Aviators Can't Live on Water Alone
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Caffeine is the most widely used drug in the world. Eighty-two to 92% of North Americans regularly consume caffeinated beverages. The average consumption is 200-600 mg/day with 20-30% of caffeine consumers ingesting >600mg/day (4). Even with such high usage rates, there has been some debate concerning caffeine and its possible dehydrating effects. Because of its purported diuretic potential many health professionals and governmental agencies have advised abstaining from caffeine consumption when attempting to prevent dehydration. Does that mean aviators should avoid caffeinated beverages based on the premise caffeine will induce dehydration? The belief that caffeine is a diuretic has been the accepted wisdom for many years, even though; there have been very few research investigations to support this belief and many others with opposing findings. As Aerospace Physiologists, we tell our aviators drink water to stay hydrated, but can caffeinated beverages be used to hydrate?

Caffeine is effective at reversing some of the effects of fatigue and can be used as a fatigue countermeasure (3). However, many aviators do not understand how to effectively manage caffeine use to maximize its effectiveness and they do not know how to mitigate the risks associated with its consumption. The goal of this article is to clear up misunderstandings concerning caffeine and hydration and to give some basic guidelines for effectively using caffeine as a fatigue management tool.

Prior to addressing the specifics of caffeine and hydration and the guidelines for use; let's go over caffeine chemistry and how caffeine affects human physiology. The active ingredient in caffeinated foods and beverages are classified chemically as methylxanthines. There are three sub-classifications of methylxanthines with 1, 3, 7-trimethylxanthine (caffeine) being the most widely consumed. Caffeine is a central nervous system (CNS) and cardiac stimulant and has a wide array of effects on the human body. For the purpose of this discussion, we will center on the CNS. Caffeine exerts its effects at CNS synapses by blocking the binding of the neurotransmitter adenosine to postsynaptic neuron receptors. Because adenosine reduces postsynaptic activity, blocking it increase the excitability of the postsynaptic neurons. This results in a general increase in CNS excitability and a catetecholamine (*e.g.* epinephrine and noreprinephrine) release from the adrenal medulla via sympathetic activation. The general physiological effects of caffeine consumption and the resulting sympathetic activation are, but not limited to, increase in heart rate, blood pressure, muscle blood flow and release of glucose from the liver (9).

Caffeine exerts its limited diuretic effects via the kidneys. An increase in blood flow to the kidneys and a reduction of electrolyte (*e.g.* Na+ and Cl-) reabsorption are primary factors involved in the water loss. The increase in blood flow to the kidneys is due to sympathic activation and peripheral vasoconstriction. This results in glomerular filtration pressure elevation ultimately leading to larger urine volumes. In addition, the lack of Na+ and Cl-reabsorption, at the kidney, leads to more water moving with the electrolytes into urine due to osmotic pressure gradients. Increased blood flow and reduced reabsorption of electrolytes illicit slightly larger urine volumes and an increase in fluid loss (14).

Caffeine can cause a slight increase in fluid loss, but is the loss significant enough to negatively affect human performance and should aviators avoid consuming any

caffeine? Debate currently exists concerning caffeine's effect on hydration status. When consumed within moderate limits (200-400 mg/day or 2-4 cups of coffee), studies have reported ingesting caffeine has little effect on hydration (1). In fact, water has been shown to have similar diuretic effects compared to caffeine. Armstrong (1) conducted a recent review of the scientific literature examined caffeine's diuretic effects. Consumption of caffeinated beverages ranging from 100 to 680 mg doses resulted in 0-84% retention of the initial fluid volume ingested, whereas, consumption of water resulted in 0-81% retention. In this study, water caused ~3% more fluid loss compared to the caffeinated beverage. In 2005, Armstrong et al. (2) reported that moderate doses of caffeine (3 and 6 mg caffeine/kg/day) over 6 days did not increase urine output above placebo and that caffeine does not put one at risk for heat stress. Researchers that conducted caffeine's effect on hydration studies have presented similar findings (7, 8, 12). It appears, based on the recent scientific literature, that moderate consumption of caffeine should not put aviators at risk for dehydration. The Naval Aviation community knows that the 3710.7T states caffeine consumption should not exceed the moderate value of 450 mg/day (3-4 cups of coffee/day). If caffeine is only a very mild diuretic, why is there a limit on the amount aviators can consume?

High does of caffeine can elicit a severe stress-like neuroendrocrine response very similar to the "fight or flight response". This stress-like response may reduce an aviator's ability to perform his or her aircraft duties, but for this response to occur, it would take ~500 mg (approximately 5 cups of brewed coffee) to be consumed in one sitting or (13). You may be thinking who drinks 5 cups of coffee in one sitting? Here is an example: A survey sampled one 16 oz specialty coffee each day over a six day period. The caffeine content ranged from 259 mg/16 oz to 564 mg/16 oz. (10). Another example is Rockstar Zero Carb, which has 360 mg in one serving. As you can see, it can be very easy to reach the 450 mg/day limit or even exceed it in one sitting. Due to the possibility to a performance degrading stress-like response (*e.g*. caffeine jitters), the use of only moderate amounts of caffeine (< 450 mg/day) may be recommended for consumption.

