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FATIGUE IN CONTINUOUS AND SUSTAINED AIRPOWER OPERATIONS: REVIEW OF PHARMACOLOGIC COUNTERMEASURES AND POLICY RECOMMENDATIONS

by

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Disclaimer

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Abstract

The use of stimulants as a fatigue countermeasure in military aviation has a long history dating back to British use of amphetamines during World War II. The issue of US pilots taking psychologically active controlled substances to counteract the effects of fatigue recently ignited a public debate following the Tarnak Farms friendly fire incident. Supporters of using stimulants in this setting maintain that fatigue induced performance degradation poses a much greater risk to pilot and aircraft safety than risks associated with stimulant medications. Conversely, opponents contend that these agents alter judgment and decision-making ability in aviators who have at their disposal an instrument with a degree of precision and lethality never before seen in the history of conventional warfare. This review represents an effort to inform the military community about the dangers of fatigue in the aviation setting along with the appropriate role of stimulants in attenuating this danger. Based on detailed analysis of existing research in the field of aviation fatigue management, along with considerations of various cognitive processes and the possible effects of stimulant medications on those processes, several concluding recommendations directed to Air Force commanders, senior leaders, policy makers, and aircrew will help guide future fatigue management measures and policies.

Introduction

On the evening of 17 April 2002, two US F-16s were airborne near Kandahar, Afghanistan providing on-call support for coalition ground forces as part of Operation ENDURING FREEDOM. The two pilots, COFFEE 51 and COFFEE 52, had been flying for approximately six hours when they detected what they perceived to be surface-to-air fire off the right side of their formation. Subsequently, COFFEE 52 requested permission from the Airborne Warning and Control System (AWACS) aircraft to employ his 20mm cannon in response to the threat. After a series of radio communications between the F-16s and the AWACS, COFFEE 52 called "self-defense" in response to seeing several men gathered near an artillery piece and released a 500-pound laser guided bomb on the target. Two minutes and twenty seconds had elapsed from the request for 20mm cannon fire and release of the bomb. The bomb detonated three feet from the gathering of men, killing four and wounding eight. The men were Canadian – friendly forces conducting a training exercise in the area (Dumas 2002).

This sequence of events, known as the Tarnak Farms friendly fire incident, caused strained relations between the US and Canada over the actions taken by the pilots and differing perspectives concerning the proper disciplinary action that should result. Both the disagreement between the US and its long time ally and the military's lengthy disciplinary process have been highly publicized by both domestic and international media. A related debate soon emerged as additional details of the Tarnak Farms incident surfaced. Specifically, both pilots ingested dextroamphetamine tablets during the flight in question, with COFFEE 52 taking his 10mg dose approximately two hours before releasing the weapon (Dumas 2002). The issue of US pilots taking psychologically active controlled substances to counteract the effects of fatigue quickly ignited a public debate, further fueled by one of the defense attorney's assertion that the Air

Force had pressured his client to take dextroamphetamine, which, he argues, may have impaired the pilot's judgment (Simpson 2003).

Despite military investigators' contention that the pilots were operating at ninety-one percent effectiveness at the time of the incident (Dumas 2002), the public debate continued unabated. The supporters of using stimulants in this setting maintain that fatigue induced performance degradation poses a much greater risk to pilot and aircraft safety, not to mention the possibility of collateral damage, than risks associated with stimulant medications. Conversely, opponents contend that these agents alter judgment and decision-making ability in aviators who have at their disposal an instrument with a degree of precision and lethality never before seen in the history of conventional warfare. They argue that awake but impaired operators are a tremendous danger in and of themselves. This continuing debate demands further study to clarify the most appropriate course of action for Air Force policy in future operations.

The use of stimulants as a fatigue countermeasure in military aviation has a long history dating back to British use of amphetamines during coastal defense operations and the extended Combined Bomber Offensive missions during World War II. On the opposing side, Axis powers Germany and Japan also reported using stimulants to combat fatigue associated with sleep deprivation in their pilots. Although not likely the first use of amphetamines in US aviators, but the first official sanctioning of their use began with Strategic Air Command in 1960, followed shortly thereafter by Tactical Air Command in 1962. Continuing, Vietnam and Operation DESERT STORM also saw the use of stimulants to combat the effects of fatigue with improved medical and administrative oversight during the later conflict that led to improved effects and pilot perceptions (Cornum 1997). Recent history has also seen use of dextroamphetamine as a force extender for long duration flights by both fighter and bomber pilots. In fact, Operation

ENDURING FEEDOM claims the longest fighter and bomber missions in the history of aerial warfare, 15.8 and 44 hours respectively (Kenagy 2004) - the likes of which would likely have been impossible without pharmacologic assistance.

This review represents an effort to inform the military community about the dangers of fatigue in the aviation setting along with the appropriate role of stimulants in attenuating this danger. This discussion begins with a description of the potentially dangerous effects of fatigue in the aviation environment and then reviews numerous operational reports with an emphasis on highlighting the scope and severity of the aircrew fatigue problem. A discussion of potential fatigue countermeasures, both non-pharmacologic and pharmacologic, is followed by a review of several anecdotal reports of stimulant use in operational settings. Existing Air Force pharmacologic fatigue countermeasure policy is summarized, followed by an analysis of various cognitive processes (i.e. vigilance, judgment, and decision-making) involved with combat pilot performance and whether stimulants alter these processes in any undesirable manner. Finally, a recommendation regarding the continued use of amphetamines among Air Force pilots is offered, along with suggested policy modifications and areas demanding further research. The desired end state is for pilots, commanders, flight surgeons, and senior leaders to be better informed as to the degree of congruence between current Air Force amphetamine policy and empiric research support for such use. Correspondingly, a clear delineation will be made of where evidence based support for the use of prescription fatigue countermeasures ends, and where commanders and other senior leaders must make difficult choices based on imperfect research, balancing demands for mission accomplishment with the need for risk minimization.

