Aviator's Fluid Balance During Military Flight

Anna Levkovsky; Sivan Abot-Barkan; Leah Chapnik; Omer Doron; Yuval Levy; Yuval Heled; Barak Gordon

INTRODUCTION: A loss of 1% or more of bodyweight due to dehydration has a negative effect on cognitive performance, which could critically affect flight safety. There is no mention in the literature concerning the amounts of military pilots' fluid loss during flight. The aim of this study was to quantify fluid loss of pilots during military flight.

METHODS: There were 48 aviators (mean age 23.9) from the Israeli Air Force who participated in the study, which included 104 training flights in various flight platforms. Bodyweight, urine specific gravity, and environmental heat strain were measured before and after each flight. Fluid loss was calculated as the weight differences before and after the flight. We used a univariate and one-way ANOVA to analyze the effect of different variables on the fluid loss.

RESULTS: The mean fluid loss rate was 462 $ml \cdot h^{-1}$. The results varied among different aircraft platforms and depended on flight duration. Blackhawk pilots lost the highest amount of fluids per flight, albeit had longer flights (mean 108 min compared to 35.5 in fighter jets). Jet fighter pilots had the highest rate of fluid loss per hour of flight (up to 692 ml, extrapolated).

CONCLUSION: Overall, at 11 flights (≈11%) aircrew completed their flight with a meaningful fluid loss. We conclude that military flights may be associated with significant amount of fluid loss among aircrew.

KEYWORDS: dehydration, pilots, aircrew.

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It has been established that proper fluid balance is essential to maintain an optimal homeostasis and the organism's function and survival. Dehydration is the result of a negative fluid balance in the organism and is common during exercise, work, and/or exposure to high temperatures. Fluid loss of 2% or more of bodyweight has a negative effect on physiological and cognitive performance, while a loss of more than 4%, which is considered severe dehydration, might harm physiological processes and functions, and with further deterioration may even lead to death. Several studies show that even mild dehydration (loss of 1% of bodyweight) might critically hamper optimal cognitive performance.[10,13,16]

Specific cognitive functions that are harmed by dehydration are visual-spatial orientation and coordination, alertness,[1,13] short term memory, mathematical reasoning, psychomotor functions, and sustained attention.[6] A study that investigated the effects of hydration on the cognitive function of 40 healthy pilots showed significant effects of low fluid intake on general flight performances and spatial cognitive tests. The changes in these parameters could have a critical effect on flight safety and might lead to aviation accidents, which are mostly (up to 91%) caused by human error.[14]

Certain populations are at a higher risk for voluntary dehydration. Voluntary dehydration often occurs due to a lack of awareness of the required amount of fluid consumption, especially when not taking into consideration the amount and type of physical activity during the day.[6,11,16] Therefore, voluntary dehydration is understandably common among athletes and military personnel.[8,15,20] From our clinical experience, it is also very common among aircrew and, especially, among fighter jet pilots. It is mainly caused by concerns with the complexity of urination during flight and by a dense schedule during the day.

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The recommendations for aviators' fluid intake during flight at the Israeli Air Force and other air forces around the world are approximations, and are based on studies that researched military personnel and athlete populations.[8,17,20] The main objectives of this study were to measure the rate of insensible fluid loss of military pilots and to evaluate the risk of dehydration in standard training flights with the purpose of setting verified recommendations.

METHODS

We performed a prospective observational study during February through May of 2014. The study included 48 participants in the Israeli Air Force (IAF) flight academy and in instructional and operational squadrons. Squadrons included fixed-wing transport (Beechcraft Bonanza and King Air), lift-utility helicopters (Blackhawks), and fighter jets (Skyhawks and Falcon F16B). We excluded female aviators because of very low numbers of female aviators in the IAF and the potential effects of variations in hormonal and menstrual state on fluid balance.[7] We also excluded aviators who were taking any medication or were ill. Informed consent was obtained from all participants. The study was approved by the Israeli Defense Forces Medical Corps institutional review board.

