



High-Performance Aircraft Respiratory Symptom Study

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Disclosure Information

Dr. Ryan Mayes



- ✧ **I have no financial relationships to disclose.**
- ✧ **I will not discuss off-label use and/or investigational use in my presentation.**
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High-Performance Aircraft Respiratory Symptom (HPARS) Study



- **Background and Results Overview**
- Distinct Cough Presentation Clustering
- Specific Variables of Interest
- Multivariable Modelling
- Conclusions



Background



- **Study requested by ACC/SG**
- **Conducted Aug-Oct 2014**
 - **5 squadrons at 4 bases in continental United States**
 - F-15E training squadron (F-15)
 - F-16 operational squadron (F-16)
 - F-22 operational squadron (F-22O)
 - F-22 training squadron (F-22T)
 - T-38 operational squadron (T-38)
 - **1 month per squadron in 2 increments**
- **Three study components**
 - Retrospective questionnaire (one time, ~7 pages)
 - **Prospective questionnaire (after each sortie, 2 pages, checkboxes)**
 - Environmental sampling (pre- and post-sortie breath samples, cockpit ozone)

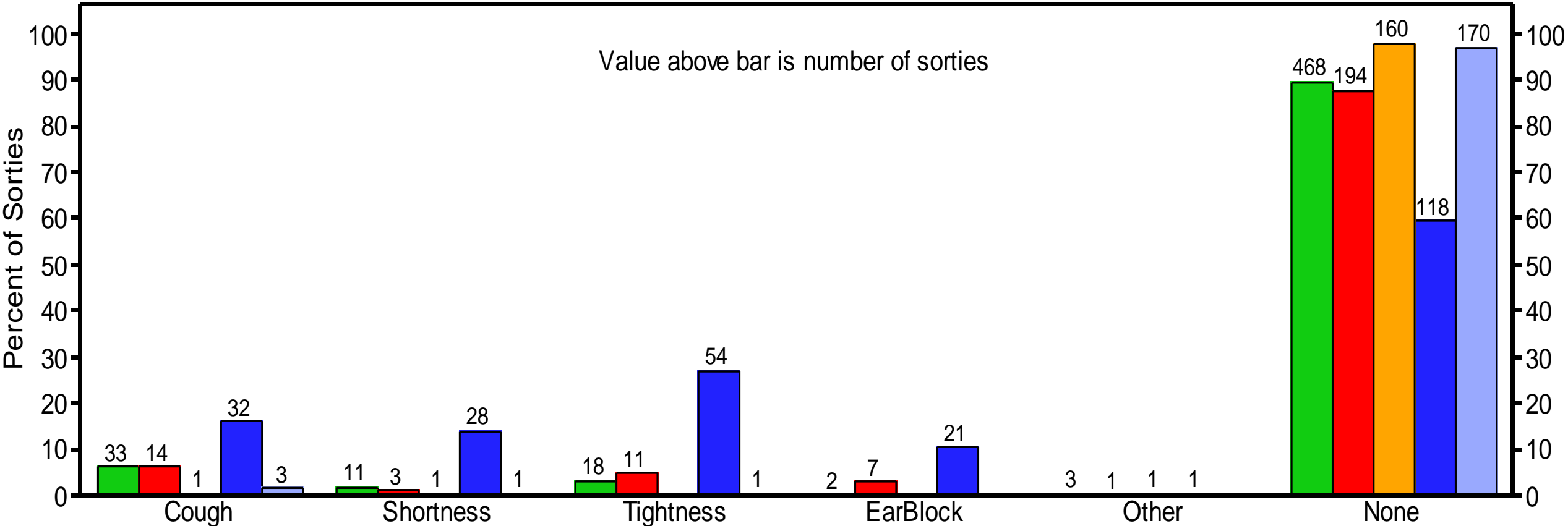
Primary goal: Establish flight-related respiratory symptom “norms” for high-performance aircraft pilots

Secondary goals: Characterize effects of system changes to F-22 & determine etiology of symptoms (if possible)