Sleep Deprivation and Fatigue

A tremendous advantage held by the US military is the capacity to conduct operations on an around-the-clock basis thus diminishing our foe's ability to respond to the myriad of threats presented to them. In carrying out these operations, our own military forces become sleep deprived, and the problem presented by fatigue may become immense. Technology helps enable continuous and sustained operations doctrine, but advances over the past several decades, on occasion, have outstripped human capacity to keep pace. By definition, continuous operations extend beyond 72 hours but do not necessarily require longer hours worked per individual, whereas sustained operations involve individual continuous performance longer than 72 hours, usually until goal attainment (Wheeler 2002). Continuous and sustained operations bolster the current Air Force concepts of Global Reach and Global Power. Thus, effective maintenance of the human weapon system is critical to mission success.

The danger of fatigue to the Air Force's mission, people, and resources is readily apparent upon examination of recent mishap statistics. From 1972 to 2000, fatigue was a causal or contributing factor in 234 of 1837 (12.7 percent) Class A aircraft mishaps – no single factor ranked more detrimental to performance and safety than fatigue (Wheeler 2002). Outside the Air Force, the effects of fatigue are also problematic. The transport industry (including rail, land, air, and sea) identified fatigue as the largest preventable cause of all accidents. In fact, between 15 and 20 percent of all transport industry accidents cited fatigue as a factor, easily surpassing alcohol or drug related causes (Akerstedt 2000). Clearly, the insidious onset of fatigue coupled with lack of a quantifiable detection method, makes recognition and intervention rather difficult, which even further increases the likelihood of accidents and safety hazards.

In 1998, Dawson and Reid attempted to correlate the performance impairment caused by fatigue with that produced from alcohol intoxication using a tracking task to measure hand-eye coordination. In the study's forty subjects, 24 hours of sustained wakefulness decreased cognitive psychomotor performance to a level equivalent with a blood alcohol concentration of 0.10 percent – a level deemed legally intoxicated in all 50 US states. Furthermore, a mere 17 hours of sustained wakefulness impaired performance to a level equivalent to a blood alcohol concentration of 0.05 percent (Dawson 1997) – a level above the Federal Aviation Administration imposed limit 0.04 percent for alcohol-induced impairment (14 CFR sec. 91.17). Dawson and Reid's influential research helped quantify the significance of fatigue's detrimental impact on performance and remains a frequently referenced work in the field of fatigue management – to include both the Air Force (Wheeler 2002) and Navy (Brown 2000) fatigue management guides.

Numerous reports published over the past 12 years highlight the extent and severity of fatigue in aviation operations in general, and US military aviation in particular. Largely subjective evidence from Army helicopter pilots at home station, Navy aviators during Operation SOUTHERN WATCH, and Air Force airlifters during the surge phase of Operation DESERT SHIELD provide additional resolution to the understanding of fatigue during military operations. A recent study evaluated more than 240 Army helicopter pilots at their home station using a survey to assess their perceptions about fatigue, as well as data related to their demographics, work hours, flight time, and sleep adequacy and quality. Important findings included pilots' average sleep per night was almost an hour less than their perceived required amount to feel fully rested, raising concerns about fatigue due to cumulative sleep debt. The study's most alarming finding was the 45 percent affirmative response to the question "Have you ever dozed off while flying?" Given the high probability of reduced quality and quantity of sleep when deployed, these data from a home station assessment of fatigue are particularly concerning given that even one hour of chronic sleep loss may adversely affect performance (Caldwell 2002).

When the USS Independence deployed during August and September 1992 in support of Operation SOUTHERN WATCH, a flight surgeon assessed pilot fatigue during continuous flight operations consisting of 1400 sorties and 5200 cumulative flight hours. The majority of pilots reported experiencing fatigue in some form, and fatigue was directly responsible for the cancellation of one sortie. Collectively, pilots lost an average of 24 minutes of sleep per day during the study period compared to baseline. While this result may not be overly concerning at first glance, subgroup analysis showed that field grade pilots lost an average of 1.6 hours per night due to increased planning responsibilities compared to more junior pilots. The authors identified mishap potential as the greatest concern of fatigue during continuous operations – most likely resulting from loss of situational awareness and/or spatial orientation (Belland 1994).

The airlift in support of Operation DESERT SHIELD was the largest in history, with up to 300 missions per day. During the surge phase (October 1990), a unit flight surgeon assessed fatigue among C-5 pilots and recorded ratings of moderate or extreme fatigue from many aircrews, especially during transoceanic flights. The author personally visualized several instances of possible impaired performance due to fatigue including fumbling radio frequency changes, decreased crew coordination, diminished checklist discipline, impaired judgment, and slowed decision-making (Bisson 1993). Given the subjective nature of fatigue assessment, aircrews need additional training to recognize their personal fatigue syndrome. Together, these three studies underscore the relevance of fatigue for pilots, commanders, and flight surgeons in operations planning and risk mitigation, including crew rest and flight duty limitations.

Non-Pharmacologic Fatigue Countermeasures

Knowing the danger of aircrew fatigue to mission success and safety, it is imperative that measures be taken that will preclude, or at the very least minimize, the risk of any undesirable outcomes. Investigations of various methods to counteract the effects of fatigue stemming from prolonged sleep deprivation, like that seen in operators during continuous and sustained operations, have resulted in varying degrees of success, utility, and applicability to military aviation. Strategies such as limiting time on task, rest breaks, and adequate pre-mission sleep, while somewhat effective, may be impractical or impossible given operational demands in the midst of a contingency. However, commanders and other leaders should do everything in their power to maximize restful aircrew sleep during crew rest periods, as avoidance of cumulative sleep debt prior to an extended duration mission is highly desirable. It is important to distinguish between sleep time and crew rest time, as the latter also includes activities such as transportation, exercise, personal hygiene, meals, and other various personal activities. While the amount of sleep required to feel fully rested can vary between individuals from four to ten hours, a target of seven hours of uninterrupted sleep should be appropriate when considering fatigue management prior to a long mission (Wheeler 2002).

Under certain circumstances, napping during a period of prolonged wakefulness may provide a very effective fatigue countermeasure. While undoubtedly not applicable to fighter airframe situations, napping may be appropriate and of significant utility in bomber and transport operations with multiple pilots and protracted periods of reduced activity and very minimal threat. A nap of almost any duration offers a performance advantage; however, a period of cognitive sluggishness, known as sleep inertia, is generally present upon awakening (Caldwell 1997c). The duration of sleep inertia often depends on which sleep phase the subject was experiencing when awakened – the deeper the sleep phase interrupted, the longer the sleep inertia will linger (Ferrara 2000). In general, naps of less than 30 minutes (known as a combat nap) or in the three to four hour range (known as a short sleep) are most desirable when seeking to minimize sleep inertia and maximize restorative value. Where appropriate, commanders should encourage combat naps and possibly short sleeps among aircrew members, as these tactics are extremely effective in maintaining performance during continuous and sustained operations because they directly address the underlying problem of fatigue, not just the symptoms (Wheeler 2002).