All participants had a preflight urine dipstick for specific gravity (SG, measured visually by a Combur10-Test by Cobas; urine SG above 1.020 is considered dehydration) and a post urination bodyweight measurement (expressed in kilograms and rounded to the nearest 100 g) by electronic scales (by Beurer manufacturing, Golborne, UK) while wearing undergarments only. The aviators completed a questionnaire that included data regarding the planned flight, amount of sleeping hours the night before the flight, and whether they performed exercise in the 24 h preceding the flight. Height was obtained from medical records and BMI was calculated as weight in kilograms divided by the squared height in meters.

Flights were performed as part of regular squadron schedules and were not designed by the investigators. Postflight data included weight measurements by the same electronic scales with only undergarments on, a urine dipstick for specific gravity, and a completed questionnaire that included data concerning food and fluid intake and urination during flight, as well as the actual flight details. Food and fluids that were taken by the aviators onboard the flight were weighted before and after the flight.

Environmental heat strain was measured on the ground using a weather pocket meter (Kestrel 1000 Wind meter, Minneapolis, MN) at each of the flights, and is expressed by a heat stress index. The fluid loss during flight was calculated as preflight bodyweight plus fluid and food intake from which postflight bodyweight was subtracted. The results were further normalized per flight duration (in minutes). We considered a loss of 1% of bodyweight to be a meaningful fluid loss.

The statistical analyses were performed with SPSS v.22 (IBM, Armonk, NY). Statistical significance was defined as $P < 0.05$. Changes in fluid loss were assessed by a paired two-tailed *t*-test within subjects and a two-tailed univariate and a one-way ANOVA to analyze different variables' effects (heat stress index, fluid intake, difference in SG value before and after the flight, physical activity, sleeping hours, BMI, and aircrew's role in Skyhawk aircrafts). In order to define platform specific fluid loss, the calculation was performed separately for each aircraft type and the aviators' role (pilots and navigators in Skyhawks). The statistical analysis used an ANOVA Univar test, which used the fixed wing transport group as a control. Initial SG value effect on fluid loss rate was analyzed by two-tailed Student's *t*-test. Assuming that the true difference in fluid loss means will be 200 ml and the standard deviation 150 ml, we needed to study 25 fighter jet flights and 13 control (nonfighter jets) flights to be able to reject the null hypothesis with probability (power) 0.8. The Type I error probability was set at 0.05. Due to multiple analyses resulting in nonsignificance, we performed post hoc power calculation for mean fluid loss of fighter jet (Skyhawk and Falcon 16) compared to nonfighter aircrafts (Blackhawk and fixed wing transport) that yielded a power of $1-\beta = 0.998$ ($\alpha = 5\%$).

RESULTS

There were 48 pilots and navigators who took part in the study: 9 fixed wing transport pilots (Beechcraft Bonanza and King Air), 11 Blackhawk helicopter pilots, 6 Falcon F16B fighter jet pilots, and 16 pilots and 6 navigators from the flight academy (Skyhawk). Blackhawk and Skyhawk, unlike other aircrafts, are not air-conditioned. The mean age of the participants was 23.9 (SD 3.8, range 20 to 41). Of the participants, 78.8% were under the age of 25. The mean (and standard deviation) of BMI, height (centimeters), and sleeping hours was 23.1 (± SD 2.5), 179.5 (± 7.5), and 6.78 (± 0.9), respectively.

The data was collected from 104 flights overall. There were 16 participants who completed 1 flight, 9 participants who completed 2 flights, and 23 who completed 3 flights. Flight durations varied between different aircrafts and squadrons (range of 20–180 min). The mean duration of flights in each aircraft platform is shown in **Table I**.

We found that 58% of the flights crews were dehydrated as was measured by SG value before the flight. In most of the flights (59.6%, $N = 62$), participants did not take fluids aboard the aircraft and only 21% ($N = 16$) of fighter jet flight pilots consumed fluids. The highest fluid consumption, at 11 flights (85%), was found among Blackhawk pilots at an average of 300 ml.