Results: Overview

F-15 F-16 T-38 F-22 O F-22 T

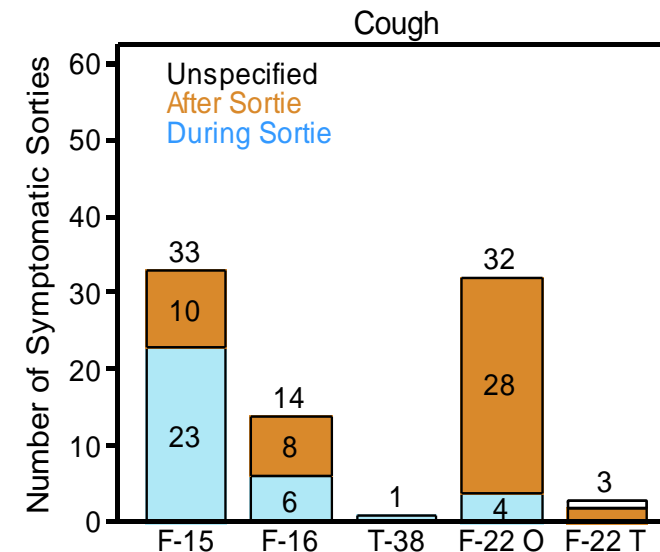




Symptom Characterization: Cough



- **Distinct presentation of cough in F-22 (All) vs. other airframes**
 - F-22 (All) cough is more severe, persistent, and reported on landing
 - 30+ minutes duration, 3/4 reported some discomfort
 - Predominantly present in F-22O
 - Non-F-22 Cough is less uncomfortable, shorter in duration, and begins in-flight
 - <5 minutes in duration, 2/3 report no discomfort



- **Oxygen settings not significantly associated with reports of cough in F-22 (All)**
- **Time spent at high Gz negatively associated with cough in F-22 (All)**
 - Despite higher Gz exposure in the F-22 (All) population, within the F-22 (All) population, cough was very rarely reported in high Gz exposure sorties
- **Altitude associated with cough in F-22 (All)**



Symptom Characterization: Shortness of Breath, Chest Tightness, Ear Block



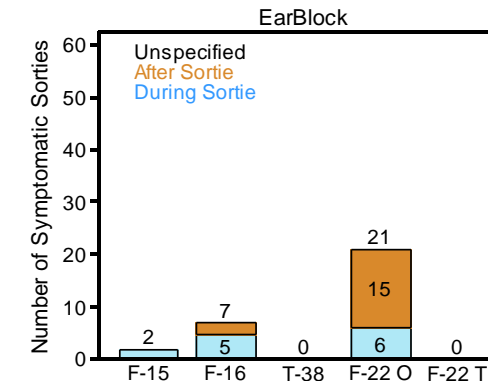
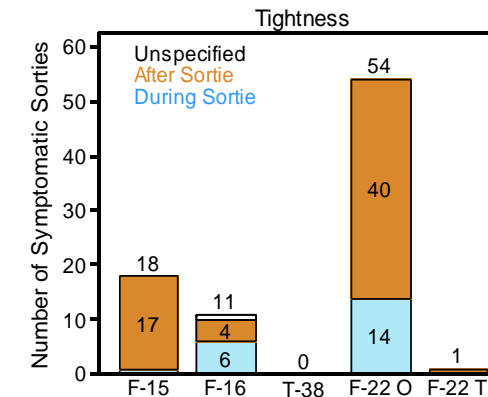
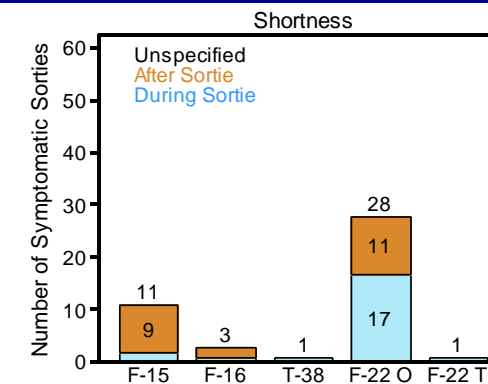
- **Shortness of breath (SOB) & Chest Tightness**

- Occurs predominantly after sortie
 - Exception: During sortie for most F-22O
- Individual susceptibility very important
- Relatively long-lasting (30+ minutes)
- SOB & Chest Tightness linked
 - Most reports of SOB were accompanied by reports of chest tightness
 - SOB with chest tightness: more likely to have prolonged SOB (statistically significant)

- **Ear Block**

- Predominantly F-22O
- Individual susceptibility not as notable as for other symptoms
- Virtually all ear block still occurring during questionnaire for F-15E and F-22O

- **“Other” symptoms largely benign**





HPARS Initial Analysis Takeaways

13%

- 13% of sorties had an associated respiratory symptom
- Most common: cough and chest tightness

1/3

- Individual susceptibility important
- 31.5% of pilots ever reported symptoms

3

- Three distinct groupings:
 - F-220
 - F-15 & F-16
 - F-22T & T-38

F-22 & time

- F-22 symptoms improved compared to previous studies

??

