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Analysis of Commute Times and Neurobehavioral Performance Capacity in Aviation Cabin Crew

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16. Abstract
Fatigue-induced impairments in neurobehavioral performance capacity may compromise safety in 24-hr operational environments, and a potential contributing factor of special interest in commercial aviation is the influence of commute times prior to reporting for duty. However, no systematic field data exist regarding actual commute times in commercial aviation or the relationship between commute times and objective neurobehavioral performance capacity. To address these issues, the present study analyzed data from 807 one-way commute episodes and corresponding performances on standardized 5-min Psychomotor Vigilance Test (PVT) sessions by 160 active cabin crew from the 2009-2010 US Civil Aerospace Medical Institute-sponsored Flight Attendant Field Study (Roma et al., 2010). All eligible pre-work commute events were categorized as commutes originating from home at the start of a work trip ("Home," n=444) or commutes while away on a work trip ("Trip," n=363). Commute times from home were more widely distributed and positively skewed than commute times during a trip, and a univariate Analysis of Covariance (ANCOVA) controlling for reserve status, gender, and age confirmed that Home commutes were significantly longer than Trip commutes (mean$\pm$SEM: 81$\pm$3 vs. 31$\pm$3 min, p<.001). Next, we utilized separate ANCOVAs as above to examine commute times based on Carrier Type (Network, Low-Cost, Regional), Seniority (Senior, Mid, Junior), and Flight Operations (Domestic, International). Crew working for Network carriers had the longest Home and Trip commutes, although this effect was an artifact of Flight Operations, as follow-up analyses of domestic-only crew revealed no differences in commute times. Analysis of Seniority revealed no differences in Home commutes; however, Trip commutes of Mid and Junior level crew (33$\pm$2 and 34$\pm$2 min, respectively) were significantly longer than those of their Senior colleagues (23$\pm$3 min, ps<.01). Crew working International flights had significantly longer Home and Trip commute times versus their counterparts working Domestic operations (Home: 123$\pm$9 vs. 73$\pm$4 min, Trip: 39$\pm$3 vs. 29$\pm$1 min, ps<.01). Finally, we organized all Commute episodes into ascending categories (Home: <30,30-60,60-90,90-120,>120 min; Trip: <30,30-60,60-90,>90 min) and utilized separate ANCOVAs as above to evaluate the relationships between commute times and mean performances of various PVT metrics. In addition, we assessed the relationship between commute times and mean predicted effectiveness scores rendered by the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) model, which accounted for sleep history and circadian factors based on each participant's actual sleep/wake/location patterns preceding each commute/PVT pairing. Analysis of Home commutes revealed no significant relationships between commute times and PVT reaction times, speed, lapses, false starts, or "effectiveness" (speed as % of individual baseline; F(4,436)s<1.5, ps>.20), although a trend in SAFTE predicted effectiveness (F(4,436)=2.36, p=.052) suggested a potential "recovery" effect of sleep obtained during commutes >120 min. Analysis of Trip commutes revealed no significant relationships between commute times and PVT reaction times, speed, lapses, false starts, effectiveness, or SAFTE predicted effectiveness (F(3,356)s<1.2, ps>.30). The apparent lack of effects on neurobehavioral performance capacity at the start of and during trips reveals the limited value of commute times *per se* as a significant predictor of fitness for duty.

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CONTENTS

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BACKGROUND

Numerous factors can affect safety, performance, and quality of life in individuals working in 24-hr operational environments such as industrial shift-work, military, health care, law enforcement, space exploration, and transportation, and one issue of increasing importance to commercial aviation is fatigue (Caldwell, 2012; Mallis, Banks, & Dinges, 2010; Nesthus, Schroeder, Connors, Rentmeister-Bryant, & DeRoshia, 2007). Fatigue is generally defined as a state of tiredness due to prolonged wakefulness, extended work periods, and/or circadian misalignment, and is characterized by decreased alertness, impaired decision-making, and diminished neurobehavioral performance capacity (Åkerstedt, 1995; Dinges, 1995).

A variety of operational and lifestyle factors can systematically contribute to fatigue, and a potential factor of special interest to both the aviation community and the traveling public is the effect of crew members' commutes prior to reporting for duty. The myriad issues relevant to commute times in aviation are thoroughly discussed by the National Research Council (NRC) in their committee report, *The Effects of Commuting on Pilot Fatigue* (2011). Among the standout issues for all stakeholders and decision makers is the lack of systematic data on commute times and the effects of commute times on fitness for duty. As part of that report, initial analyses of archival personnel data from commercial carriers revealed a wide range of potential commute times based on home-to-domicile distances of >30,000 pilots, with approximately 50% of mainline and regional pilots living ≤150 miles away from their domicile base (presumably commuting via ground-based transportation) and 22% living between 750 to >2,250 miles (presumably commuting via air transport; NRC, 2011). Recent survey results of transportation workers revealed average self-reported commute times from home to work of 45.5 min in the 202 pilot respondents, with 37% commuting at least 60 min (National Sleep Foundation [NSF], 2012). Similar survey work of >9,000 cabin crew personnel also broached the issue of commuting, with 62% of respondents reporting commute times of <90 min and 38% reporting commutes >90 min (Avers, King, Nesthus, Thomas, & Banks, 2009). Of course, linear distance from home to domicile can at best yield only a very coarse estimate of commute times, whereas self-reported commute times are at best an estimated average, neither of which can account for day-to-day variations in real commute times due to traffic, flight delays, or other unforeseen complications. Although the data described above provide valuable first steps in scientifically approaching the issue of commuting in commercial aviation, no systematic field data exist on actual commute times or the potential effects of real commutes on neurobehavioral performance capacity. To address these gaps, the present study analyzed data from 807 pre-work commute episodes and corresponding performances on 5-min Psychomotor Vigilance Test (PVT) sessions by 160 active cabin crew from the 2009-2010 U.S. Civil Aerospace Medical Institute (CAMI)-sponsored Flight Attendant Field Study (Roma et al., 2010). Although the aforementioned project was not expressly designed as an investigation of commute times, the extensive database of daily activity logs and standardized neurobehavioral performance testing represents a valuable resource for generating objective, empirical insights on commuting and performance capacity in commercial aviation crew.