There were 11 aircrew who completed their flight with a meaningful fluid loss of more than 1% of bodyweight, among them 7 Blackhawk flights representing 41% of all flights in this platform (Table I). On average, participants lost 0.52% (range of 0.41% in the F16 to 0.87% in the Blackhawk) of bodyweight during flight. The percentage of fluid loss from bodyweight is shown in **Fig. 1**. There was a meaningful difference between the observed variance within and between each flight platform. Blackhawk flights lasted longer than the fighter jets' flights (CI = 95%, $P < 0.001$, observed power = 1) and Blackhawk

Table I. Aviators' Calculated Fluid Loss Rate per Hour.

PLATFORM	NUMBER OF FLIGHTS	MEAN FLIGHT DURATION (min)	>1% BODYWEIGHT LOSS FLIGHTS		FLUID LOSS RATE PER HOUR (ml)				ESTIMATED TIME TO 1% BODYWEIGHT LOSS (min)
			NUMBERS	PERCENT	MEAN	SD	MEDIAN	IQ	
Fixed wing transport (The Beechcraft Bonanza and King Air)	21	145	3	14	174.8	105.7	124	350	282
Blackhawk	17	108	7	41	397.7	148.2	305	208	126
Skyhawk (pilots)	39	38	1	3	460.0	337.8	545.5	350	72
Skyhawk (navigators)	11	36	0	0	550.8	348.3	450	412.5	67
Falcon 16B	16	29	0	0	692.2	335	611.3	564.2	67
Total	104	67	11	11	462		404		123

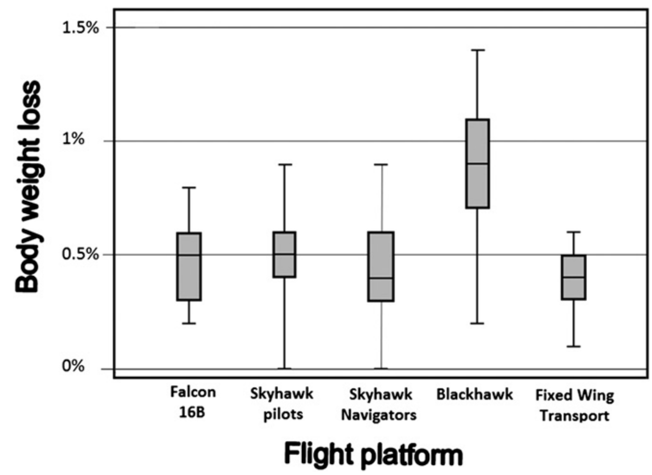

Fig. 1. Percentage of bodyweight loss as an indication of fluid loss per flight.

pilots lost significantly more fluids per flight (CI = 95%, P = 0.001, observed power = 0.96).

Fluid loss was normalized to flight duration and the fluid loss rate per hour was calculated. The data is shown in Table I and the fluid loss percentage of bodyweight per hour is shown in **Fig. 2**. A high variance was observed among fighter jet flights. Fighter jet pilots and navigators had the highest fluid loss rate per hour, as demonstrated by the median of the fluid loss rate. All platforms, compared to the fixed wing transport group, lost significantly more fluids (CI = 95%, fighter jets $P < 0.001$, observed power = 1; and $P = 0.033$, observed power = 0.6 for Blackhawk pilots).

We examined whether or not fluid loss was affected by the aircrew's role in the Skyhawk jet (pilot or navigator) by comparing aircrew at the same age (22.9 yr old on average) who flew on the same days (not in the same flights). There was no significant correlation revealed between pilots' fluid loss (0.76% of bodyweight) and navigators (0.73%). There was also no significant correlation between the specific gravity test before the flight and the fluid loss rate during the flight (CI = 95%, $P = 0.34$), nor a correlation between the difference in SG value before and after the flight and the fluid loss rate during the flight (CI = 95%, $P = 0.15$).

