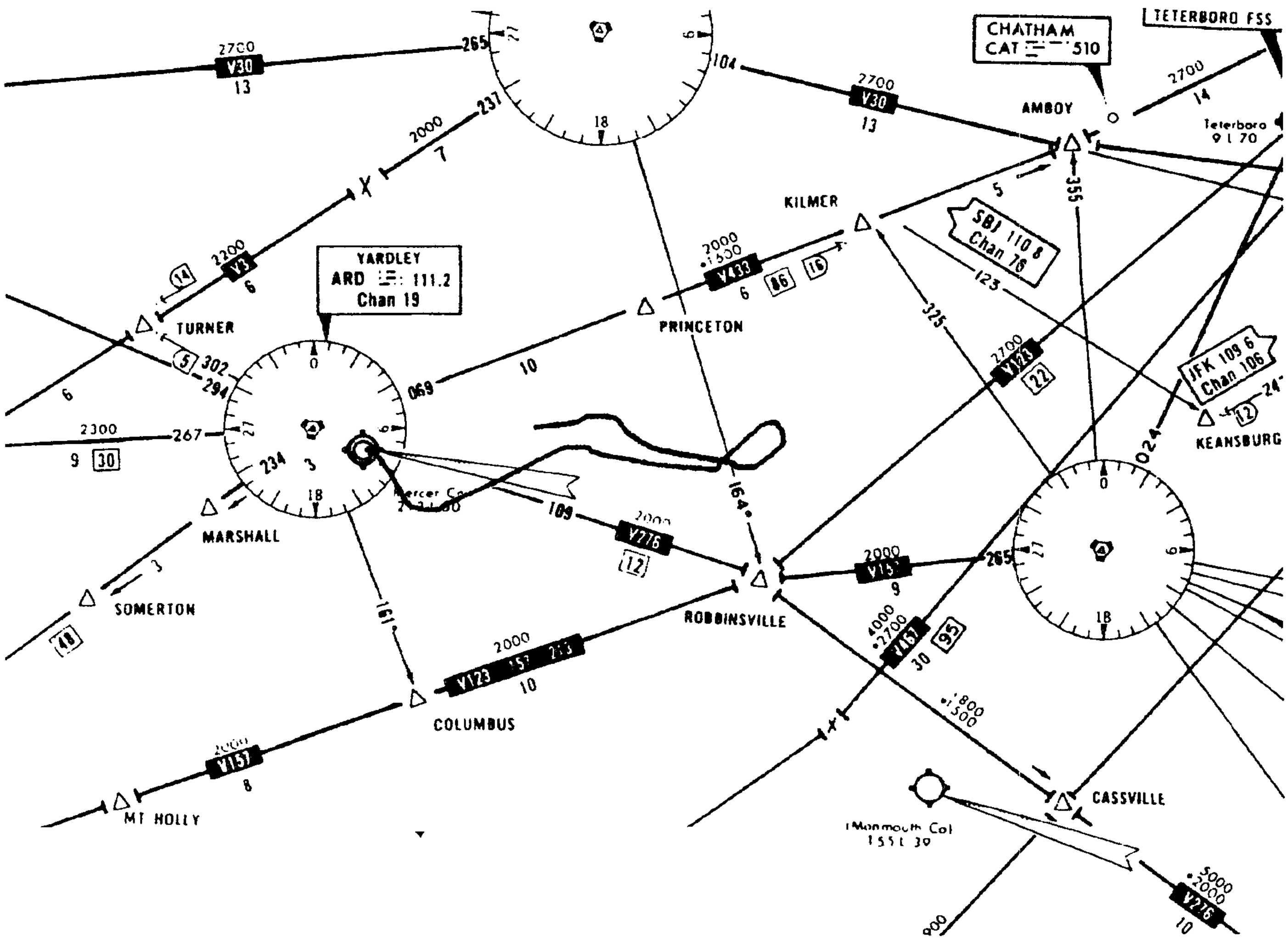

Fig. 2. Ground track of G-LOC pilot who stalled and "spun-in" on take-off.

