INCIDENCE OF G-INDUCED LOSS OF CONSCIOUSNESS AND ALMOST LOSS OF CONSCIOUSNESS IN THE ROYAL AIR FORCE

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ABSTRACT

INTRODUCTION: Exposure to sustained +Gz acceleration with inadequate G protection can result in G-induced loss of consciousness (G-LOC) or almost loss of consciousness (A-LOC). The UK Royal Air Force (RAF) last conducted a survey of G-LOC within their military aircrew in 2005 with interventions subsequently introduced. The aim of this study was to repeat the 2005 survey in order to evaluate the impact of those interventions. **METHODS:** An anonymous questionnaire, requesting details of G-LOC and A-LOC events was mailed to all RAF pilots (n=1878) and weapons systems operators (WSOs) (n=473) irrespective of aircraft currently flown. **RESULTS:** The questionnaire was returned by 809 aircrew (34.4% response rate). 120 (14.8%) aircrew reported at least one episode of G-LOC and 260 (32.2%) reported at least one episode of A-LOC. The reported prevalence of G-LOC in the previous 2005 survey was 20.1% (n=454). There was an increased reporting of G-LOC in the Hawk, Tucano and Grob Tutor aircraft, with 5 G-LOC and 19 A-LOC events reported in the Grob Tutor compared to none in 2005. **DISCUSSION:** The prevalence of reported G-LOC has decreased in the surveyed populations, which may be due to the introduction of centrifuge training, but also may be influenced by patterns of G exposure and other factors. Scope for further reduction remains through correct execution of the anti-G straining manoeuvre (AGSM) with centrifuge training early in flying training and use of a structured conditioning programme to increase the general strength of muscles involved in the AGSM.

KEY WORDS

G-LOC; A-LOC; survey; acceleration

INTRODUCTION

Exposure to high levels of +Gz acceleration may result in G-induced loss of consciousness (G-LOC) or almost loss of consciousness (A-LOC). +Gz protection is usually enhanced for fighter pilots by the use of an anti-G straining manoeuvre (AGSM) and anti-G trousers. If the AGSM is not performed, or is inadequate, then G-LOC is more likely.[7] G-LOC may result in a period of incapacitation (lack of purposeful movement) lasting 30 seconds or more, consisting of a period of absolute incapacitation (unconsciousness) and relative incapacitation (confusion/disorientation).[15] Following this some aircrew may require further time (up to two minutes or longer) to fully recover and regain cognition with the capacity to act effectively.[7] This can cause a significant occupational hazard to aircrew of high-performance aircraft and has resulted in catastrophic consequences with aircraft and personnel loss.

A-LOC has been described as causing a disconnection between the desire and the ability to act.[10] It is characterised by a number of physiological, emotional and cognitive signs and symptoms, and features include sensory abnormalities, amnesia, confusion, euphoria, loss of short-term memory, paralysis, reduced auditory acuity, and motor abnormalities.[14] These symptoms are similar to the relative incapacitation phase of G-LOC and have led to the concept of a G-LOC Syndrome with a broad spectrum of possible neurologic manifestations[14] which can result in serious motor and cognitive impairments in the high +Gz environment.

The signs and symptoms of G-LOC were reported as early as 1918[6] but active determination of G-LOC incidence did not begin until 1982.[8] A number of military air forces have surveyed the incidence of G-LOC and A-LOC in their aircrew over the last twenty years. These studies have indicated that approximately 8-20% of military aircrew have experienced G-LOC[1,4,12] and 14-52% have experienced A-LOC[10,12] at some point in their career. The Royal Air Force (RAF) conducted two surveys of G-LOC within their military aircrew in 1987[11] and 2005[5], with 19.3% and 20.1% respectively of aircrew reporting such an event at some point in their career.