There was no significant correlation revealed between the heat stress index to the overall pilot fluid loss percentage. A separate analysis of fighter aircrafts that are air-conditioned (Falcon 16B) and non-air-conditioned (Skyhawk) did not show any association between fluid loss rate and the air-conditioning system (CI = 95%, Pearson correlation test $P = 0.1$). Other variables that were also examined, such as BMI, physical activities, sleeping hours, age, and fluid intake during flight, did not show any significant association with fluid loss rate.

DISCUSSION

In the current study, we examined the rate of insensible fluid loss among military pilots and the risk of dehydrating during

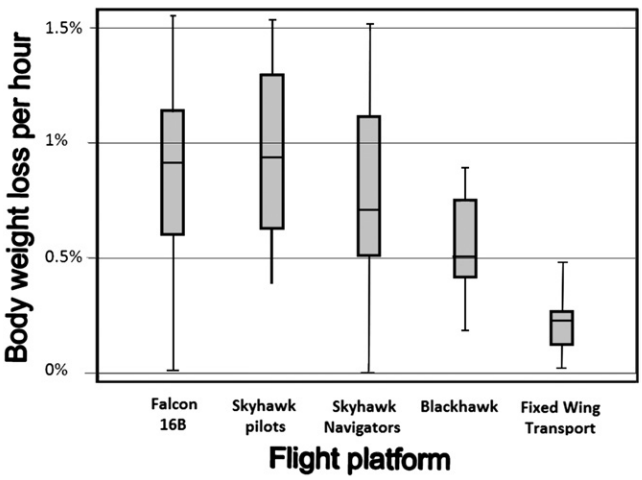

Fig. 2. Percentage of bodyweight loss as an indication of fluid loss per hour.

training flights. The data was collected during 104 training flights of different flight platforms among 48 pilots and navigators.

In approximately 11% of flights, pilots were found to lose meaningful amounts of fluids of more than 1% of their bodyweight. The average overall fluid loss percentage of bodyweight was 0.52% per flight and the mean rate was 0.62% per hour. Dehydration has been previously found to be associated with poor cognitive performance—the greater the dehydration the worse cognitive performance.[16] Lindseth showed in a study, using 40 male U.S. pilots (mean age 20.3), that performance of hydrated pilots in test flights was significantly better than that of pilots who were dehydrated, while using weight loss as a dehydration measure.[14]

Fluid balance is very delicate and is affected by many factors such as fluid intake, fluid loss (by respiration and perspiration), exposure to heat strain, physical activity, etc. Hydration level is defined as the balance between consumed and lost water. Aircrew personnel's hydration levels might be affected by several environmental and ergonomic factors, which vary between flight platforms.

Voluntary dehydration is well known in certain populations. An investigation conducted by the IDF Institute of Military Physiology found that soldiers who worked while being exposed to heat strain conditions with an unlimited water supply consumed only 50% of the fluid amount that was evaporated by sweat. This phenomenon is even greater (fluids consumption is even less than 50%) when the water supply was scarce, or has a foul or salty taste.[3] By measuring SG, we found that 58% of the aircrew in the study began their flight dehydrated, although it is important to note that SG is of limited accuracy in this regard.[2,12,18] We posit that the main reasons for voluntary dehydration during flight are their tight schedule and the uncomfortable urination method available to aircrew (exceptions are aircrew personnel flying in fixed wing transport).[21]

The implications of dehydration in military flights are substantial. Heat strain and its physiological effects on cognitive performance were widely investigated. Flight crews encounter heat stress during preflight, engine start, taxiing out, and standing by for takeoff. Total ground time can be considerable, even to fighter crews.[21] Additionally, the heat load inside the cockpit is higher than on the ground because of the reduced air velocity, greenhouse effect, personnel equipment, and increased radiant heat load produced by the electronic equipment in the aircraft and inner metabolic processes in the crew's bodies.[19,21] As we expected, we did not find an association between environmental heat stress and the pilots' fluid loss in platforms with or without air-conditioning.