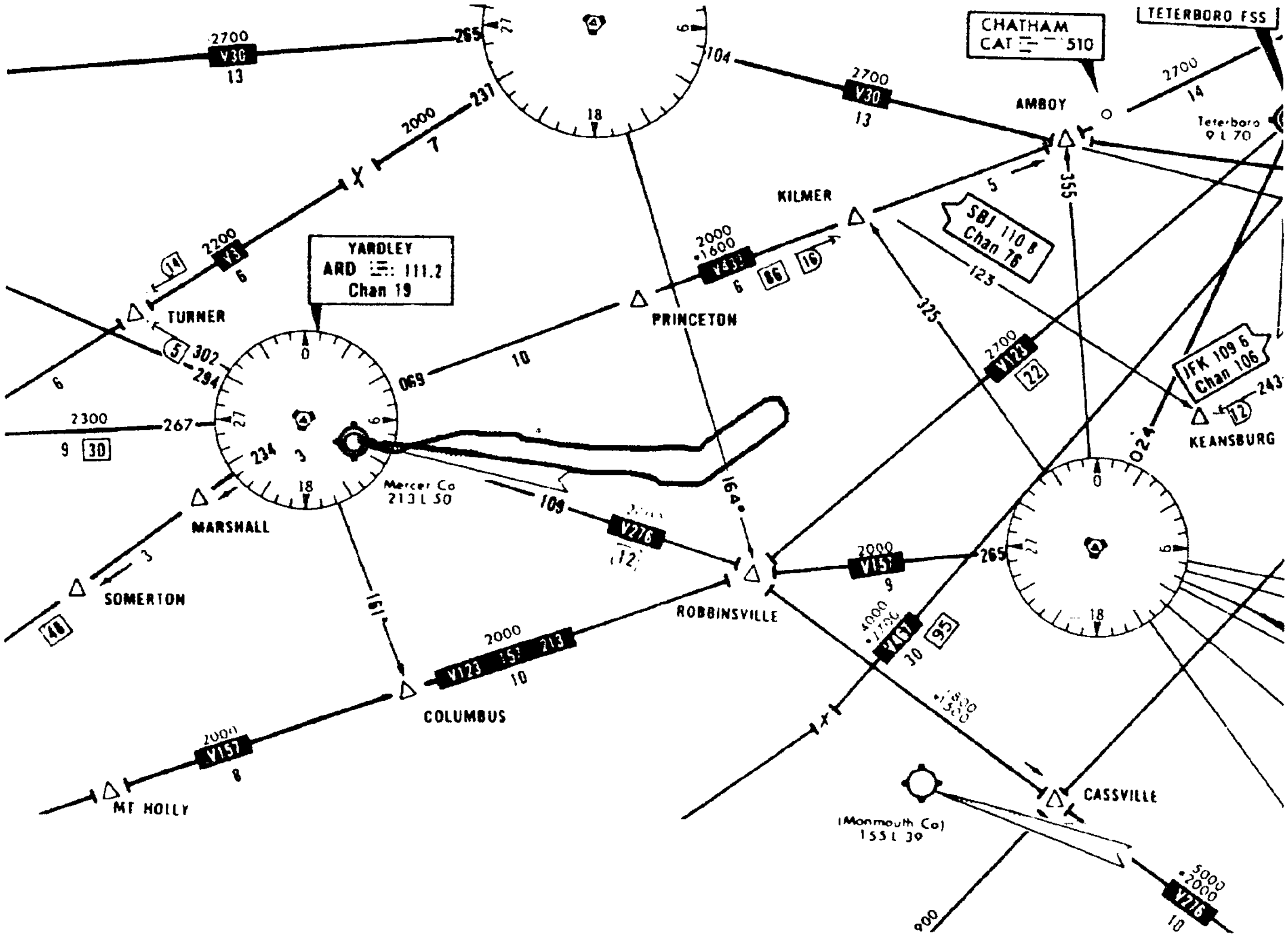

Fig. 3. Ground track of uneventful flight.

training was ceased in order to facilitate a timely exposure to the simulator flying task, although a few pilots who wanted a subsequent attempt on the centrifuge were given the opportunity after their simulator sessions were completed.