- Symptom etiology not clear



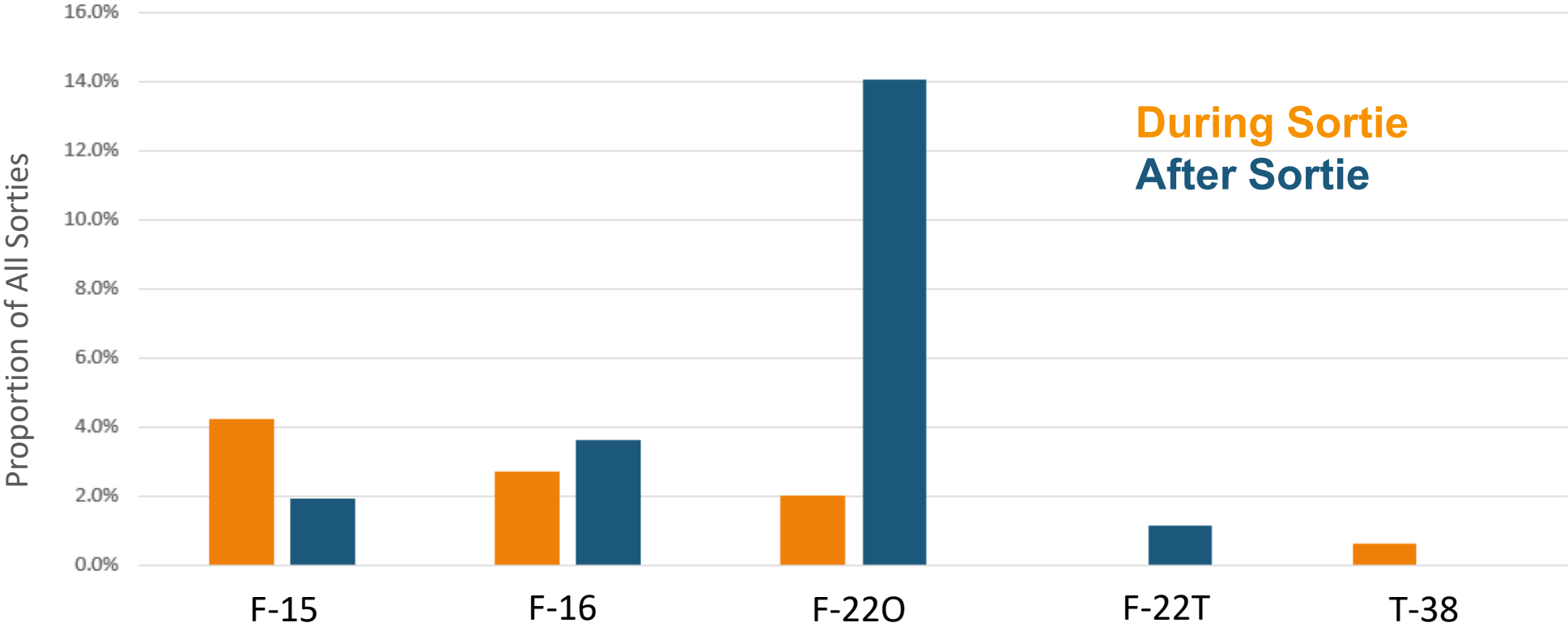
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Cough Incidence by Time of Onset



F-22 cough is more likely to occur after sortie than other airframes

- 14% of F-220 sorties report cough with onset after sortie against only 2% outside F-220¹