Another reason an aviator should be aware of the total amount of caffeine they are consuming is that individual tolerance can determine to what degree caffeine will affect their physiology and ultimately their performance. For example, an aviator who drinks 6-7 cups of strong coffee every day will have a greater tolerance to its stimulating effects compared to those who only use caffeine sparingly or not at all (6). To recognize how caffeine may affect an aviator, a novel caffeine user can experiment with caffeine use several days prior to critical missions and deployments so they can be aware of caffeine's effects. On the other hand, regular users may not be as responsive to caffeine's stimulating effects reducing it's effectiveness as a fatigue countermeasure. Another aspect to consider is that regular caffeine users can be at risk for withdrawal if they do not have regular caffeine access. Withdrawal from caffeine can cause general fatigue, irritability, and headaches none, of which, are conducive to performing flight duties. The risk of withdrawal in regular caffeine users can be reduced by slowly ceasing its use over a few weeks prior to times when there may not be regular access to caffeine. Not only will ceasing caffeine intake reduce the risk of withdrawal, it will sensitize the aviator to the effects of caffeine increasing it's effectiveness as a fatigue countermeasure. To increase caffeine sensitivity, it is recommended caffeine consumption be gradually reduced and stabilized at 50% for 2-7 days prior to use as a fatigue management tool (5). Whether used on a regular basis or only sparingly, aviators should understand before hand how caffeine will affect their performance in the aircraft.

Based on the current research concerning caffeine's lack of diuretic effects, it can be concluded that moderate caffeine usage over a 7 day period does not negatively impact hydration or increase the risk of heat stress (1,2, 7, 8, 12). However, the long term effects (i.e. > 7 days) of caffeine consumption are unclear at this time (1). Furthermore, excessive consumption of caffeine, especially in novel users, can have negative consequences such as over stimulation of CNS, withdrawal and de-sensitization. Even though these possible risks exist, they are manageable. An aviator can mitigate the risk of caffeine over-consumption and de-sensitivity by being aware of caffeine content in the foods and beverages they consume, by understanding their response to caffeine consumption, and by being aware of the amount caffeine consumed during the day/night. By educating our aviators concerning the risks of use and how to manage use, the likely hood of them experiencing any of the negative aspects of caffeine consumption can be significantly reduced.

Caffeinated beverages with moderate amounts (< 450 mg/day) of caffeine can be recommended to supplement water to maintain or improve hydration levels. By providing proper education concerning caffeine and hydration management at Aviation Survival Training Centers and by Aeromedical Safety Officers, aviators will be better prepared to manage their hydration status and caffeine consumption. Water is always best for hydration purposes, but we should not steer our aviators away from fluids containing caffeine due to possibility of dehydration. The bottom line is that as long as the aviator understands the idiosyncratic effects caffeine may have on their performance and they understand the manageable risks associated with caffeine intake, moderately caffeinated beverages may be used without the fear of negatively affecting the aviator's performance.

Due to the fact that moderate caffeine will not increase the risk of dehydration in our aviators and its possible usage risks can be effectively managed, its use as a fatigue management tool is warranted. Strategically using caffeine has been shown to improve alertness in those who are awake during abnormal hours of the day (*e.g.* 0300) and those who accumulated fatigue over a period days or weeks (5). Instead of aviators consuming caffeine haphazardly throughout the day, aviators can strategically use caffeine to maximize its effectiveness. The aviator should use caffeine during naturally occurring times of low alertness that occur during the circadian troughs and avoid caffeine during times of naturally high levels of alertness. For most people, the low alertness troughs typically occur between 1500-1800 and 0300-0600. The effects of caffeine can take ~30 minutes to manifest (4); therefore, the use of caffeine should start at least 30 minutes prior to decreased levels of alertness. The effective caffeine dose can vary significantly among users and its effectiveness can be task dependent, but the optimal range appears to be somewhere around 400 mg (11). For example, a mission that will be schedule to take place during 0200-0600 the aviator would plan to start caffeine consumption around 0130-0230. If this same aviator plans to go to sleep at 0800, they would terminate the use of caffeine between 0300 and 0400 because the stimulating effects last ~3-4 hours (5). By terminating caffeine intake 3-4 hours prior to bedtime the stimulating effects should subside and the chance of insomnia will be reduced. By using during periods of low alertness levels, by terminating use a few hours before sleep and by starting use prior to the onset of fatigue, the effectiveness of caffeine as a fatigue countermeasure can be greatly enhanced.

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