Immediately after the centrifuge runs, all pilots of both experimental groups egressed the gondola, and were flying the simulator (located about 40 ft from the centrifuge pit door) within 5 min of leaving the gondola. The HSG group pilots flew the task only once after G-exposure, while the G-LOC group pilots flew the task twice after centrifuge runs, once immediately after G-LOC and

TABLE III. RMS ERROR VALUES (MEAN ± SEM) BY GROUPS AND TRIALS, ACROSS ALL ELEVEN SCORED FLIGHT PARAMETERS).

Parameter	HSG group				G-LOC group				
	control 1	control 2	control 3	post HSG	control 1	control 2	control 3	postgloc 1	postgloc 2
Manifold pressure	15.7 ± 2.0	13.7 ± 2.6	13.4 ± 2.0	22.9 ± 3.9	13.3 ± 2.1	15.4 ± 2.2	19.7 ± 3.7	23.4 ± 5.2	19.1 ± 4.6
Propeller RPM	668 ± 73	811 ± 102	1301 ± 501	984 ± 75	901 ± 153	955 ± 187	1077 ± 228	1120 ± 142	1207 ± 245
Departure airspeed	113.7 ± 21.4	94.3 ± 17.8	87.9 ± 13.7	88.8 ± 12.8	111.0 ± 19.8	98.8 ± 18.5	106.3 ± 16.4	79.5 ± 12.2	78.3 ± 12.8
VOR tracking	18.7 ± 1.3	17.8 ± 3.3	16.2 ± 1.8	14.3 ± 1.0	17.9 ± 3.5	17.8 ± 3.3	18.0 ± 2.1	19.6 ± 2.1	14.7 ± 3.1
Outbound heading	41.6 ± 11.1	29.9 ± 3.2	26.8 ± 6.6	22.8 ± 4.1	31.8 ± 8.0	33.1 ± 5.4	15.1 ± 4.4	20.5 ± 4.4	17.1 ± 3.8
Turn rate	8.9 ± 0.4	8.8 ± 0.5	9.3 ± 1.1	8.4 ± 0.5	7.9 ± 0.5	8.7 ± 0.9	9.3 ± 1.10	8.3 ± .6	7.6 ± 0.3
Altitude during turn	673 ± 74	650 ± 87	616 ± 125	507 ± 52	945 ± 302	728 ± 205	530 ± 56	476 ± 74	429 ± 82
Inbound heading	32.1 ± 8.1	35.7 ± 5.5	34.6 ± 6.9	41.4 ± 5.6	108.8 ± 51.4	38.0 ± 9.8	35.4 ± 3.4	54.3 ± 9.1	40.3 ± 4.2
Localizer deflection	13.0 ± 1.8	9.7 ± 1.3	9.1 ± 1.0	9.5 ± 1.1	10.2 ± 1.4	8.3 ± 0.9	9.8 ± 1.5	10.0 ± 1.3	7.7 ± 0.6
Glide slope deflection	21.5 ± 5.4	32.6 ± 12.1	11.4 ± 2.1	10.5 ± 1.4	12.4 ± 2.9	15.1 ± 4.3	18.4 ± 5.9	16.3 ± 3.2	10.5 ± 0.7
Approach airspeed	80.8 ± 15.9	112.3 ± 26.9	41.1 ± 5.0	66.2 ± 17.2	65.5 ± 11.7	83.0 ± 19.9	46.4 ± 7.1	54.8 ± 9.9	49.9 ± 8.3