Following the 2005 survey, centrifuge-based training based on STANAG3827 was introduced for all UK Ministry of Defence (MOD) fast-jet aircrew at an early stage in their flying career, and additionally included aircrew converting to high performance aircraft such as the Typhoon (capable of up to +9 Gz with an onset rate of more than 8 $G.s^{-1}$). There has been no measure of the prevalence or awareness of A-LOC within RAF aircrew in these aircraft, although the first documented fatality attributed to A-LOC was reported in 2012.[9]

The aim of this study was to re-assess the prevalence of G-LOC in the RAF following the 2005 survey and additionally to determine the prevalence of A-LOC in view of the widespread introduction of centrifuge training since the previous survey. This should enable identification of aircrew groups potentially most at risk. In addition, the survey was also intended to determine the level of G awareness within the RAF aircrew and attitudes towards various measures designed to reduce the incidence of G-LOC and A-LOC. This survey includes 5 years of operational service of the +9 Gz capable Typhoon aircraft, which was not fully operational in previous surveys.

METHODS

Data collection

In 2012, an anonymised questionnaire requesting details of G-LOC and A-LOC events was designed by the RAF Centre of Aviation Medicine and distributed by mail to all currently serving RAF pilots (n = 1878) and weapons systems operators (WSOs) (n = 473) (total n = 2351 aircrew), irrespective of aircraft currently flown (including rotary wing and multi-engine aircraft). The aim was to gain information not only from current fast jet aircrew, but also those who may have previously experienced G-LOC or A-LOC in training aircraft. In the UK, rotary wing aircrew are able to transfer to instructor roles on training aircraft during their flying career. The same questionnaire from the previous RAF surveys[5,11] was used in order to allow comparison of results, with the addition of questions asking the aircrew to describe any A-LOC event suffered and frequency, and details of any regular physical conditioning training (aerobic and anaerobic conditioning, and strength training) they had participated in, and whether they had participated in centrifuge training.

Responses were anonymous and were returned by mail, in an enclosed stamped addressed envelope in order to encourage full and honest reporting. Data collected included basic details (age, current aircraft and role), in addition to whole career G-LOC and A-LOC experience and, if either was reported, details of the most significant incident. A definition of ‘most significant’ was not provided in the survey but rather it was assumed that aircrew would describe the incident remembered most vividly or of most significant threat to safety. In cases where respondents reported more than one episode, only one event was included in the subsequent analysis, using details of the most significant G-LOC or A-LOC episode reported. Details included approximate date of the incident, aircraft type, level of experience at the time of the incident (hours on type and total hours), whether the respondent was controlling the aircraft at the time of the incident, maximum G, G onset rate, whether the aircraft was unloaded prior to the manoeuvre which caused the incident, whether the respondent was performing an AGSM, and was the respondent wearing a functioning anti-G suit. Attitudes towards various measures designed to reduce the incidence of G-LOC/A-LOC were assessed such as flying currency, centrifuge training, conditioning training, use of an anti-G suit, and G theory lectures. Data from returned questionnaires were captured electronically using an optical marker system (Remark Office OMR 8.0, Gravic, Malvern, PA). The study protocol was approved in advance by the RAF Experimental Medicine Scientific Advisory Committee and the Ministry of Defence Research Ethics Committee (Ref: 362/GEN/12).

Statistical analysis

The full cohort was described using descriptive statistics for categorical data. Aircrew who had experienced an A-LOC or G-LOC and had reported their most significant event (second part of the questionnaire), were also described and compared against level of experience using the chi-square test. Attitudes to anti-G-LOC measures were compared by age and level of experience using the chi-square test with *alpha* set at $p \leq 0.05$. Statistical analysis was performed using SPSS software (v 22.0.1, SPSS Inc, Chicago, IL) and Stata SE v12.0 (StatCorp, College Station, TX, USA).

RESULTS

Of 2351 aircrew, the questionnaire was returned by 809 (34.4% response rate), of whom 615 were pilots and 194 were WSOs. The majority of responders were aged 30-34 years. The largest group to respond were fast jet aircrew (n = 258, 31.9%), with multi-engine (n = 154, 19%), rotary (n = 135, 16.7%), ground tour (n = 109, 13.5%), Intelligence, Surveillance, Target Acquisition & Reconnaissance aircraft (ISTAR) (n = 57, 7.1%), light aircraft trainer (n = 52, 6.4%), and test flying/other (n = 44, 5.4%) also represented.