METHOD

All human subjects procedures involved in this project were independently reviewed and approved by the Institutional Review Boards of both the U.S. Federal Aviation Administration (FAA) and the Institutes for Behavior Resources. The formal letters of approval from each institution are available upon request from the authors. All data have been de-identified to protect the privacy of those who participated and preserve the anonymity of the companies for whom they worked.

Participants

We refer the reader to Roma et al. (2010) for extensive details on subject recruitment, materials, and data collection protocol for the CAMI Flight Attendant Field Study. Briefly, all eligible applicants were active U.S.-based flight attendants categorized according to three broad factors serving as the organizing framework for the study's design. These factors were Carrier Type (Network, Low-Cost, or Regional), Seniority (self-identified Senior 1/3, Mid 1/3, or Junior 1/3), and majority Flight Operations (Domestic or International). A total of 202 flight attendants participated in the study, and as described below, a total of 160 individuals contributed data suitable for the analyses presented herein.

Materials and Data Collection

Each participant was issued a touchscreen-based personal digital assistant device (PDA, AT&T Tilt™) for maintaining a daily activity log and collecting objective performance data. Using a custom-programmed graphical interface on the PDA, all participants maintained the activity log by recording the location (airport code) and local start time of various activities such as commuting, on-duty periods, and sleep episodes. The definitions for all log events are presented in Roma et al. (2010), although for the present study, we offer the excerpted definition of "Commute" below:

> We use this term more like a 9-to-5 office worker, so log "Commute" to represent any personal transit time from home/crash-pad/hotel to show time when you check-in at the airport for work. Commuting is also any personal transit time from the airport back to home/crash-pad/hotel after your work day has ended. [Note: Participants were also instructed during training that "Commute" includes deadhead flights immediately preceding or following a work day].

In addition to the activity log, participants were required to complete up to four discrete test sessions per day: Pre-Sleep, Post-Sleep, Pre-Work, and Post-Work. Participants were instructed to complete the Pre- and Post-Sleep sessions within ~15 min of going to bed and waking up, respectively. In addition, on work days, participants were instructed to complete the Pre- and Post-Work sessions within ~1 hr of "check-in" and "check-out" (the beginning and end of the entire duty day, respectively). Each test session began with a 5-min touchscreen-based Psychomotor Vigilance Test (PVT) programmed under the same parameters as the Palm-based PVT previously developed at the Walter Reed Army Institute for Research (Thorne, Johnson, Redmond, Sing, Belenky, & Shapiro, 2005; Lamond, Dawson, & Roach, 2005) and effectively utilized for various field studies in 24-hr operational environments (Ferguson et al., 2008; Lamond, Petrilli, Dawson, & Roach, 2006).

Each participant contributed data every day, as described above, for a continuous 3 to 4-week study period. To maintain consistency across days, locations, and conditions, all participants were instructed to conduct their test sessions in a comfortable, normally lit environment with as few sensory distractions as possible. All participants were informed that safety and fulfilling their professional duties supersede all study requirements, and they were explicitly instructed to never engage in any research activities while actively engaged in or responsible for any work-related activities.

Data Processing and Analysis

Commute events. Given the focus on fitness for duty following commutes, we limited our analyses exclusively to Pre-Work test sessions completed after or within 15 min of the end of logged Commute events. Other logged Commute events were excluded from analysis if they were <2 min in duration, if there was a >60 min latency between the end of the preceding "No Work" event (indicating off duty either at home or away on a work trip) and subsequent Commute start time, or if the Pre-Work PVT test was initiated >90 min after the end of the logged Commute. These selection parameters are somewhat arbitrary and may be rather conservative, but the loss of some valid cases in order to minimize the influence of logging and technical errors ultimately increases confidence in the validity of the resulting Commute-PVT pairings used for analysis. The only commuting variable available for analysis was duration (henceforth expressed in minutes); although participants had the option to provide supplemental notes in their activity logs, details regarding commute modality (i.e., walking, driving, public transportation, flying) or lodging accommodations were not provided in sufficient quantity for analysis.