The growing importance of physical fitness in meeting the demands of an increasingly expeditionary force has produced a notable culture change in the Air Force, making the effects of conditioning and exercise in fatigue prevention worthy of study. Today, Air Force personnel must be prepared to meet the challenges of performing intense duties in austere environments, often amidst extremes of temperature (Jumper 2003). While highly fit individuals are surely more resistant to physical fatigue from prolonged exertion, unfortunately, research has not shown them to be any more resilient to mental fatigue from sleep deprivation than their less fit peers (Angus 1992). Therefore, while improved aviator fitness is highly desirable and operationally advantageous for many other reasons, it does not offer sizeable benefit under sleep deprived conditions. On another note, brief intervals of exercise (i.e. running or cycling) have shown capable of counteracting fatigue for short periods up to 30 minutes (Horne 1995). Although exercise may be useful for ground personnel, regrettably, this approach does not offer much, if any, utility to aircrew due to restricted mobility and confined spaces. In aggregate, non-pharmacologic fatigue countermeasures fall far short of an idyllic approach; therefore, the demands of continuous and sustained operations require use of additional ameliorative strategies.

Pharmacologic Fatigue Countermeasures

When non-pharmacologic approaches are not appropriate or applicable, and performance is at risk of degrading to dangerous levels, pharmacologic interventions may offer an effective, short-term solution. While many of the previously mentioned non-pharmacologic approaches address the principal problem of sleep deprivation, certain medications offer the ability to prevent or reverse the effects of fatigue for hours or days until restorative sleep is available. These stimulants are advantageous because of their effectiveness, ease of use, and lack of dependence upon environmental or scheduling factors (Caldwell 2003a). Research information exists for several stimulant medications, but three are worthy of further comment due to their frequent use, volume of supporting research, and status under Air Force policy.

Caffeine

Caffeine is a widely available and socially acceptable stimulant that can effectively sustain alertness for several hours after consumption. Research has demonstrated caffeine's ability to sustain vigilance and reaction time in fatigued subjects under military conditions (Gillingham 2004, Tikuisis 2004) and experiences of Navy pilots during Operation SOUTHERN WATCH showed it to be beneficial in mitigating the effects of fatigue (Belland 1994). A majority of the US adult population consumes a psychologically active dose of caffeine daily, a fact that limits it widespread application as a fatigue countermeasure because tolerance develops to its alertness enhancing effect in just a few days (Caldwell 2003a). Escalating doses can overcome this tolerance; however, this approach runs the risk of causing other side effects that do not build tolerance as quickly, such as anxiety and tremor. Overall, caffeine is effective as a short-term fatigue management strategy, but tolerance, side effects, and modest effectiveness compared to other alternatives limit its formal use in an operational environment.

Dextroamphetamine

Dextroamphetamine is the most widely studied and extensively utilized pharmacologic fatigue countermeasure. Its use by military forces dates back to World War II (Cornum 1997) and possibly even earlier. It gained public prominence throughout the middle decades of the twentieth century as an often-used drug of abuse. In response to this growing public misuse, it received classification as a Schedule II controlled substance, the most highly restricted category for medically useful products, emanating from its documented potential to cause psychological and physical dependence. Abuse and addiction notwithstanding, measured doses administered under controlled conditions have shown to be effective in mitigating fatigue's negative effects – with very little, if any, risk of addiction. As mentioned earlier, the Air Force formally authorized dextroamphetamine more than forty years ago. During this period, not a single event of pilot disqualification occurred due to inappropriate use or abuse of this medication – reinforcing the low risk of misuse with disciplined adherence to established controls (Cornum 1997). Several studies underscore dextroamphetamine's benefit in sustaining vigilance during extended operations – forming the basis for the continued use of this agent in Air Force aviators.

In a study by Newhouse et al, subjects endured sleep deprivation for 48 hours while completing various simple mental tasks such as addition-subtraction and logical reasoning trials. Research evaluation considered both speed and accuracy of the participants' accomplishment of the tasks. Dextroamphetamine proved effective in improving response accuracy on each trial during the sleep deprivation period, along with measured response time. Side effects were minor and expected – including increases in blood pressure and heart rate (Newhouse 1989). Overall, effects of dextroamphetamine were highly favorable and very influential for those in the aviation community – solidifying this study as a seminal work in the fatigue management literature. In fact, more than 12 years after its original publication, the most recent Air Force policy letter cites this article as foundational evidence for existing guidelines (Murray 2001).

A series of studies from the US Army Aeromedical Research Laboratory build upon Newhouse's findings, but these four reports are in an aviation setting using Army helicopter pilots (Caldwell 1995, 1997a, 1997d, 2000a). The four studies vary in sleep deprivation periods from 40 hours (three studies) to 64 hours (one study), and in aviation test procedure employed – a simulator in three studies and actual flight operations in the other. Admirably, all four studies compare the effects of dextroamphetamine to placebo across two successive sleep deprivation periods, with participants randomly receiving dextroamphetamine or placebo in each session. This methodology facilitates extrapolation of the findings because subjects served as their own control group and the sequencing of sleep deprivation periods more accurately reflects combat operations – multiple extended periods without sleep, often in close proximity.

Collectively, results showed that administration of dextroamphetamine effectively attenuates the negative impact of fatigue on flight performance. Specifically, the authors remarked, "Flight skills remained at or above normal throughout the entire testing period and did not succumb to the circadian / fatigue related drop in the early morning" (Caldwell 2003b, 1132). Unfortunately, there was no systematic examination of side effects, but researchers did note that participants receiving dextroamphetamine showed an increase in talkativeness, but not recklessness or carelessness. After the test session, there was evidence of impaired sleep for participants receiving the stimulant – sleep was lighter, possibly providing less restorative value. This finding is likely of minimal significance under conditions of adequate post-mission sleep. However, magnification of chronic sleep debt may develop with the repeated use of dextroamphetamine combined with over zealous limitations on crew rest (Caldwell 2003b).