At least one episode of A-LOC or G-LOC was reported by 301 (37.2%) of responding aircrew. 120 (14.8%) reported at least one episode of G-LOC and 260 (32.2%) reported at least one episode of A-LOC. 79 (9.8%) aircrew reported at least one episode of both G-LOC and A-LOC.

292 aircrew described their most significant A-LOC (188) or G-LOC (104) event. Of the 517 non-responses for this section of the questionnaire, 508 had never experienced an A-LOC or G-LOC event and 9 had experienced an A-LOC or G-LOC event but did not describe it. Aircrew who reported an event and those who did not had similar age groups ($p<0.097$), current roles ($p=0.124$) and current aircraft ($p<0.039$) except for fast jet. Of the fast jet aircrew, 106 (36%) reported an event *versus* 152 (29%) who had not reported an event, ($p<0.043$).

In those aircrew who had reported an event, G-LOC and A-LOC were reported to have occurred most commonly during training (n = 63 (60.6%) suffered G-LOC and n = 111 (59%) suffered A-LOC), but were also reported by aircrew at instructor level (n = 19 (18.3%) G-LOC and n = 39 (20.7%) A-LOC), squadron (line) pilot level (n = 11 (10.7%) G-LOC and n = 25 (13.4%) A-LOC), and test pilots and other miscellaneous groups (n = 10 (9.6%) G-LOC and n = 11 (5.9%) A-LOC) (Fig. 1.).