Neurobehavioral performance. Each PVT test yields a number of output variables per session, including mean Reaction Time (RT, msec), mean Speed ([1/RT]*1000), total Lapses (RTs > 500 msec), and total False Starts (FS, premature responses), all of which were included as objective neurobehavioral performance metrics. In addition to these measures, we also included corresponding "Predicted Effectiveness" results as previously rendered by the SAFTE™/FAST™ biomathematical modeling system (Hursh et al., 2008, 2010, 2011) as well as analogous "Actual Effectiveness" scores based on real PVT data; both variables represent PVT Speed as a percentage of individual baseline (see Roma, Hursh, Mead, & Nesthus, 2012, for calculation details). To avoid undue influence of extreme outliers on the calculation of Effectiveness as a percentage of individual baselines, sessions with mean PVT Speed greater than two standard deviations above the grand distribution mean were excluded from further processing. We then removed practice sessions recorded during training, sessions with timestamps dated outside the respective individual's activity log, and all sessions from individuals for whom valid modeling reports could not be produced due to corrupted files, processing errors, or unreliable activity logging. Ultimately, the selection processes described above yielded a total of 807 valid Commute episodes and corresponding Pre-Work PVT sessions from 160 flight attendants (mean = 42 yr, range = 22-67 yr). Of those 807 Commute-PVT pairings, 69% were from female crew and 21% were from crew on reserve status.

Data analysis. To provide insight on the different contexts in which commuting takes place, all Commute-PVT pairings were categorized as either commutes originating from home at the start of a work trip ("Home," $n = 444$) or commutes while away on a work trip ("Trip," $n = 363$). Several variables were analyzed via separate univariate Analyses of Covariance (ANCOVA) controlling for age, gender, and reserve status. First, Home and Trip commute times were compared to each other. Next, Home and Trip commutes were each analyzed by separate ANCOVAs with respective between-groups factors of Carrier Type (Network, Low-Cost, or Regional), Seniority (Senior, Mid, or Junior), and Flight Operations (Domestic or International). Finally, to evaluate the relationship between commute times and neurobehavioral performance capacity, all Home and Trip commutes were grouped into ascending Commute Time bins (Home: <30, 30-<60, 60-<90, 90-<120, $\geq$120 min; Trip: <30, 30-<60, 60-<90, $\geq$90 min), and all PVT performance metrics were subjected to separate ANCOVAs with a between groups factor of Commute Time, as described above. For all analyses, significant main effects were followed by Fisher's LSD post-hoc comparisons as appropriate. Unless otherwise noted, all data are presented as estimated marginal means $\pm$ SEM. All analyses were two-tailed with statistical significance set at $\alpha = .05$. A summary of the total number of commute episodes used for each analysis is presented in Table 1.

Home and Trip Commute Episodes per Analysis		
Analysis	**Commute Type**	
	Home	**Trip**
All	444	363
Carrier Type		
Network	185	122
Low-Cost	126	89
Regional	133	152
Carrier Type (Domestic Only)		
Network	117	63
Low-Cost	126	89
Regional	133	152
Seniority		
Senior	168	104
Mid	153	123
Junior	123	136
Flight Operations		
Domestic	376	304
International	68	59
Commute Times & Performance		
<30 min	46	234
30-60 min	195	92
60-90 min	114	27
90-120 min	29	10
>120 min	60	--

Table 1: Home and Trip Commute Episodes per Analysis.