On the topic of side effects, the medical literature clearly shows that dextroamphetamine increases blood pressure, speeds heart rate, and may cause insomnia or impaired sleep quality. Research of this stimulant in populations of young, healthy aviators has reconfirmed these long established side effects (Caldwell 1996, Caldwell 1997b), but these effects are unlikely to have appreciable effects on pilot performance during flight operations. However, another study suggests that dextroamphetamine may cause some degree of tunnel vision – a much more concerning finding for aviators. When arousal becomes overly intense, it floods one's attention mechanisms and limits information gathering ability – akin to the "fight-or-flight" response – leading to visual tunneling. This effect is very troubling for pilots because dangers or threats may present from any part of the visual field – on dashboard controls or outside the cockpit canopy (Mills 2001). This worrisome finding demands additional research to clarify its implications for combat airpower operations where maximal situational awareness is critical.

The question of dextroamphetamine's effects on judgment remains largely unanswered in the literature, despite interest following the Tarnak Farms friendly fire incident. Several studies suggest that dextroamphetamine impairs judgment (Davis 1947, Hurst 1962, Smith 1964); however, other reports either refute, or do not replicate this finding (Baranski 1997, Hurst 1966, Newhouse 1992). The critical issue in these studies is the definition of judgment and its relation to decision making during combat airpower missions. The predominant definition of "judgment" in these studies relates to one's ability to self-assess performance on a simple mental task versus researcher-measured performance. While this question of performance estimation is interesting, it bears little relevance to decision making under complex, stressful, time constrained situations – the kind demanded of pilots engaged in combat. Operational safety requires further investigation along this line, although with a much more robust research definition of judgment.

Modafanil

Modafinil is a recent addition to the prescription stimulant market that may offer some promise in the military aviation setting. The US Food and Drug Administration (FDA) granted approval for this new entity in late 1998, with approved uses in narcolepsy and shift work sleep disorder. The FDA classifies modafinil as a controlled substance, however, it is much less likely to cause physical or psychological dependence compared to dextroamphetamine – hence modafinil's less restrictive regulatory classification (Cephalon Inc. 2004). Due to its relatively recent availability, research into its effects is not as voluminous as either caffeine or dextroamphetamine, but there are noteworthy reports of its alertness enhancing effects that may be very valuable in military aviation. These positive reports recently prompted Air Force officials to authorize modafinil use in fighter and bomber pilots, although with more restrictive guidelines and limitations than with the longstanding stimulant of choice, dextroamphetamine.

First, Army helicopter pilots remained awake for 40 hours during two separate sessions while performing flight maneuvers in a simulator. Participants randomly received modafinil during one session and placebo during the other. Overall, pilots achieved better aviation scores after receiving modafinil, suggesting its ability to attenuate the effects of sleep-induced fatigue. Of note, a few study participants reported occasions of nausea, vertigo, and dizziness. Although total side effect frequency was low, this is a very noteworthy finding given the possibility of these unfavorable side effects occurring during actual flight operations (Caldwell 2000b).

More recently, Air Force F-117 pilots conducted flight maneuvers in a simulator while enduring 37 hours of wakefulness. Comparisons between modafinil and placebo showed some degree of performance degradation in both groups when compared to baseline, non-fatigued measurements. However, modafinil maintained flight accuracy at about 85 percent of baseline levels, whereas the participants receiving placebo performed at only 40 percent of baseline – a highly significant difference between groups. Once again, side effects were low, but reports of nausea and lightheadedness were more frequent in those taking modafinil (Caldwell 2004).

One head-to-head, non-aviation study tested modafinil and dextroamphetamine (double the current Air Force approved dose) during 64 hours of continuous wakefulness. While both were effective at maintaining performance, results showed those receiving dextroamphetamine felt more "wired," whereas those receiving modafinil offered comparatively more neutral remarks about their state of arousal (Pigeau 1995). Exact interpretation is difficult due to the double dose in one group; however, this finding could have either positive or negative implications in an operational setting, depending on viewpoint. On one hand, modafinil's more neutral arousal effect is preferable because recipients are likely functioning in a more normal cognitive state. Conversely, the lack of any perceptible effect on arousal may lead to repeat dosing in an effort to gain an effect, risking detrimental side effects with higher doses.

Differentiation between dextroamphetamine and modafinil as the preferable fatigue management strategy is an approximate process – at best, educated guesses guide this choice. Aviation studies exist for both agents, however, no head-to-head, definitive comparisons exist in this setting to aid in directing future policy. Both agents are effective at attenuating fatigue induced performance degradation, but comparisons of simulator research and operational reports subtly suggest that dextroamphetamine may be slightly more effective. Although side effects of increased blood pressure and heart rate may occur with dextroamphetamine, modafinil's potential to cause nausea, lightheadedness, and/or dizziness during a combat mission is possibly more concerning to pilots. While it is certainly nice to have two effective alternatives, there is a clear need for additional aviation research to better define the medication of choice.

Air Force Perspectives

Air Force Policy

Crew rest and flight duty limitations form the foundation of the Air Force's fatigue management program, with the collective goal of maintaining performance in operators who conduct extended and highly demanding missions. The relevant Air Force Instruction (AFI) specifically states, "Commanders and mission planners must assess the impact of factors that reduce aircrew alertness," and "must terminate a mission or mission leg if safety may be compromised by fatigue factors" (AFI 11-202V3 2003, sect 9.2). Crew rest is required before an aviator's flight duty period begins, with the directed 12-hour crew rest consisting of at least ten hours of restful activities to include eight hours of uninterrupted sleep. Shortening the crew rest period to ten hours during continuous operations (defined as three or more 12-hour duty periods separated by the minimum crew rest) in order to maintain a 24-hour work/rest cycle is permissible, but the eight-hour sleep requirement remains in effect. In addition to crew rest instructions, delineation of maximum flying time exists to minimize the likelihood of cumulative fatigue and is as follows: 56 hours per seven days, 125 hours per 30 days, and 330 hours per 90 days. This published guideline concludes by identifying the combined contributions of pre-mission rest, non-pharmacologic and pharmacologic countermeasures, as well as aircrew education and training initiatives, in the management of fatigue (AFI 11-202V3 2003).