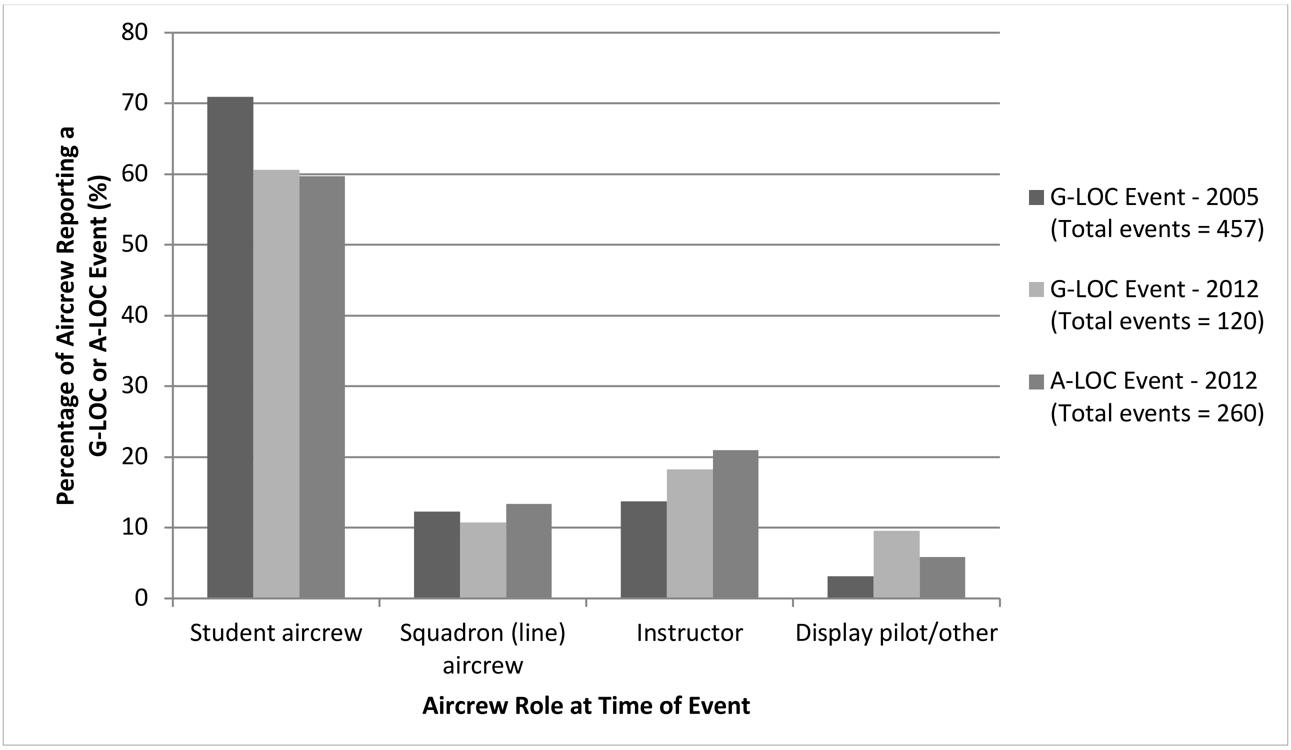

Fig. 1. Percentage of aircrew reporting G-induced Loss of Consciousness (G-LOC) / Almost-Loss of Consciousness (A-LOC) events broken down by aircrew role from the 2005 survey (457 reported a G-LOC event) and the 2012 survey (301 reported either a G-LOC or A-LOC event, and 79 aircrew reported both G-LOC and A-LOC events).

The types of aircraft in which G-LOC and A-LOC were experienced were predominantly trainers including the Hawk, Tucano and Grob Tutor, making up 68 (65.4%) of the G-LOC and 134 (71.3%) of the A-LOC totals (Table I). G-LOC events in front line (operational) aircraft accounted for 4 (3.9%) of total episodes, and A-LOC for 25 (13.4%). If only current fast jet aircrew are considered and aircrew in all other roles are excluded, 38 (36.5%) reported a G-LOC event and 68 (36.2%) reported an A-LOC event.

	Number reporting G-LOC		Number reporting A-LOC
Aircraft type	**2005** (n=433)	**2012** (n=103)	**2012** (n=186)
Hawk (trainer aircraft)	106 (23.3%)	35 (34%)	66 (35.5%)
Tucano (trainer aircraft)	71 (15.6%)	28 (27.2%)	49 (26.3%)
Jet Provost (trainer aircraft) †	175 (38.5%)	21 (20.4%)	12 (6.5%)
Grob Tutor (trainer aircraft)	0 (0%)	5 (4.9%)	19 (10.2%)
Bulldog (trainer aircraft) †	21 (4.6%)	5 (4.9%)	4 (2.2%)
Tornado GR1/GR4 (frontline aircraft)	4 (0.9%)	3 (2.9%)	9 (4.8%)
Tornado F3 (frontline aircraft) †	7 (1.5%)	1 (1%)	10 (5.4%)
Typhoon (frontline aircraft)	*	0	5 (2.7%)
Firefly (trainer aircraft) †	8 (1.8%)	0	4 (2.2%)
Harrier (frontline aircraft) †	1 (0.2%)	0	1 (0.5%)
Hunter (frontline aircraft) †	3 (0.7%)	0	1 (0.5%)
Other	37 (9.3%)	5 (4.9%)	6

Table I. Aircraft type at G-induced Loss of Consciousness (G-LOC) / Almost Loss of Consciousness (A-LOC) event in the 2012 survey compared against the 2005 survey. * Typhoon came into RAF Service following the 2005 survey. † No longer in RAF Service at the time of the 2012 survey.

G-LOC was most common in aircrew with <100 hours on that type of aircraft (n = 65, 63.1%), with A-LOC prevalence at 110 (58.8%). Both were also more prevalent in aircrew with <249 total flying hours in their careers (G-LOC 61 (58.7%), A-LOC 95 (50.5%)).

Since the last survey of RAF aircrew and the introduction of centrifuge training in 2005, for all fast-jet aircrew early in their training, a total of 47 G-LOC and 127 A-LOC events have been reported (Fig. 2.).