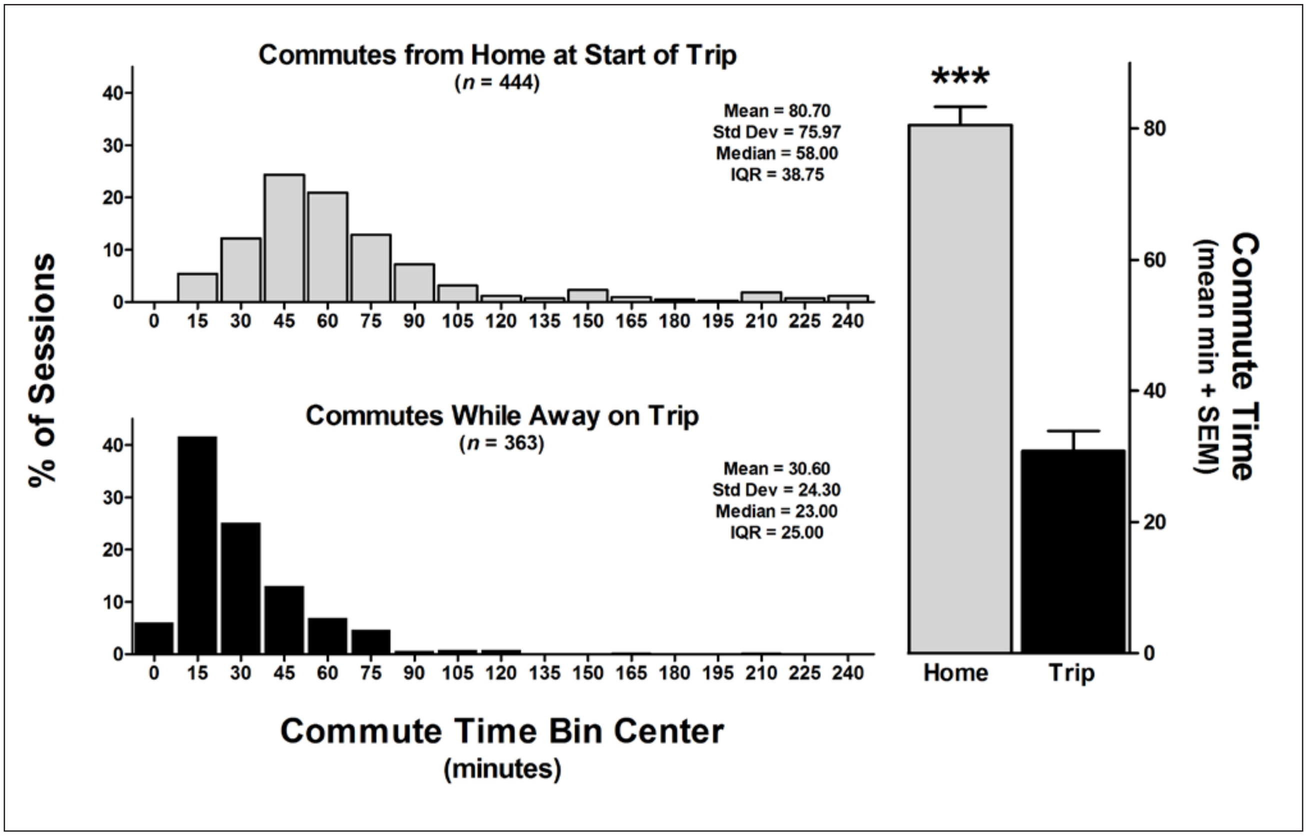

Figure 1: Frequency Distributions and Descriptive Statistics of all Home and Trip Commutes (***p < .001).

RESULTS

Commute Times

Home vs. trip. Figure 1 presents the frequency distributions and summary statistics for all Home and Trip commutes. Commute times from home at the start of a work trip were more widely distributed than commutes during a trip (range: 9-609 min vs. 2-209 min), and ANCOVA analysis confirmed that mean Home commutes were significantly longer than mean Trip commutes (80.5 $\pm$ 2.75 vs. 30.8 $\pm$ 3.05 min; $F(1,802) = 145.38$, $p < .001$).

Analysis of carrier type. An initial ANCOVA revealed a significant main effect of Carrier Type on both Home and Trip commutes (Fs > 3.7, ps < .05), with post-hoc analyses indicating longer Home and Trip commutes in Network versus Low-Cost crew (ps < .01; other ps > .05). However, subsequent analyses suggested a possible confound due to the crew working international operations—all of whom work for Network carriers. Re-analysis of the Carrier Type factor in crew working domestic-only operations confirmed no effect of Carrier Type on Home or Trip commute times (Fs > 2.6, ps > .07; see Fig. 2).

Analysis of seniority. ANCOVA analysis of Seniority revealed no effects on Home commutes ($F(2,438) = 2.04$, $p > .10$). However, as seen in Figure 3, Trip commutes varied significantly as a function of Seniority ($F(2,357) = 7.06$, $p < .001$), with modestly but significantly longer commute times in Mid- and Junior-level crew compared to their Senior colleagues (33 $\pm$ 2 and 34 $\pm$ 2 min, respectively vs. 23 $\pm$ 3 min; ps < .01).

Analysis of flight operations. As depicted in Figure 4, ANCOVA analysis of flight operations revealed significantly longer commutes in International crew compared to their Domestic counterparts in both the Home and Trip contexts (Home: 123 $\pm$ 9 vs. 73 $\pm$ 4 min, Trip: 39 $\pm$ 3 vs. 29 $\pm$ 1 min; Fs > 7.4, ps < .01).

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Home commutes. As seen in Figure 5, ANCOVA analyses revealed no significant relationships between commute times from home at the start of a work trip and subsequent Pre-Work PVT RT, Speed, Lapses, False Starts, Effectiveness, or SAFTE/FAST predictions ($F(4,436)$s < 2.40, ps > .05).

