INTRODUCTION
Studies by NASA have shown that astronauts obtain only about 6 hours of sleep per day on average during space flight. Laboratory experiments have shown that such sleep reduction can result in substantially enhanced probability of performance failure within a few days [1]. This vulnerability may be exposed during emergencies in space (due to equipment failure, mission timeline problems, or other stressors) involving extended mission demands and further sleep loss, resulting in possibly catastrophic outcomes. Yet, considerable inter-individual differences in the magnitude of performance failure during extended wakefulness have been documented [2]. This project is the first to quantify trait-like and state-specific contributions to this variability in human vulnerability to performance impairment from sleep loss.

METHODS
Materials
To date, n=19 normal, healthy subjects (age 29.1±5.4; 9 females) each participated in three laboratory-based sleep deprivation sessions, at intervals of 2–4 weeks. The study protocols for the three sessions were identical, and involved 36 hours (from 10:00 until 22:00 the next day) of behaviorally monitored total sleep deprivation in an isolated laboratory with fixed ambient temperature (21 °C) and light (<50 lux). Every 4 hours, subjects received a standardized meal. Every 2 hours, they were tested on a 60-minute neurobehavioral performance test battery, which included a Karolinska Sleepiness Scale (KSS; pre-test), a digit–symbol substitution task, a critical tracking task, a word signal detection task (WSDT), a psychomotor vigilance task (PVT), and another KSS (post-test). Subjects were given a 12-hour recovery sleep opportunity following each of the three exposures to total sleep deprivation. Two weeks prior to the actual experiment, all subjects slept a night in the laboratory and underwent neurobehavioral testing during wakefulness the next day for the purpose of adaptation to the experimental procedures.

Experimental Conditions
On the 7 days preceding each of the three sleep deprivation sessions, subjects were scheduled to sleep either 12 hours (time in bed 22:00–10:00) so as to satiate their need for sleep, or 6 hours (time in bed 04:00–10:00) in order to simulate the chronic sleep reduction typically observed in space. The sleep satiation condition occurred twice, and the sleep restriction condition once, in randomized order. Compliance was verified by means of actigraphy and a diary, and subjects called the laboratory to report their bedtimes. The last of the 7 sleep periods preceding total sleep deprivation was spent inside the laboratory. Subjects were not allowed to use alcohol, caffeine, tobacco or drugs.

Data Analysis
Neurobehavioral performance outcomes (averages over the last 24 hours of the 36 hours of sleep deprivation) in the two prior sleep satiation conditions were subjected to random-effects analysis of variance (ANOVA) to compute trait (between-subjects) variance as a percentage of total (between-subjects and within-subjects) variance for vulnerability to performance impairment from sleep loss. Random-effects ANOVA over the average of the prior sleep satiation conditions versus the prior sleep restriction condition was then used to calculate a first-order approximation of state variance as a percentage of trait variance.

RESULTS AND DISCUSSION
Trait variance in performance impairment from sleep loss ranged from 61.4% (PVT performance lapses) to 91.2% (WSDT correct detections) of total variance in the two exposures to 36 hours of sleep deprivation following 7 days of sleep satiation (P<0.005). State-specific variance related to prior sleep restriction was estimated to be no greater than 14.5% (pre-test KSS sleepiness score) of the trait variance in the data. Thus, while sleep history affected vulnerability to performance deficits during 36 hours of extended wakefulness, the dominant determinant of performance failure during extended wakefulness was trait vulnerability to sleep loss. This has important implications for the use of mathematical models to predict performance capability during space flight, considering the small number of astronauts on board space craft. These mathematical models should accommodate trait-like inter-individual differences in order to give meaningful predictions of crew vulnerability during critical episodes in space flight [3].

REFERENCES