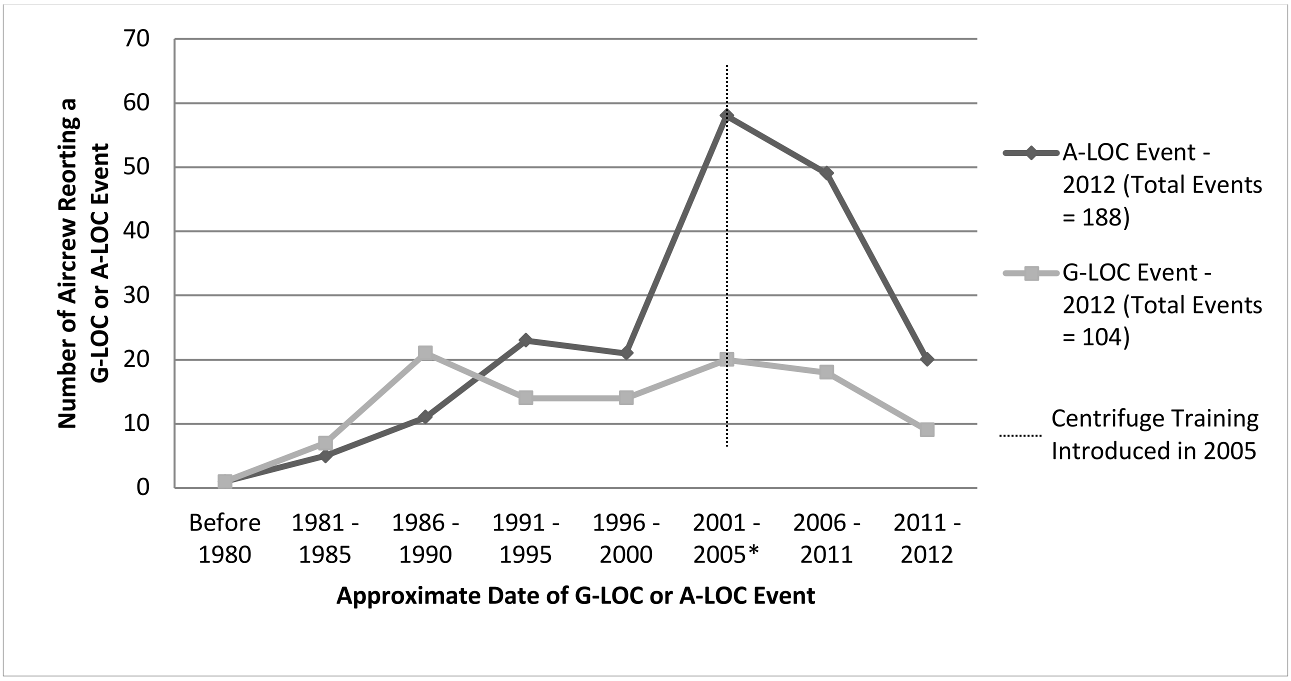

Fig. 2. Number of aircrew reporting a G-induced Loss of Consciousness (G-LOC) / Almost Loss of Consciousness (A-LOC) event broken down by the approximate date from the 2012 survey (total of 104 aircrew reported a G-LOC event and 188 reported an A-LOC event). * Centrifuge training was introduced for all fast-jet aircrew early in their training in 2005.

G-LOC or A-LOC occurred in the range of +4 to +9 Gz, with the majority of cases occurring at +5 to 5.9 Gz (n = 32 (32.7%) for those reporting a G-LOC event and 60 (35.3%) for A-LOC). Acceleration onset rate was described as 'rapid' in 94 (92.2%) of G-LOC and 153 (83.2%) of A-LOC events. The majority of G-LOC (n = 83, 80.6%) and A-LOC (n = 127, 67.6%) events were experienced by aircrew who were not controlling the aircraft at the time. G-LOC and A-LOC after exposure to acceleration at <1 Gz prior to positive Gz (commonly referred to as 'push pull') featured in 24 (24.5%) of G-LOC and 46 (25.6%) of A-LOC events. Only 58 (56.3%) of aircrew claimed to be performing an AGSM when G-LOC occurred, but 134 (71.7%) were straining when A-LOC occurred. The majority of aircrew were not wearing a functioning anti-G suit when G-LOC occurred (n = 75, 72.1%) as there is no anti-G system in the Grob Tutor or Tucano trainer aircraft. Ninety two (49.5%) aircrew experiencing an A-LOC event were using a functioning anti-G suit.