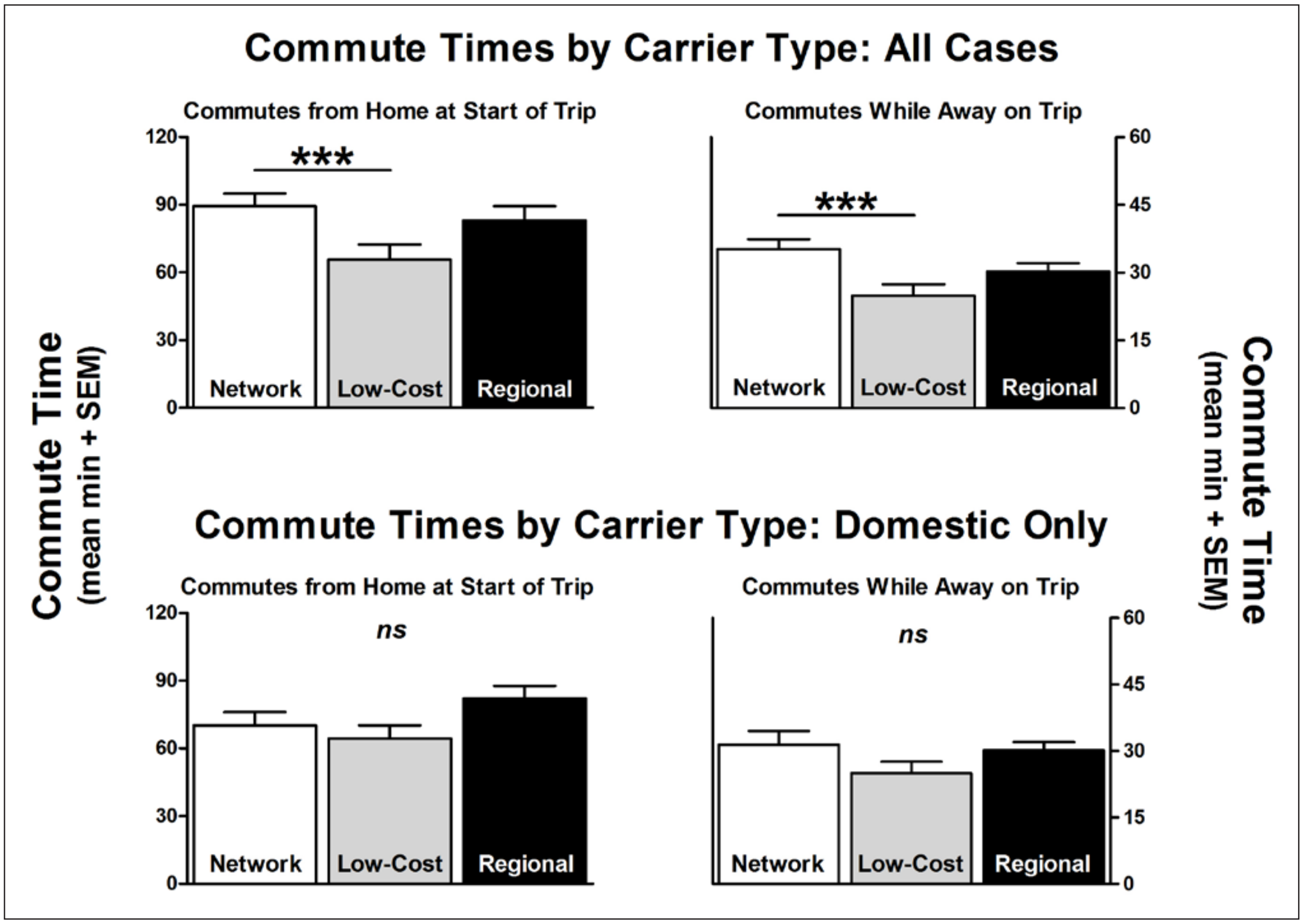

Figure 2: Home and Trip Commute Times as a Futnction of Carrier Type in all Crew (top panels) and Crew Working Only Domestic Flight Operations (bottom panels; ***p < .001, ns = not significant).

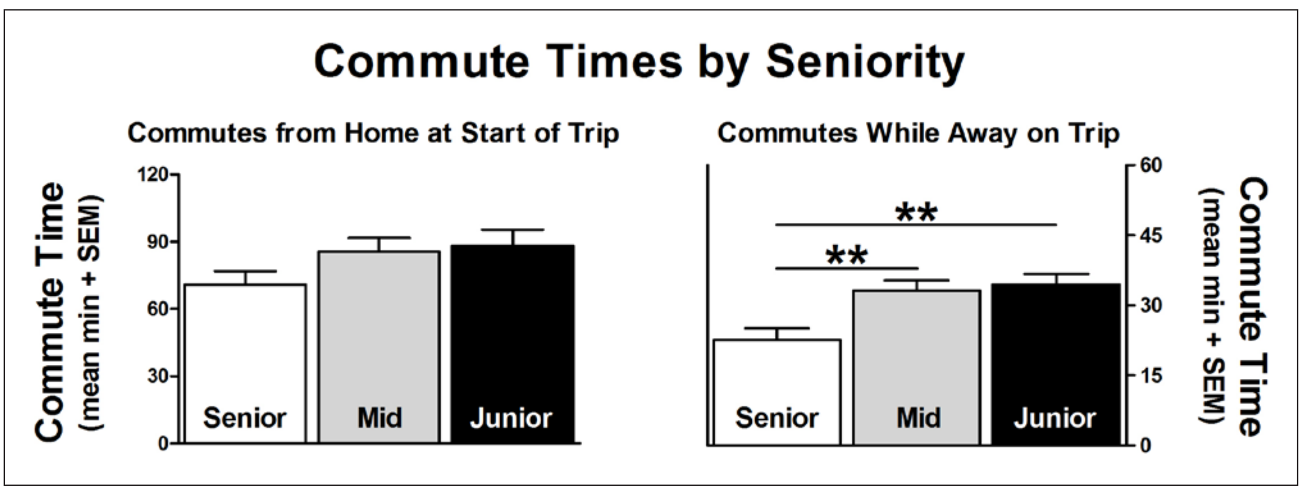

Figure 3: Home and Trip Commute Times as a Function of Seniority (**p < .01).