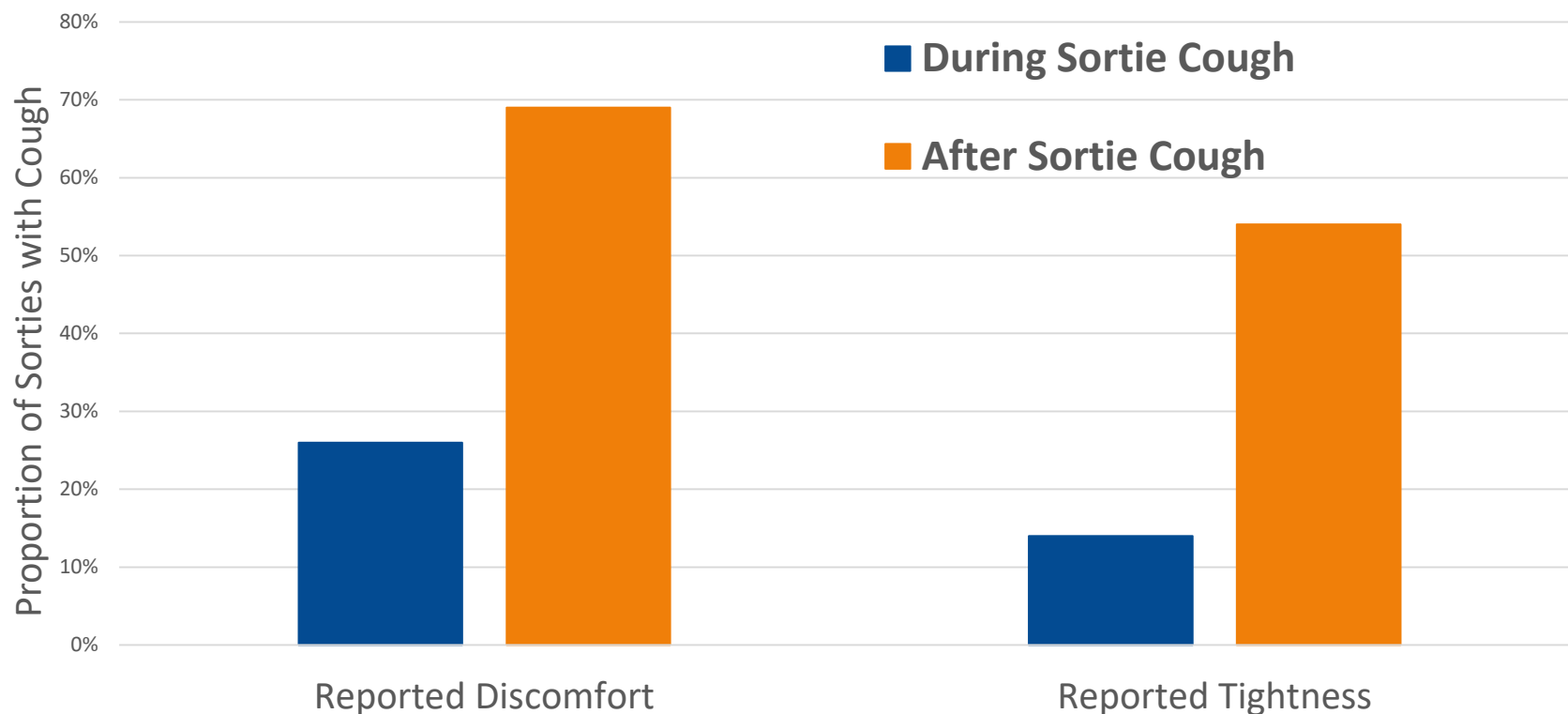
F-22 cough is less likely to begin during sortie

- 1.1% of F-22 (All) sorties report cough with onset during sortie against 3.2% outside F-22 (All)²