The current survey included a series of questions concerning G awareness and the perceived value of training in the prevention of G-LOC and A-LOC. 94.2% of respondents recognised the importance of flying currency, 95.1% the use of an anti-G suit, 87.7% attendance of G-theory lectures, 84.2% participation in physical conditioning training, and 72.8% considered centrifuge training important (Table II). Notably only 249 (30.8%) respondents reported that they had participated in centrifuge training.

How important do you consider each of the following in reducing instances of G-LOC & A-LOC?	**2005*** (2259)	**2012*** (809)
Flying currency	90.1 (2037)	94.2 (772)
Anti-G suit	87.6 (1987)	95 (745)
Physical conditioning	82.7 (1869)	84.2 (748)
Classroom G-theory lectures	80.3 (1815)	87.7 (758)
Centrifuge training	55.6 (1255)	72.8 (720)

Table II. Comparison of the proportion of aircrew responding positively (‘very’ or ‘fairly’ important) to a series of questions concerning G awareness and perceived value of training in the prevention of G-induced loss of consciousness (G-LOC) and Almost Loss of Consciousness (A-LOC) in the 2005 and 2012 surveys. * % (n) values are shown.

Of the 287 aircrew who reported either a G-LOC or A-LOC event, 194 (67.6%) felt that centrifuge training was either ‘very’ or ‘fairly important’ in reducing instances of G-LOC or A-LOC. 524 felt that centrifuge training was of value, with 330 (62.9%) having not experienced a G-LOC or A-LOC event ($p<0.048$).

Respondents were also asked how often they participated in regular aerobic or anaerobic conditioning and strength training. The majority participated in regular aerobic conditioning (624 total respondents) with 376 (60.7%) participating in 2-3 sessions per week. 234 respondents (49.7%) participated in 1 weekly anaerobic session (self-defined by the respondents), with 200 (42.5%) participating in 2-3 sessions weekly. This was similar for regular strength training (483 total respondents), with 230 (46.9%) participating in 1 and 215 (43.9%) participating in 2-3 sessions per week. Unfortunately the 2005 survey did not ask aircrew if they participated in any form of exercise programme, making comparison with the 2012 survey very difficult. There was also no option for aircrew to indicate if they performed no exercise in the 2012 survey as it was assumed they would complete at least one exercise session per week.

In the 2012 survey (n = 809) compared with that of 2005 (n = 2259), there was a lower prevalence of G-LOC (14.8% and 20.1% respectively, p<0.001). Compared with the 2005 survey (454) those who described their G-LOC experience in the 2012 survey (104) had less flying experience, with a higher proportion of events being reported in aircrew with less than 250 hours total flying hours (78% and 64% of GLOC occurrences respectively, p<0.001). There was increased reporting of G-LOC in the Hawk, Tucano and Grob Tutor aircraft.

DISCUSSION

The reported prevalence of G-LOC events in the RAF reduced from 20.1% in 2005 to 14.8% in 2012. A-LOC was reported by 32.2% of respondents in the 2012 survey. The G-LOC prevalence rate is generally in line with other military defence forces who have surveyed their aircrew in the last 20 years, reporting incidences of 8-20%.[1,5,14] However the prevalence of reported A-LOC (32.2%) in RAF aircrew is higher than that reported in a survey involving aircrew from the US Navy, Marine Corps and Air Force[10] (14%) but less than aircrew in the Royal Australian Air Force (RAAF)[12] (52%). The higher prevalence for the RAAF may be as a result of the aircrew being verbally briefed on the signs and symptoms of A-LOC prior to completing the survey. An increase in reporting of A-LOC from 2000 is noted in the literature,[10,12] with the term 'A-LOC Syndrome' coined in 2003[14] but this may in part be due to an increased awareness of the phenomenon in both the aeromedical and aircrew community. The 2005 RAF survey[5] did not ask aircrew about any possible A-LOC experiences.