Extremely detailed and specific guidance also exists for the use of pharmacologic fatigue countermeasures, known in the Air Force aviation community as "Go Pills." The guidelines' explicitness is understandable and necessary since these agents are psychologically active controlled substances that the FDA has not formally sanctioned for use under these circumstances. The Air Force currently authorizes both dextroamphetamine and modafinil for fighter and bomber missions only; however, use of either modality requires the exhaustion on non-pharmacologic approaches, continued adherence to crew rest requirements, and written approval in advance from the commander and senior flight surgeon. Furthermore, to avoid any drug interactions and/or additive stimulative effects, the same aviator on a single mission may not use the two Go Pill options simultaneously, but different aircrew members may use different options on the same mission and individual aviators may use either alternative from one mission to another (Taylor 2003).

Specifically, the Air Force authorizes use of dextroamphetamine in single pilot fighter missions longer than eight hours and dual pilot bomber missions of 12 hours or more (Headquarters USAF/XO message). Because of modafinil being a newer product with less extensive research in the aviation environment compared to dextroamphetamine, the Air Force only authorizes its use in dual piloted bombers conducting missions longer than 12 hours and F-15 weapons systems operators conducting missions longer than eight hours. Fighter pilots, or any pilot in a single seat operation, may not use modafinil at this time, pending additional research (Taylor 2003). Guidelines establish clear mission length for use of Go Pills, but also recognize their possible benefit in shorter duration missions. Medically related requisites before use of either Go Pill include informed consent and ground testing. The informed consent process consists of counseling between the aircrew member and the flight surgeon that includes an explanation of the risks and benefits associated with either dextroamphetamine or modafinil, with clarification and emphasis that the use of Go Pills is voluntary on the part of the aviator. Current Air Force regulations for the use of Go Pills build on substantive investigation of their effects in the aviation environment, keeping in mind the need to prevent or reverse fatigue induced performance degradation while maximizing safety for operators and aircraft alike.

Air Force Operational Experiences

Several anecdotal reports of dextroamphetamine's use and experiences under actual combat situations add to its body of aviation related research. While limitations exist in the appropriate or widespread extrapolation of these data because of their quasi-experimental, retrospective, or case report methodology, they offer important insight into usage patterns, pilot perceptions, and recommendation for future use. These four reports describe three combat airpower operations covering 17 years and collectively serve as positive field validation of current Air Force policy.

The first report describes Operation EL DORADO CANYON, when four F-111 Ravens attacked targets in Libya on 14-15 April 1986. Pilots flew 13-hour missions after extended planning sessions, totaling their cumulative wakefulness to well beyond 24 hours at the time of landing. Every aircrew member utilized dextroamphetamine, with all reporting benefit from its effects in counteracting fatigue that peaked during the last few hours of the mission. There were no complications or mishaps during the flight, thus, the author concluded that dextroamphetamine was a successful Go Pill (Senechal 1988).

Combat pilots in Operation DESERT STORM also used dextroamphetamine to prevent fatigue, with details offered in an investigation of those operating F-16s, F-15, A-10s, and F-4s in close air support, interdiction, and combat air patrol missions. Results showed that use of Go Pills during transoceanic deployment and combat operations was 65 and 57 percent, respectively. Use was much lower in F-4 and A-10 pilots flying short, close air support missions, while some F-15 units flying combat air patrol missions documented use in 96 percent of pilots. Most use of Go Pills was occasional and overwhelmingly rated as either beneficial or essential (Emonson

1995). The author concluded, "Dextroamphetamine is a safe and effective medication which improved aircrew cockpit performance and enhanced flight safety" (Emonson 1995, 263).

The final two reports are from Operation IRAQI FREEDOM, the first from F-16 fighter pilots and the second from B-2 bomber pilots. In the first account, 19 fighter pilots offered their experiences with, and impressions of, both fatigue and dextroamphetamine during high operations tempo combat operations. Sixteen of 19 aviators (84 percent) utilized Go Pills at some point during the study period, with all dosages occurring late in the mission, usually after departing the combat zone or prior to landing. The most frequently reported problem was difficulty sleeping after the mission, due to the medication's residual effects from taking doses too late in the mission. Overall, the author's conclusion about dextroamphetamine was positive, however, she does offer the recommendation of considering Go Pills during mission planning instead of relying on an in-flight, possibly fatigue impaired decision about Go Pill use. This planning step may also facilitate consumption earlier in the flight, thus, avoiding the post-landing insomnia reported by these pilots (Schultz 2004).

Finally, an investigation of B-2 pilots conducting extended bombing missions from both the continental US (35-hour average) and a forward location (17-hour length) closer to the area of operations showed that pilots often took advantage of their Go Pills to combat fatigue. Fifty-seven percent of pilots departing from the continental US used dextroamphetamine compared to 97 percent of those operating from the forward location. The suggested reason for the difference in usage rates was the more free time available for US based pilots to nap during transoceanic travel. Overall, side effects were remarkably low and pilots offered high marks for its beneficial effects. Like the other studies, the author deemed dextroamphetamine safe and effective in mitigating fatigue during extended bomber missions (Kenagy 2004).

Cognitive Processes

Pilots perform a wide variety of functions while operating an aircraft, especially under combat situations. These tasks vary from basic piloting skills such as take offs, landings, and maintaining course, to more complex tasks including aerial refueling, and finally those involving much higher order cognitive processes such as responding to threats and attacking targets (Kenagy 2004). For combat pilots, these tasks traverse the entire continuum of cognitive functioning – ranging from attentiveness and vigilance at the lower end of the spectrum to judgment and decision-making at the opposite extreme. Fatigue affects these distinct processes at differing rates, with attentiveness and vigilance being the most susceptible to the negative consequences of fatigue. In comparison, judgment and decision-making are somewhat less sensitive; however, they too will suffer the same erosive effects if sleep deprivation periods continue unabated (Wheeler 2002). It follows that interrelations between these concepts – fatigue from prolonged sleep deprivation and various echelons of cognitive processing – should build the foundation for fatigue management considerations in the future, especially when contemplating pharmacologic strategies.