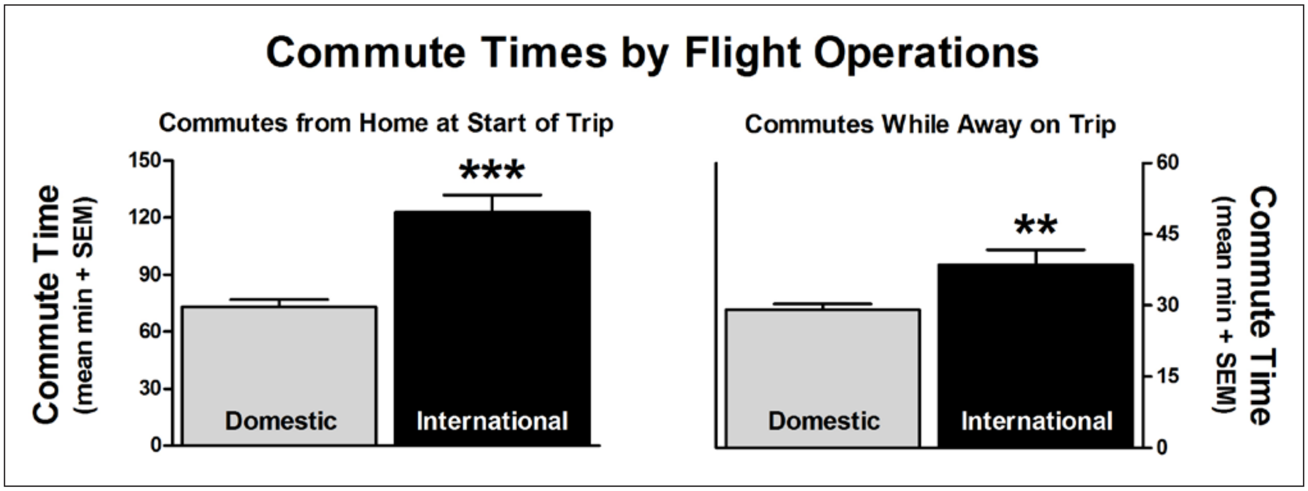

Figure 4: Home and Trip Commute Times as a Function of Flight Operations (**p < .01, ***p < .001).

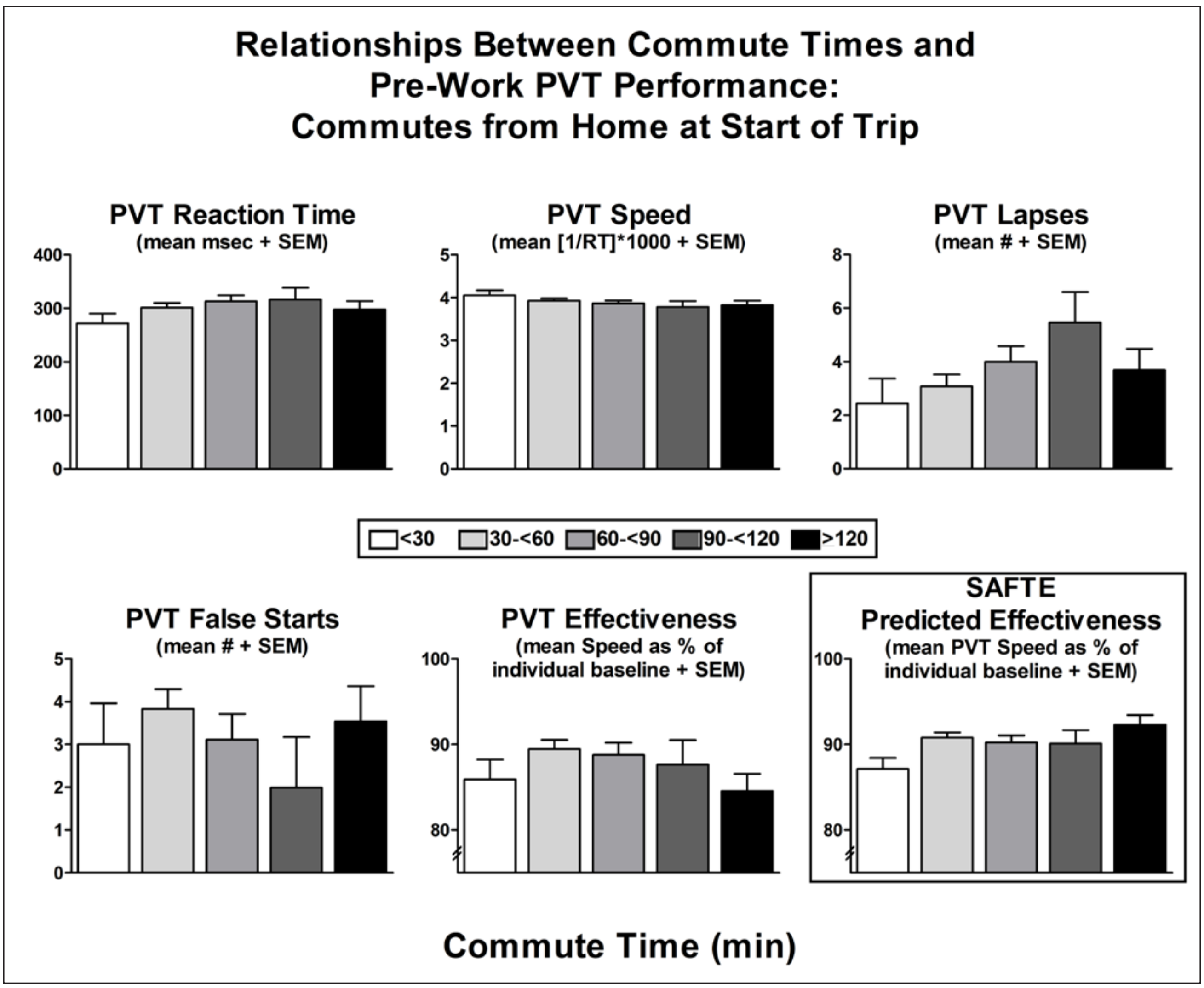

Figure 5: Relationships Between Commute Times from Home at the Start of a Work Trip and Objective Pre-Work Neurobehavioral Performance Measures. Inset (bottom right): Performance Effectiveness as Predicted by the SAFTE/FAST Biomathematical Fatigue Modeling System Based on Actual Sleep/Wake/Location Data.