Both comparisons are statistically significant



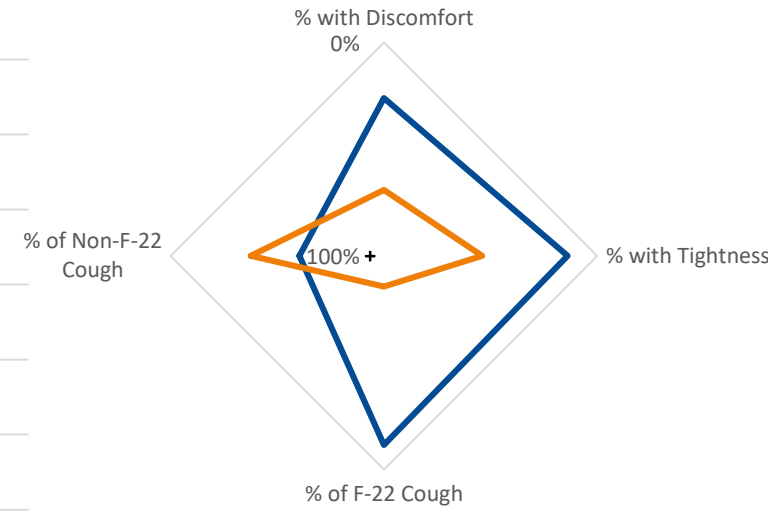
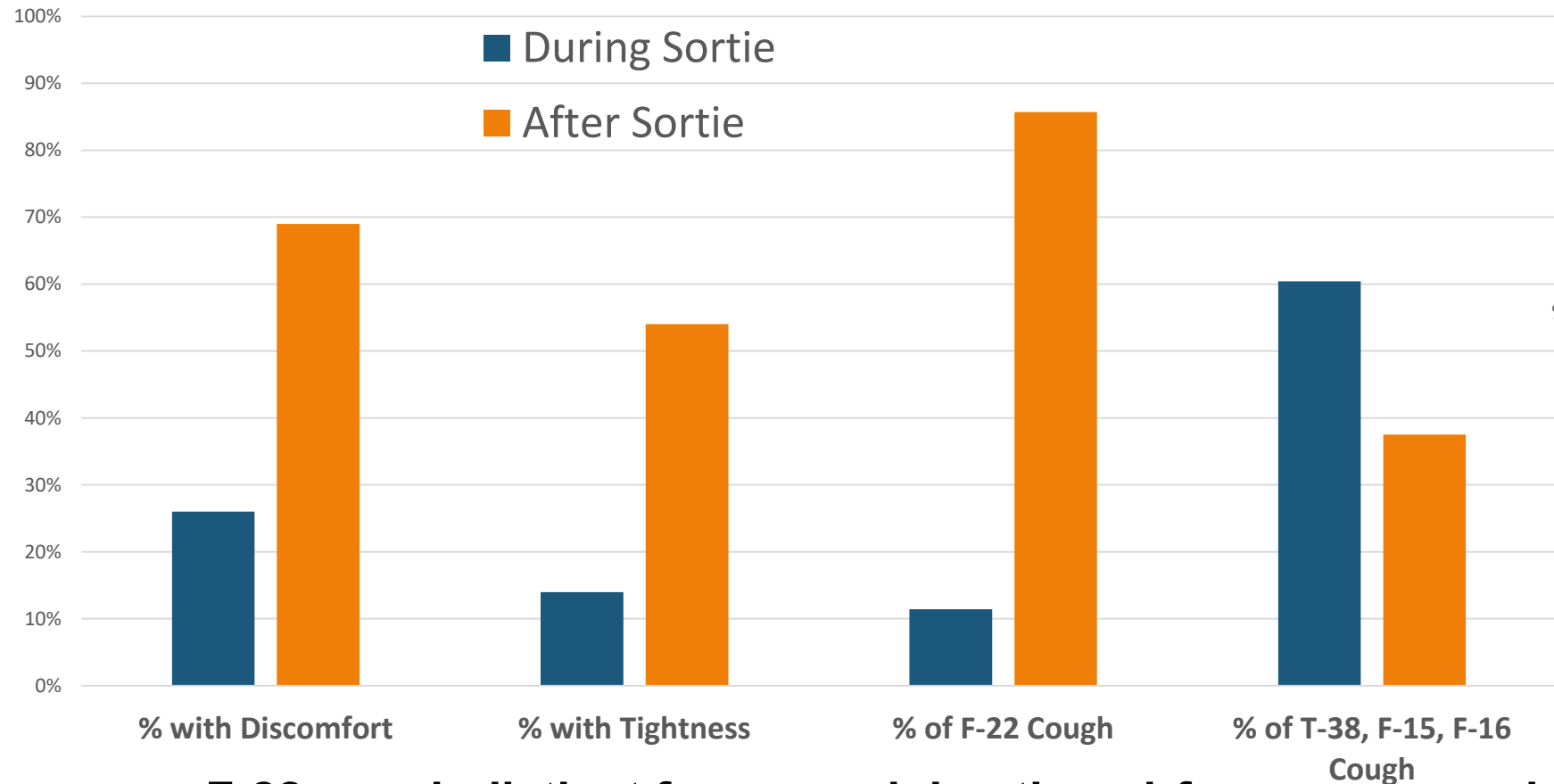
Cough Presentation Comparison



- Previous findings noted relationship between cough and chest tightness
- 69% of after sortie onset cough reported “a little discomfort” or more; 26% of during sortie onset cough reported “a little discomfort” or more¹
- 54% of after sortie onset cough reported co-occurrence of tightness of chest on same sortie; 14% of during sortie onset cough reported co-occurrence of tightness of chest on same sortie²
- Both associations are statistically significant