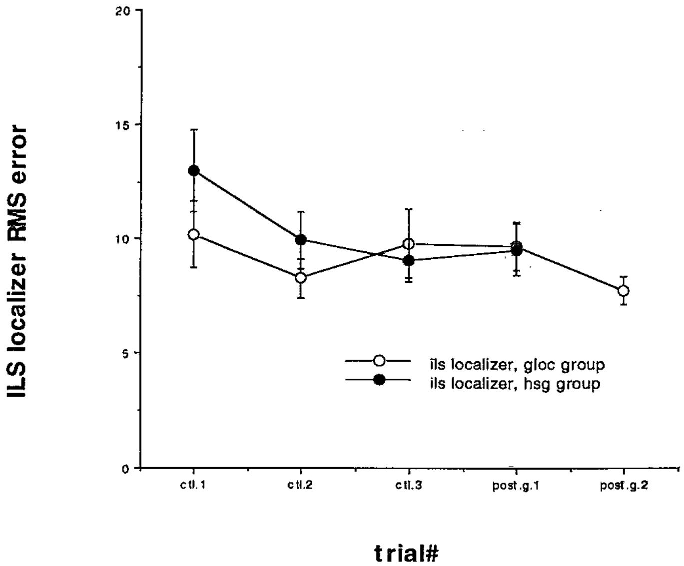

Fig. 4. Ability to track ILS localizer pre- and post-Gz.

again 45 min after G-LOC. This was included to assess whether or not a flying performance decrement induced by G-LOC would resolve after 45 min.

A MacIntosh IIci computer was used to sample the flight instrument output voltages via an analog to digital converter at a sampling frequency of 1 Hz. These voltages were run through a computer run algorithm that used regression equations to convert the instrument output voltages to the simulator instrument values. Flying performance was assessed by calculating RMS (Root Mean Square) error on 11 flight parameters. The RMS error values were submitted to a MANOVA (Multivariate Analysis of Variance).

RESULTS

All simulator flights were performed without significant error except for one post-G-LOC flight, immediately after G-LOC. In this instance the pilot stalled and spun the simulator on take-off. The simulator was recovered to normal flight by the investigator, placed on the outbound VOR radial at the correct airspeed and attitude and the pilot was instructed to carry on with the flight. The pilot then proceeded to fly a considerable distance off track to the right (about 2 mi) and then corrected back to the left in order to re-capture the outbound radial. He then performed a poor procedure turn (almost circular rather than the prescribed race track pattern). Because he failed to select the ILS frequency, he captured what he thought was the ILS localizer, but which was in fact the VOR radial on which he had attempted to fly outbound after take-off. The same cockpit instrument presents VOR and ILS feedback to the pilot. For VOR feedback the full scale deflection of the centering needle is ±10° (either side of the selected radial) and the glidepath needle (not part of the VOR) is "flagged" in the center position (normally indicated by a red panel covering a small window in the instrument) warning the pilot that the glidepath is not active. When the ILS is active, full-scale deflection of the localizer and glidepath needles is ±2.5° (left or right of the localizer or above or below the glidepath) and there are no warning flags visible on the instrument. The data acquired from this flight was impossible to use in the MANOVA. Interestingly, this pilot returned to the simulator 45 min after his G-LOC to perform very well on his second post-G-LOC flight. The ground track of this pilot's first post-G-LOC flight is shown in **Fig. 2** while for comparison, the ground track from an uneventful flight is shown in **Fig. 3.**