G-LOC and A-LOC prevalence may be higher in both RAF surveys than other military defence forces that reported G-LOC incidences of 8-10%[1,17] and A-LOC incidences of 14%[10] due to methodological differences. Lower incidences of G-LOC and A-LOC have been reported in studies that surveyed only current fast-jet aircrew[1,10,17] which may have resulted in missing some people who experienced a G-LOC or A-LOC event early in their flying training but then went on to non-high performance aircraft. In all three RAF surveys,[5,11] aircrew flying non-high performance aircraft were questioned, yet G-LOC was reported in 44% and A-LOC in 43.6% of non-fast jet (transport, rotary, light aircraft and ISTAR) aircrew. This is likely to relate to experiences during the various stages of their flying training as all RAF aircrew complete elementary flying training in a light aircraft (currently the Grob Tutor) prior to being streamed to fast-jet, rotary-wing or multi-engine aircraft.

The relatively low response rate of 34% may be a result of 'survey fatigue' within the aircrew population. The survey was sent to all registered RAF aircrew regardless of current role or geographical location, with follow up emails to all squadron commanders requesting them to encourage aircrew to return the completed survey. Every effort was made to obtain a representative sample of the population however, an element of selection bias may have occurred. A number of aircrew contacted the investigators to enquire if they should complete the survey despite having a predominantly rotary or transport aircraft background and no experience of G-LOC or A-LOC. They were advised to return the completed survey as the aim was to include flying training in the broader examination of G-LOC/A-LOC prevalence. It is possible that only aircrew who had experienced a G-LOC or A-LOC event returned the survey. However, it is also possible that some may have experienced an incident and did not respond for fear of being removed from flying duties. A verbal brief to aircrew prior to distributing the survey which explained its purpose, and the signs and symptoms of both G-LOC and A-LOC may have encouraged a greater response rate. The response rate may also be confounded by the very nature of G-LOC and A-LOC, in that aircrew can suffer from poor recall and amnesia following an incident[4] and this might result in under-reporting.

The prevalence of reported G-LOC and A-LOC events remains high in aircrew under training (G-LOC 60.6%, A-LOC 59%) although it has reduced from the previous survey (G-LOC 70.9%). Similarly, the predominant trainer aircraft (Hawk, Tucano, Grob Tutor) accounted for 65.4% of G-LOC and 71.3% of A-LOC events (Table I). This was slightly reduced from the 77.4% of G-LOC events reported in 2005 and may result from the introduction of centrifuge-based training for all fast jet aircrew prior to the Tucano flying phase. The centrifuge training involves two sessions conducted over one day. The first session consists of a series of graduated runs wearing no countermeasures, progressing from +3.5 Gz for 15 seconds up to +5.5 Gz for 15 seconds. Following a short break of a few hours, the second session consists of a series of graduated runs wearing five-bladder anti-G trousers, progressing from +4.5 Gz for 15 seconds up to +7 Gz for 15 seconds. The runs enable compliance with STANAG 3827 although the centrifuge is only capable of an onset rate of 1 $G.s^{-1}$. Since 2005, there has also been a new G-limit of +5 Gz (previous G-limit was +6 Gz) introduced for the Tucano aircraft to reduce fatigue life on the airframe which may also have contributed to the fall in G-LOC events compared with the 2005 survey.