Undeniably, attentiveness and vigilance are exceptionally critical skills for operation of any vehicle, under all circumstances, regardless of duration. Every driver of an automobile knows the importance of these attributes – staying attuned to the road, other vehicles, and driving conditions are paramount for safe vehicle operation. As discussed earlier, numerous studies of pharmacologic fatigue countermeasures demonstrate their ability to prevent and/or reverse the untoward effects of fatigue on attentiveness and vigilance. These studies provide evidentiary support for use of stimulants in facilitating safe aircraft piloting during continuous and sustained airpower operations. It follows that attentiveness and vigilance are necessary, but not sufficient, conditions for the effective performance of combat airpower operations – judgment and decision-making are critically important as well.

Although stimulant studies, specifically those using dextroamphetamine, have amassed notable substantiation of benefit on attentiveness and vigilance, equivalent data for effects on judgment and decision-making do not exist. Several studies used simple arithmetic calculations as a proxy for higher cognitive functions. Others sought to define judgment as one's ability to assess their own performance after performing these simple arithmetic calculations, both during fatigued periods and after receiving a stimulant. While these attempts at identifying higher order cognitive effects are noteworthy, these surrogate markers bear little semblance to those that face operators of combat aircraft. Decisions faced by operators are often ill structured, multi-factorial, extremely time constrained, amidst rapidly changing conditions, and with very high stakes for both success and failure. The name found in the research literature that describes decision making under these circumstances is Naturalistic Decision Making. Development of this new model arose as a more complete alternative to "classical" decision making which focused on artificially contrived, usually meaningless scenarios (Cannon-Bowers 1996).

To date, there are no literature reports of Naturalistic Decision Making evaluations among sleep-deprived aviators, either with or without stimulant assistance. However, there are military related investigations of this new paradigm. In 1996, Kaempf et al evaluated decision making in a complex command and control environment, using the Combat Information Center aboard a US Navy AEGIS cruiser as their study setting. Findings showed that these highly trained and experienced decision makers made their actual choices very quickly, usually with very little deliberation. Most interestingly, before making the actual decision, participants were primarily concerned with developing additional situational awareness, and often went through considerable effort to gain it. The authors define situational awareness as, “a state of knowledge that includes three components: the perception of elements within the environment, the comprehension of their meaning, and the understanding of their anticipated status in the near future” (Kaempf 1996, 223). The conclusion was that decision makers rely on their vast training and experience using recognitional processes to make their decisions. The primary concern in making decisions via this method is one’s situational awareness (Kaempf 1996).

These finding are encouraging for two reasons. First, it proposes that well trained and highly skilled individuals make complex decisions in uncertain and time constrained situations based on recognition of events and patterns from their experiences. Given that Air Force fighter and bomber pilots train under similarly complex circumstances at Red Flag and the Weapons School, they are much better prepared when facing complex decisions during combat. Secondly, research supports the ability of pharmacologic stimulants to maintain attentiveness and vigilance under sleep deprived conditions. Attentive and vigilant operators should develop situational awareness to a much greater extent and level of detail than those pilots experiencing some degree of impairment from the negative effects of fatigue. It follows that stimulants, such as dextroamphetamine and modafinil, should indirectly maintain or improve judgment and decision making in highly trained combat pilots through the facilitation of more accurate situational awareness. This hypothesis relies on the assumption that attention and vigilance play a similar role in the basic elements of flying an aircraft (well documented in stimulant studies) as with the development of situational awareness. However, it is unproven whether the more passive process of developing situational awareness is analogous to the more active process of flying, specifically in regards to its association with stimulant-induced enhancement of attention and vigilance.

Recommendations

First, it is clear that the continued use of pharmacologic fatigue countermeasures under voluntary conditions is essential to the conduct of safe air operations, thus, continuation of current policy is advisable. Air Force policy makers must remain steadfast in the face of periodic public criticism and occasional political questioning – armed with the knowledge of the solid empiric support for this force enabler. The basis of this recommendation emanates from careful balancing of risk parameters. Research abounds showing the risks of operating an aircraft while fatigued, so too are studies showing the ability of stimulants to mitigate these risks. Conversely, conjecture and speculation largely define the risks associated with stimulant use in fatigued aviators, with the paltry and conflicting evidence of stimulant-altered judgment deriving from studies that inaccurately define and poorly relate this concept to decision making under realistic conditions. Furthermore, suggestions of impaired judgment and decision making from stimulant use overlook and/or underestimate the role that attention and vigilance play in the development of situational awareness – which has shown to be foundational for decision-making in complex, time constrained environments. Therefore, it is inappropriate to discontinue or further restrict the use of pharmacologic fatigue countermeasures due to hypothetical risks when evidentiary support clearly highlights more significant and better-defined risks associated with not maintaining alertness and vigilance while flying.

Next, a revision is necessary for the current informed consent document (Go Pill Form 1) that requires completion by the aircrew member and flight surgeon before granting authorization to ingest dextroamphetamine. The current informed consent document lists side effects typically found in medical reference books or in the manufacturer's published prescribing information – appropriate for the overwhelming majority of medical circumstances, but not sufficiently complete for aviators, because it fails to mention any possibility of tunnel vision. Documentation of this effect remains limited in the literature, thus, requiring further exploration to delineate its onset, duration, and severity. There is a very low likelihood that the severity of this effect would dictate banning stimulants from the cockpits of combat aircraft, but there are possible aspects of this effect that may necessitate refining guidelines for the optimal use of stimulants in certain mission types or at particular times within a mission. Just as pilots are aware of distorted and narrowed vision during high G-force maneuvers, likewise, aviators who might sometime ingest dextroamphetamine certainly need to know about this possibility as well.

Finally, there is a need for additional research to better define the effects of pharmacologic fatigue countermeasures under real world circumstances, specifically in regards to higher order cognitive processes. Existing research provides solid support for the role of stimulants in sustaining piloting ability in fatigued aviators by maintaining lower order cognitive processes (i.e. alertness and vigilance). One can make a strong argument that judgment and decision-making under complex, time-constrained circumstances are contingent on robust situational awareness, thus, dependent on alertness and vigilance. However, substantiation of this assertion does require further research. Using the Naturalistic Decision Making construct as a research model, creation of new study methodologies will yield results that answer important questions about pilot decision-making in operational situations while fatigued – either with or without pharmacologic intervention. Such programs as Red Flag and the Weapons School offer the most realistic decision-making conditions for combat pilots short of open hostilities, making them great mediums for study. Investigations of pilot judgment and decision making in these intense, but controlled situations will offer valuable data to guide the future of fatigue management strategies and policy.