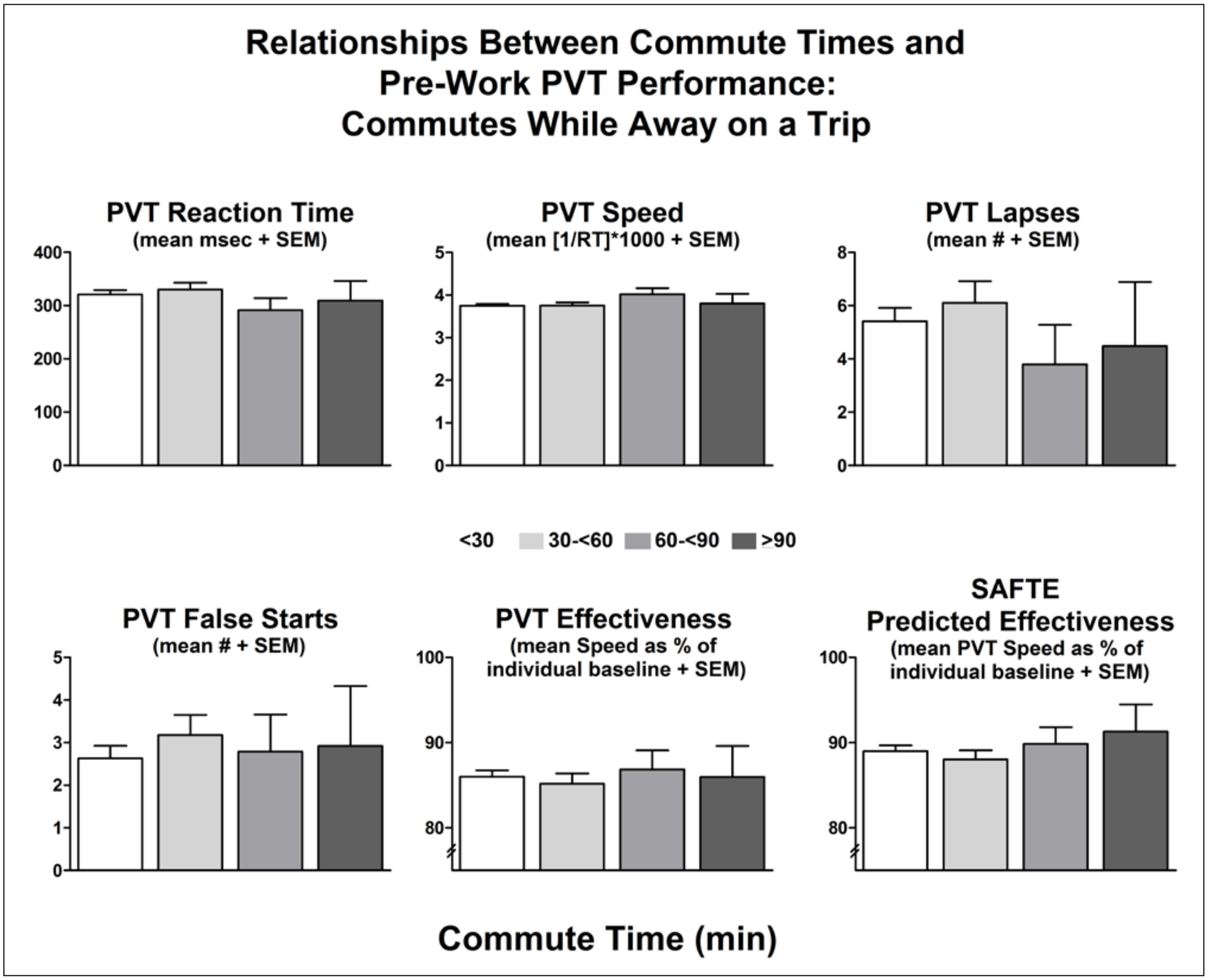

Figure 6: Relationships Between Commute Times While Away on a Work Trip and Objective Pre-Work Neurobehavioral Performance Measures. Inset (bottom right): Performance Effectiveness as Predicted by the SAFTE/FAST Biomathematical Modeling System, Based on Actual Sleep/Wake/Location Data.

Trip Commutes. As with the Home commutes, ANCOVA analyses of commutes while away on a work trip revealed no significant relationships between commute times and subsequent Pre-Work PVT RT, Speed, Lapses, False Starts, Effectiveness, or SAFTE/FAST predictions ($F(3,356)$s < 1.20, *p*s > .30; see Fig. 6).

DISCUSSION

It is widely recognized that fatigue is a multidimensional phenomenon, characterized by complex interactions between biological, behavioral, and environmental forces; few operational contexts exemplify this complexity and the potentially devastating consequences of mismanaged fatigue quite like commercial aviation (Caldwell, 2012). Recent human-factors safety incidents such as the 2009 Colgan Air Flight 3407 tragedy have heightened public awareness of fatigue in aviation and the potential role of extended commute times so common in the aviation profession. The present study offered a systematic field assessment of actual commute times and their potential impact on objective measures of neurobehavioral performance capacity in a broadly representative sample of aviation cabin crew. Average commutes of the general U.S. working population are estimated to range from 15-23 min each way, with 90% commuting less than 60 min and only 8% commuting longer than 60 min (Gallup Inc., 2007). Previous survey work (Avers et al., 2009; NSF, 2011) suggests consistently longer commute times in aviation crew, with much higher percentages of pilots and flight attendants embarking on commutes exceeding 60 min when compared to the general public. With >45% of commutes from home exceeding 60 min, >13% exceeding 120 min, and average commute times exceeding 80 min, the present study's analysis provides clear empirical support that the commercial aviation community fundamentally differs from the general population in their commuting patterns.