Of concern is the number of aircrew who have reported either a G-LOC (5) or A-LOC (19) event in the Grob Tutor, as none were reported in the 2005 survey. All RAF aircrew commence their flying training on the Grob Tutor aircraft and as such have minimal flying experience. As part of their training, they receive classroom-based G theory lectures and basic AGSM instruction. In light of the results of this survey, it may be prudent to develop the current G-theory lectures for all aircrew on the Grob Tutor to include a more formal practice of a correct AGSM technique which could involve centrifuge training. Centrifuge training is deemed by many to be extremely important, by providing the opportunity to practice an effective and efficient AGSM technique in a non-threatening environment,[13,17] which may play a role in protecting aircrew against high G forces in the operational environment.[13]

Student aircrew reported a higher incidence of both G-LOC and A-LOC events, presumably due to their relative inexperience in both G awareness and ability to perform an effective AGSM.[13] This may account for the relatively unchanged number of aircrew who claimed to be performing an AGSM when G-LOC (56.3% in 2012 and 55.3% in 2005) and A-LOC (71.7%) occurred. It seems reasonable to conclude that their AGSM was inadequate, started too late during the manoeuvre and were unable to catch up (‘behind the G’), or that the individuals were too fatigued to maintain sufficient cerebral blood flow during the manoeuvre. G-LOC events may be related to fatigue and/or complacency. A timely and proficient AGSM is essential for all high +Gz exposures.[16]

The RAF rate for G-LOC events may have reduced as a consequence of the introduction of centrifuge-based training following the last survey which occurred for all fast jet streamed aircrew at an early stage in their flying career, and for those converting to high performance aircraft such as Typhoon. However, it should be noted that only 33% of respondents had participated in centrifuge training, with the others having undergone flying training before this policy was introduced. Of the 105 who reported a G-LOC event, 58 (55.2%) had not completed centrifuge training ($p<0.028$). Due to the structure of the survey, it is unclear whether those who did report a G-LOC event had completed centrifuge training prior to the event. Future surveys should include greater detail of centrifuge training and whether this improved the ability to recognise G-LOC or A-LOC symptoms. Of note, the UK centrifuge is unable to replicate the requirements for STANAG 3827 onset rates, which is at least 3 $G.s^{-1}$ (the onset rate is 1 $G.s^{-1}$).[2] Some UK operational/frontline aircraft exhibit an onset rate of at least 8 $G.s^{-1}$ (Typhoon), but these aircrew receive aircraft based high G onset top up training.

Respondents were asked a series of questions concerning G awareness and their perceived value of training in the prevention of G-LOC and A-LOC (Table II). The number responding positively (‘very’ or ‘fairly’ important) increased for all the questions when compared to 2005. This suggests that awareness of basic prevention measures was high, although the issue of selection bias should be considered. The perceived importance of centrifuge training increased the most amongst responders (72.8% in 2012 and 55.6% in 2005). 524 aircrew felt that centrifuge training was of value, with 330 (62.9%) having not experienced a G-LOC or A-LOC event ($p<0.048$).

Physical conditioning can also emphasise the necessity of both anaerobic and aerobic fitness training to combat fatigue during a demanding sortie.[17] Anaerobic training can increase muscle mass, strength and endurance, which is reported to have a beneficial effect on +Gz tolerance.[4] By increasing the general strength of muscle groups involved in the AGSM, anaerobic training can improve the effectiveness of the manoeuvre.[3]

A structured and progressive Aircrew Conditioning Programme has now been designed by one of the authors (ES), which aims to enhance pilot performance through improvements in the ability to repeatedly perform an effective AGSM. Further work to investigate whether it improves pilot performance in a high G environment is now underway.

Whilst the prevalence of reported G-LOC has decreased since the previous survey in 2005 from 20.1% to 14.8%, G-LOC remains a hazard to all aircrew, particularly during the initial stages of flying training. This is highlighted by the responding RAF aircrew reporting 5 G-LOC and 19 A-LOC events in the Grob Tutor all since the 2005 survey. Measures to significantly reduce the incidence of G-LOC and A-LOC events in these aircrew should be taken and could include more formalised G-theory classroom lectures and correct execution of the AGSM which could involve centrifuge training earlier than currently undertaken. A structured conditioning programme which is designed to increase the general strength of muscle groups involved in the AGSM could also be considered.

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