The data for the MANOVA therefore came from the 17 HSG pilots and from 11 of the 12 G-LOC pilots. The demographics of G-LOC by currency on aircraft type are shown in Table I. All G-LOC's in this study occurred at +7 Gz. There were no significant differences in simulated flying performance on any of the 11 flight parameters after HSG exposure or after G-LOC in these pilots. The mean RMS error values ± SEM (standard error of the mean) for each of the 11 monitored flight parameters are illustrated in **Table III.** The RMS error values ± SEM for the ILS localizer tracking ability are plotted over trials for each of the two groups in **Fig. 4.** There were 3 comparisons made across all 11 flight parameters. The first comparison was between groups over the first three control flights (taken the day prior to the centrifuge exposure), which demonstrated that there was no difference in performance between the HSG and the G-LOC pilots before they were exposed to the centrifuge. The second comparison was also between groups but compared the third control flights and the first post G-exposure flights, which showed there was no effect of centrifuge exposure on flying performance for either the HSG pilots or the G-LOC pilots. The third comparison was within the G-LOC group, and showed that there was no significant improvement in flying performance during their second post-G-LOC flight relative to their first post-G-LOC flight. The MANOVA results for the three comparisons for each the other 10 flight parameters were exactly the same as for the ILS localizer tracking ability; i.e., no significant differences.

In spite of having demonstrated an intact ability to carry out instrument flying after G-LOC, in response to a survey applied to all pilots in this study, all of the G-LOC pilots reported that they felt they would perform poorly in a tactical environment because they all felt their situation awareness (SA) was compromised. SA is the knowledge state which is necessary for survival and success in a tactical aviation environment, and is sometimes defined by pilots as "a complete awareness of everything within an imaginary sphere several miles in radius that has the pilot's own aircraft at its center". Endsley (5) provides a more academic definition of SA: "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

DISCUSSION

Considering that immediately after G-LOC, 11 of the 12 G-LOC pilots flew the simulator as well as in their control flights and as well as their HSG counterparts, the question arises as to what caused one of these pilots to experience such dramatic difficulty in his first post-G-LOC flight.

During a review of the G-LOC videotapes it became apparent that 6 of the 12 pilots had involuntary motor activity (the not-unexpected arm flailing and torso jerking over the course of about 4 s) coincident with recovery of consciousness. Of these 6 G-LOC pilots who demonstrated this motor activity, the pilot who experienced the performance difficulties had a much different type of convulsive activity that lasted twice as long as the convulsions of the other pilots (about 8 s). Further, rather than demonstrating the random motor activity typical of the other G-LOC pilots, this pilot had bilateral synchronous, tonic-clonic motor activity suggestive of a seizure. This pilot's electroencephalograph (EEG) records from his aircrew selection medical examination revealed epileptiform activity with 3 Hz slow waves during hyperventilation. On the basis of this abnormal EEG he was initially rejected for pilot training. After consultation with a civilian neurologist, he was ultimately selected for pilot training. Given the nature of this pilot's G-LOC with bilateral synchronous tonic-clonic motor activity as distinct from the random motor activity usually seen with G-LOC and the supporting EEG evidence of epileptiform 3 Hz slow wave activity on a previous EEG, a case can be made to suggest that this pilot probably had a G-LOC-induced seizure and experienced post-ictal confusion that severely affected his simulator flying ability immediately after G-LOC (9). However, by 45 min after the G-LOC he was sufficiently recovered to fly the instrument task in a normal, uneventful manner.

With respect to the other G-LOC pilots who flew the simulator very well, it appears that they readily performed the over-learned "housekeeping" tasks of flying an aircraft, but their self-reports of degraded SA would suggest that their higher order thinking is probably somewhat compromised immediately after G-LOC. To study this possibility, a further group of pilots post-G-LOC will be assessed using a situational awareness task such as SAGAT (situational awareness global assessment technique), developed by Endsley (6). Another interesting question is the notion of how well G-LOC pilots would cope with an unexpected emergency during the over-learned task of flying by instruments. No doubt, future work done in this laboratory will address this question. Further, while the idea of flying the simulator immediately upon regaining consciousness (as distinct from 5 min post-G-LOC) is not particularly operationally relevant, one must wonder whether or not some of the G-LOC pilots who flew the simulator very well in the current paradigm might have demonstrated a brief but transient performance decrement if we had been able to assess them immediately upon regaining consciousness.

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