Conclusion

Despite recent advances in technology that have dramatically altered the nature of modern warfare – stealth, precision munitions, advanced computer systems, and unmanned aerial vehicles – the human weapon system remains central to the operation of these innovations and ultimately determines their overall success or failure. Increasingly, technological advances challenge the limits of human performance capabilities, requiring adaptation or modification of innate human characteristics in order reduce or eliminate limiting factors on the employment of these high-tech weapon platforms. Fatigue is one such limiting factor. Bomber missions exceeding 40 hours and fighter missions over 15 hours undoubtedly push the limits of effective human performance under sleep-deprived conditions. Given the importance of combat pilots and aircraft to US national interests, in terms of both economic investment and combat capabilities, it is appropriate to implement measures to maximize their safety and ensure the appropriate application of their power in the face of highly fatiguing conditions. Based on detailed analysis of existing research in the field of aviation fatigue management, along with considerations of various cognitive processes and the possible effects of stimulant medications on those processes, several concluding recommendations directed to Air Force commanders, senior leaders, policy makers, and aircrew will help guide future fatigue management measures and policies.

Bibliography

Aeronautics and Space Act. *Code of Federal Regulations*. Title 14, Vol. 2, sec. 91.17

Air Force Instruction (AFI) 11-203V3. *General Flight Rules*, 6 June 2003

Akerstedt, Torbjorn. Consensus Statement: Fatigue and Accidents in Transport Operations. *Journal of Sleep Research* 9, (2000):395.

Angus, R.G., Pigeau, R.A., and Heslegrave, R.J. Sustained Operation Studies: From the Field to the Laboratory. In *Why we nap: Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep*. Edited by C. Stampi. Boston: Birkhäuser, 1992..

Baranski, Joseph V., and Pigeau, Ross A. Self-Monitoring Cognitive Performance During Sleep Deprivation: Effects of Modafinil, d-Amphetamine, and Placebo. *Journal of Sleep Research* 6, (1997):84-91.

Belland, K.M., Bissel, C. A Subjective Study of Fatigue During Navy Flight Operations Over Southern Iraq: Operation Southern Watch. *Aviation, Space, and Environmental Medicine* 65, no. 6 (June 1994):557-561.

Bisson, Roger U., Lyons, Terence J. and Hastel, Charles. Aircrew Fatigue During Desert Shield C-5 Transport Operations. *Aviation, Space, and Environmental Medicine* 64, no. 9 (September 1993):848- 853.

Brown, Dave, and Barker, C.O. *Performance Maintenance During Continuous Flight Operations*. Naval Aerospace Medical Research Laboratory. 2000.

Caldwell, John A., Caldwell, J. Lynn, Crowley, John S., and Jones, Heber D. Sustaining Helicopter pilot Performance with Dexedrine During Periods of Sleep Deprivation. *Aviation, Space, and Environmental Medicine* 66, no. 10 (October 1995):930-937.

Caldwell, John A. Effects of Operationally Effective Doses of Dextroamphetamine on Heart Rates and Blood Pressures of Army Aviators. *Military Medicine* 161, no. 11 (November 1996):673-678

Caldwell, John A., Caldwell, J. Lynn, and Crowley, John S. Sustaining Female Helicopter Pilot Performance With Dexedrine During Sleep Deprivation. *The International Journal of Aviation Psychology* 7, no. 1 (1997a):15-36.

Caldwell, John A., and Caldwell, J. Lynn. Recovery Sleep and Performance Following Sleep Deprivation with Dextroamphetamine. *Journal of Sleep Research* 6, (1997b):92-101.

Caldwell, John A. Fatigue in the Aviation Environment: An Overview of the Causes and Effects As Well As Recommended Countermeasures. *Aviation, Space, and Environmental Medicine* 68, no. 10 (October 1997c):932-938.

Caldwell, John A., and Caldwell, J. Lynn. An In-Flight Investigation of the Efficacy of Dextroamphetamine for Sustaining Helicopter Pilot Performance. *Aviation, Space, and Environmental Medicine* 68, no. 12 (December 1997d):1073-1080.

Caldwell, John A., Smythe, Nicolas K., Leduc, Patricia K., and Caldwell, J. Lynn. Efficacy of Dexedrine for Maintaining Aviator Performance During 64 Hours of Sustained Wakefulness: A Simulator Study. *Aviation, Space, and Environmental Medicine* 71, no. 1 (January 2000a):7-18.

Caldwell, John A., Caldwell, J. Lynn, Smythe, N.K., and Hall, K.K. A Double-Blind, Placebo-Controlled Investigation of the Efficacy of Modafinil for Sustaining the Alertness and Performance of Aviators: A Helicopter Simulator Study. Psychopharmacology 150, (2000b):272-282.

Caldwell, John A., and Gilreath, Steven R. A Survey of Aircrew Fatigue in a Sample of US Army Aviation Personnel. *Aviation, Space, and Environmental Medicine* 73, no. 5 (May 2002):472-480.

Caldwell, John A. Fatigue in Aviation Special Operations: Understanding the Problem and Possible Ways to Fix It. *Air Force Special Operations Command Commando Safety Journal*, Winter 2003a:28-35.

Caldwell, John A., Caldwell, J. Lynn, and Darlington, Kecia K. Utility of Dextroamphetamine for Attenuating the Impact of Sleep Deprivation in Pilots. *Aviation, Space, and Environmental Medicine* 74, no. 11 (November 2003b):1125-1134.

Caldwell, John A., Caldwell, J. Lynn, Smith, Jennifer K., and Brown, David L. Modafinil's Effects on Simulator Performance and Mood in Pilots During 37 Hours Without Sleep. *Aviation, Space, and Environmental Medicine* 75, no. 9 (September 2004):777-784.

Cannon-Bowers, Janis A. Salas, Eduardo, and Pruitt, John S. Establishing the Boundaries of a Paradigm for Decision-Making Research. *Human Factors* 38, no. 2 (1996):193-205.