As we have shown, fighter pilots and navigators lost more fluids per hour than others. Even though some fighter jets are equipped with air-conditioning systems, conditions such as greater physiological stress caused by high levels of acceleration and the concomitant G loads (which necessitate intense muscle activation, among other things)[5] and a prolonged waiting for takeoff, might increase the aircrew's heat stress, especially on hot days. Beyond the cognitive impairment mentioned before, dehydration might be critical for fighter jet pilots due to its influence on G tolerance. Baldini et al.[4] showed in a study examining 10 male fighter pilots that heat stress and the resultant dehydration have an important role in determining endurance to G load. Another study showed that the dehydration itself reduces G tolerance, as it was measured that during exposure to the same high-level G (7 G), endurance time decreased by nearly 50%.[19]

As was found in the observed fluid loss rate per flight only one fighter pilot ended his flight with a meaningful level of dehydration. This sole dehydration among the examined fighter jet aircrew might be explained by the short duration of trainee flights at the Flight Academy. Operational flight durations, however, vary between different squadrons and at times could last longer than 2 h. In these cases, fighter pilots are at a higher risk for dehydration. In the current study, most flights were dog-fights, which are usually of shorter duration, albeit very intense physiologically and physically. In longer, less intense flight scenarios, fluid loss might be different.

In contrast, fixed wing transport flights are the longest (145 min), but the physiological burden upon the aircrews in those flights is of a lesser degree, and so is the fluid loss as it was measured in the current study. Moreover, fixed wing transports are equipped with toilets, enabling comfort in urination, resulting in a lower probability of voluntary preflight dehydration.

Helicopter pilots experienced more fluid loss than other platforms: 41% of the pilots (7 of 17 flights pilots) finished their flights with meaningful fluid loss. The approximated time, as we calculated, to achieve a meaningful level of dehydration is just over 2 h (126 min), while the average helicopter flight duration, as we observed in the current study, was 108 min. Helicopters, especially lift utility helicopters like the UH-60 Blackhawk of the IAF, are designed with large transparent windshields, which enlarge the surface area of the helicopter and, as a result, a larger amount of solar radiation is trapped and amplified, thereby creating a greenhouse effect inside the cockpit. This phenomenon is greater with prolonged waiting on the ground (cockpit temperature can reach 60°C on hot days), or during low altitude flight, and is worsened by lack of air conditioning.[9] These reasons might explain the greater loss of fluids among helicopter pilots.

Urine SG is sometimes considered a marker for dehydration. However, we did not find any association between the amount of fluid loss and SG. This finding is supported by recent studies[2,12] that also make the claim that SG assessment is not sensitive enough to notice slight losses of bodyweight, such as 1%. In addition, we wanted to see if the initial SG level of an examined individual could predict, and thereby prevent, dehydration, but did not find any association in this respect either. In the current study, we measured fluid loss rate by weight, which is considered the best method.

Flight design in the current study was induced by the instructional needs. We had no influence on the time of the day at which the tested flights took place, flight duration, taxiing out and waiting for takeoff times, etc. In this way, we were able to conduct a real-world study in instructional settings. We found that in this context aircrew probably begin their flights dehydrated (58% by SG $\geq$ 1.020) and compounded their situation through fluid loss during flight, although we should bear in mind that SG is a questionable measure for dehydration. In operational settings, where the daily schedule is even more intense, voluntary dehydration might be even greater. Added to that the possibility of longer flights, sometimes with equal physiological demands, and the importance of rehydration during flight is even higher.

In conclusion, up until now, the recommendations of fluid intake amount during flight were approximations, partly based on fluid intake recommendations for moderate physical activity. This study, as far as we know, is the first one to accurately support recommendations of fluid consumption during military flights. We posit that a substantiated fluid intake recommendation will encourage fluid consumption among aviators and will prevent dehydration.

We found that the fluid loss rate during a training military flight is meaningful and might cause a danger to aircrew's cognitive function, morbidity, and mission safety. The greatest loss per hour was among fighter jet aircrew, but due to short duration of the flights, most of them did not achieve a meaningful fluid loss. Helicopter pilots lost less fluids per hour, but due to longer flight durations they lost the most fluid per flight. Flights spanning longer than an hour require additional fluid consumption during the flight in order to prevent dehydration. These fluids should start to be consumed at the beginning of each flight. Further research is warranted on the cognitive change during flight and its association with fluid balance.