Additional analyses of operationally-relevant demographic variables also revealed significant variations in commute times as a function of seniority and flight operations. The nature of the shorter Trip commutes in senior crew, compared to their mid- and junior-level colleagues, is unknown; however, speculating on the pattern of longer commutes from home in crew working international versus domestic flights is a bit more intuitive. Specifically, crew who work primarily international operations typically work fewer trips of longer duration each month, often with longer recovery periods in-between trips, when compared to their counterparts working domestic operations (especially for Regional carriers). As such, even extended commutes over great distances may be less burdensome, given their relative infrequency, especially in light of the perceived benefits of international operations in terms of consolidated flight hours (and corresponding pay), fewer flight segments per duty period, and the potential for more widely distributed workloads afforded by larger crew sizes.

Although the present study revealed patterns consistent with other estimates suggesting systematically longer commutes in commercial aviation crew versus the general public, the most important issue and primary impetus of our analysis was to address the knowledge gap regarding the relationship between commute times and performance capacity at the start of a duty period. Indeed, one of the National Research Council's key conclusions in their examination of commuting in pilots was that:

> There is potential for pilots to become fatigued from commuting. However, there is insufficient evidence to determine the extent to which pilot commuting has been a safety risk in part because little is known about specific pilot commuting practices and in part because the safety checks, balances, and redundancies in the aviation system may mitigate the consequences of pilot fatigue (NRC, 2011, p. 4).

Our analyses used real-time activity logs to document more than 800 actual commute episodes in a broadly representative cross-section of aviation cabin crew, but found no consistent significant evidence of a predictive relationship between commute duration and multiple performance metrics derived from standardized PVT tests taken at the start of the duty period. This was true for pre-work commutes originating from home at the start of a trip, as well as commutes completed while away on a trip.

For addressing the issue of commuting in commercial aviation, the systematic and objective data from the 807 Commute-PVT pairings we analyzed are unique in their quality but are somewhat limited in their quantity. By way of comparison, our recent validation study of the SAFTE/FAST fatigue-modeling system utilized more than 10,000 individual PVT test sessions from the Flight Attendant Field Study database (Roma et al., 2012). As with the modeling study, more data points may have provided additional sensitivity to detect significant effects. For example, Figure 5 revealed an apparent linear increase in mean Lapses following commutes from home up to 120 min, followed by an unexpected decrease after commutes exceeding 120 min, with a corresponding increase in SAFTE/FAST predicted effectiveness, although analysis of neither variable achieved statistical significance (SAFTE/FAST $p > .052$).

Interestingly, since our SAFTE/FAST predictions were based on actual sleep/wake/location data, those results combined with informal notes from participants suggest potential decrements as a function of commute times for those whose commutes require unusually early wake-up times, but not among those with the longest commutes that may include restorative rest opportunities involving passive transportation modalities (e.g., "power nap" during deadhead flight). Nonetheless, the consistent and statistically supported findings of no relationship between commute times and most performance outcomes clearly dominated the results, and even if the potential effect described above did emerge as significant, it would only further support the notion that commute times *per se* are of limited value as a predictor of fitness for duty, and that commute duration is only relevant insofar as it impacts the primary drivers of fatigue such as sleep debt and circadian misalignment, accounted for by validated biomathematical fatigue models.

Finally, although the initial effort represented by the present study focused exclusively on pre-work neurobehavioral performance capacity contiguous with documented commute episodes, future analyses may also consider latent effects of commuting that do not emerge until the end of the duty period (i.e., Post-Work PVTs). Even if the commute itself has no effect, the sleep debt incurred to accommodate aviation personnel's longer-than-average commutes may still linearly contribute to fatigue. However, if extended commutes using active transportation modes (e.g., driving oneself) consume attentional resources, then it may be considered a functional extension of the work day. In either case, the independent or combined effects of sleep debt and workload may not be apparent until the period of extended wakefulness reaches its peak at the end of the work day. Still, it is worth noting that even if the speculative relationship described above were empirically confirmed, commute time itself as a predictor would remain relevant only insofar as it affects the aforementioned primary drivers of fatigue.

In conclusion, our data suggest that effective fatigue risk management strategies in commercial aviation need not include prescriptive rules based solely on commute times. Our initial primary analysis of the Flight Attendant Field Study dataset (Roma et al., 2010) revealed that virtually all cabin crew begin their work days significantly below individualized optimal baseline performance levels, and the present study does not indicate commute times as a significant contributor to this phenomenon, at least when superimposed against the disrupted sleep and circadian processes that pervade the aviation community. Despite considerable differences between pilots and cabin crew in background/training and on-duty tasks, the two groups do not fundamentally differ in their inherent biological vulnerability to fatigue or in their professional responsibilities to public safety. Moreover, both groups are subject to the same extreme operational complexities of prolonged wakefulness, circadian misalignment, and extended duty periods that contribute to fatigue and compromised performance. Therefore, we consider the results of the present study to be reasonably generalizable across commercial aviation. Although we found no convincing evidence of commute time effects on performance, the comprehensive database from which the present analysis was derived is a valuable resource that could continue to generate important insights on sleep/work/wake patterns and other operational factors that may affect on-duty neurobehavioral performance capacity in the "real world." As such, we encourage continued investigation of the Flight Attendant Field Study dataset in the spirit of scientifically informed decision-making to improve safety, performance, health, and quality of life for those who work in and rely on 24-hr operations.

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