Cephalon Inc. *Provigil Prescibing Information*. West Chester, PA, February 2004.

Cornum, Rhonda, Caldwell, John, and Cornum, Kory. Stimulant Use in Extended Flight Operations. *Airpower Journal* 11, no. 1 (Spring 1997):53-58.

Davis, D. Russell. Psychomotor Effects of Analeptics and Their Relation to "Fatigue" Phenomena in Aircrew. *British Medical Bulletin* 5, (1947):43-45.

Dawson, Drew, and Reid, Kathryn. Fatigue, Alcohol, and Performance Impairment. *Nature* 388, (17 July 1997):235.

Dumas, Mark J., and Sargeant, Stephen T. *Summary of Facts: Tarnak Farmas Friendly Fire Incident near Kandahar, Afghanistan*. MacDill Air Force Base, FL: Untied States Central Command, June 2002.

Emonson, David L., and Vanderbeek, Roger D. The Use of Amphetamines in US Air Force Tactical Operations During Desert Shield and Storm. *Aviation, Space, and Environmental Medicine* 66, no. 3 (March 1995):260-263.

Ferrara, Michele, De Gennaro, Luigi, and Bertini, Mario. Time-Course of Sleep Inertia Upon Awakening from Nighttime Sleep with Different Sleep Homeostasis Conditions. *Aviation, Space, and Environmental Medicine* 71, no. 3 (March 2000):225-229.

Gillingham, Robin L., Keefe, Allan A., and Tikuisis, Peter. Acute Caffeine Intake Before and After Fatiguing Exercise Improves Target Shooting Engagement Time. *Aviation, Space, and Environmental Medicine* 75, no. 10 (October 2004):865-871.

Headquarters United States Air Force, Air and Space Operations (HQ USAF/XO) Message. 200958Z Feb 01. To All Major Command Commanders, Surgeons General and Operations Officers, 20 February 2001.

Horne, J.A., Foster, S.C. Can exercise overcome sleepiness? *Sleep Research* 24, (1995 supp A):437

Hurst, Paul M. The effects of d-Amphetamine on Risk Taking. *Psychopharmacologia* 3, (1962):283-290.

Hurst, Paul M., and Weidner, Marianna F. *Drug Effects Upon Cognitive Performance Under Stress*. Office of Naval Research Report No. ONR-H-66-3. Washington, DC: Office of Naval Research, August 1966.

Jumper, Gen John. *Chief's Sight Picture: Fit to Fight*, 30 July 2003.

Kaempf, George L., Klein, Gary, Thordsen, Marvin L., and Wolf, Steve. Decision Making in Complex Naval Command-and-Control Environments. *Human Factors* 38, no. 2 (1996):220-231

Kenagy, David N., Bird, Christopher T., Webber, Christopher M., and Fischer, Joseph R. Dextroamphetamine Used During B-2 Combat Missions. *Aviation, Space, and Environmental Medicine* 75, no. 5 (May 2004):381-386.

Mills, Kenneth C., Spruill, Susan E., Kanne, Roy W., Parkman, Katherine M., and Zhang, Ying. The Influence of Stimulants, Sedatives, and Fatigue on Tunnel Vision: Risk Factors for Driving and Piloting. *Human Factors* 43, no.2 (Summer 2001):310-327.

Murray, Brig Gen Gary H., Commander, Air Force Medical Operations Agency. To All Air Force Major Command Surgeons General. Letter. Subject: Policy Letter on the Implementation of HQ USAF/XO Message, Combat Air Force (CAF) Aircrew Fatigue Countermeasures, 26 June 2001.

Newhouse, Paul A., Belenky, Gregory L., Thomas, Maria L., Thorne, David R., Sing, Helen C., and Fertig, Joanne B. The effects of d-Amphetamine on Arousal, Cognition, and Mood After Prolonged Total Sleep Deprivation. *Neuropsychopharmacology* 2, no. 2 (1989):153-164.

Newhouse, Paul A., Penetar, David M., Fertig, Joanne B., Thorne, David R., Sing, Helen C., Thomas, Maria L., Cochran, Joyce C., and Belenky, Gregory L. Stimulant Drug Effects on Performance and Behavior After Prolonged Sleep Deprivation. *Military Psychology* 4, no. 4 (1992):207-233.

Pigeau, Ross A., Naitoh, P., Buguet, A., McCann, C., Baranski, Joseph V., Taylor, M., Thompson, M., and Mack, I. Modafinil, d-Amphetamine and Placebo During 64 Hours of

Sustained Mental Work: Effects on Mood, Fatigue, Cognitive Performance, and Body Temperature. *Journal of Sleep Research* 4, (1995):212-228.

Schultz, Darlene, and Miller, James C. Fatigue and Use of Go/No-Go Pills in Extraordinarily Long Combat Sorties. *Aviation, Space, and Environmental Medicine* 75, no. 4 (April 2004):370-371.

Senechal, Peter K. Flight Surgeon Support of Combat Operations at RAF Upper Heyford. *Aviation, Space, and Environmental Medicine* 59, no. 8 (August 1988):776-777.

Simpson, Doug. Air Force pushed pilots to take amphetamines, lawyer says in 'friendly fire' case. *The Detroit News*, 2 January 2003.

Smith, Gene Marshall, and Beecher, Henry K. Drugs and Judgment: Effects of Amphetamine and Secobarbital on Self-evaluation. *Journal of Psychology* 52, no. 2 (1964):397-405.

Taylor, Lt Gen George Peach, Air Force Surgeon General, and Keys, Lt Gen Ronald E., Deputy Chief of Staff for Air and Space Operations. To All Air Force Major Command Vice Commanders. Letter. Subject: Modafinil and Management of Aircrew Fatigue, 2 December 2003.

Tikuisus, Peter, Keefe, Allan A., McLellan, Tom M., and Kamimori, Gary. Caffeine Restores Engagement Speed But Not Shooting Precision Following 22 Hours of Active Wakefulness. *Aviation, Space, and Environmental Medicine* 75, no. 9 (September 2004):771-776.

Wheeler, Dan, ed. *Warfighter Endurance Management During Continuous Flight and Ground Operations*. Brooks Air Force Base, TX: United States Air Force School of Aerospace Medicine. 2002.