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REFERENCES

1. Adan A. Cognitive performance and dehydration. J Am Coll Nutr. 2012; 31(2):71–78.
2. Armstrong LE. Hydration assessment techniques. Nutr Rev. 2005; 63(6 Pt 2):S40–S54.
3. Armstrong LE, Epstein Y. Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. Int J Sport Nutr. 1999; 9(1):1–12.
4. Balldin UI, Siegborn J. G-endurance during heat stress and balanced pressure breathing. Aviat Space Environ Med. 1992; 63(3):177–180.
5. Bollinger RR, Carwell GR. Biomedical cost of low-level flight in a hot environment. Aviat Space Environ Med. 1975; 46(10):1221–1226.
6. D'Anci KE, Vibhakar A, Kanter JH, Mahoney CR, Taylor HA. Voluntary dehydration and cognitive performance in trained college athletes. Percept Mot Skills. 2009; 109(1):251–269.
7. Eijsvogels TM, Scholten RR, van Duijnhoven NT, Thijssen DH, Hopman MT. Sex difference in fluid balance responses during prolonged exercise. Scand J Med Sci Sports. 2013; 23(2):198–206.
8. Epstein Y, Druyan A, Heled Y. Heat injury prevention–a military perspective. J Strength Cond Res. 2012; 26(Suppl. 2):S82–S86.
9. Froom P, Caine Y, Shochat I, Ribak J. Heat stress and helicopter pilot errors. J Occup Med. 1993; 35(7):720–724.
10. Ganio MS, Armstrong LE, Casa DJ, McDermott BP, Lee EC, et al. Mild dehydration impairs cognitive performance and mood of men. Br J Nutr. 2011; 106(10):1535–1543.
11. Greenleaf JE. Problem: thirst, drinking behavior, and involuntary dehydration. Med Sci Sports Exerc. 1992; 24(6):645–656.
12. Hamouti N, Del Coso J, Mora-Rodriguez R. Comparison between blood and urinary fluid balance indices during dehydrating exercise and the subsequent hypohydration when fluid is not restored. Eur J Appl Physiol. 2013; 113(3):611–620.
13. Lieberman HR. Hydration and cognition: a critical review and recommendations for future research. J Am Coll Nutr. 2007; 26(5, Suppl.) 555S–561S.
14. Lindseth PD, Lindseth GN, Petros TV, Jensen WC, Caspers J. Effects of hydration on cognitive function of pilots. Mil Med. 2013; 178(7):792–798.
15. Magee PJ, Gallagher AM, McCormack JM. High prevalence of dehydration and inadequate nutritional knowledge among university and club level athletes. Int J Sport Nutr Exerc Metab. 2017; 27(2):158–168.
16. Masento NA, Golightly M, Field DT, Butler LT, van Reekum CM. Effects of hydration status on cognitive performance and mood. Br J Nutr. 2014; 111(10):1841–1852.
17. Montain SJ. Hydration recommendations for sport 2008. Curr Sports Med Rep. 2008; 7(4):187–192.
18. Muñoz CX, Johnson EC, Demartini JK, Huggins RA, McKenzie AL, et al. Assessment of hydration biomarkers including salivary osmolality during passive and active dehydration. Eur J Clin Nutr. 2013; 67(12):1257–1263.
19. Nunneley SA, Dowd PJ, Myhre LG, Stribley RF, McNee RC. Tracking-task performance during heat stress simulating cockpit conditions in high-performance aircraft. Ergonomics. 1979; 22(5):549–555.
20. Rogers R, Cole R. Hydration status in US military officer students. US Army Med Dep J. 2016; Jan.-Mar.:24–29.
21. Sawka MN, Wenger CB, Montain SJ, Lovell M. Heat stress control and heat causality management. Washington (DC): U.S. Army Research Institute of Environmental Medicine; 2003.