Distinct Presentations by Time of Onset



F-22 cough distinct from cough in other airframes on a variety of measures

The unique operating environment of the F-22 may explain distinction

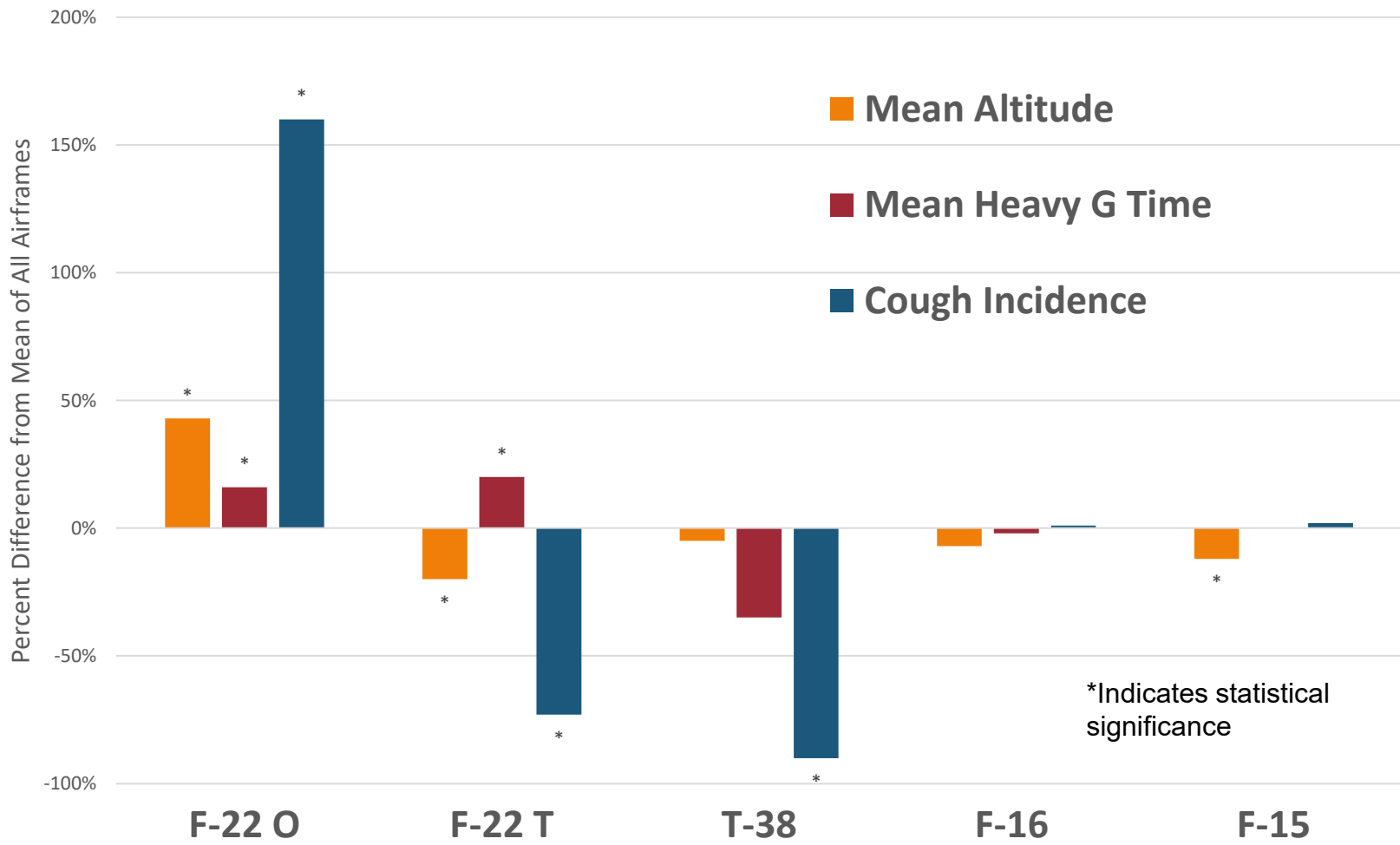
- Difference in operations and in cough rates at the F-22 operational vs. training squadrons sampled



Airframe Exposures vs. Total Cough by Airframe



Percent Difference from Mean of All Airframes



- ✧ **F-22O operational use distinctly different than other airframes**
- ✧ **All F-22 had higher altitude operations in this study**
- ✧ **Difficult to distinguish operational from airframe associations**
- ✧ **Only in F-22O was there a strong association between cough and chest tightness reports**
 - F-15 and F-16 reported weak associations
 - F-22T and T-38 had insufficient cough/tightness for meaningful analysis



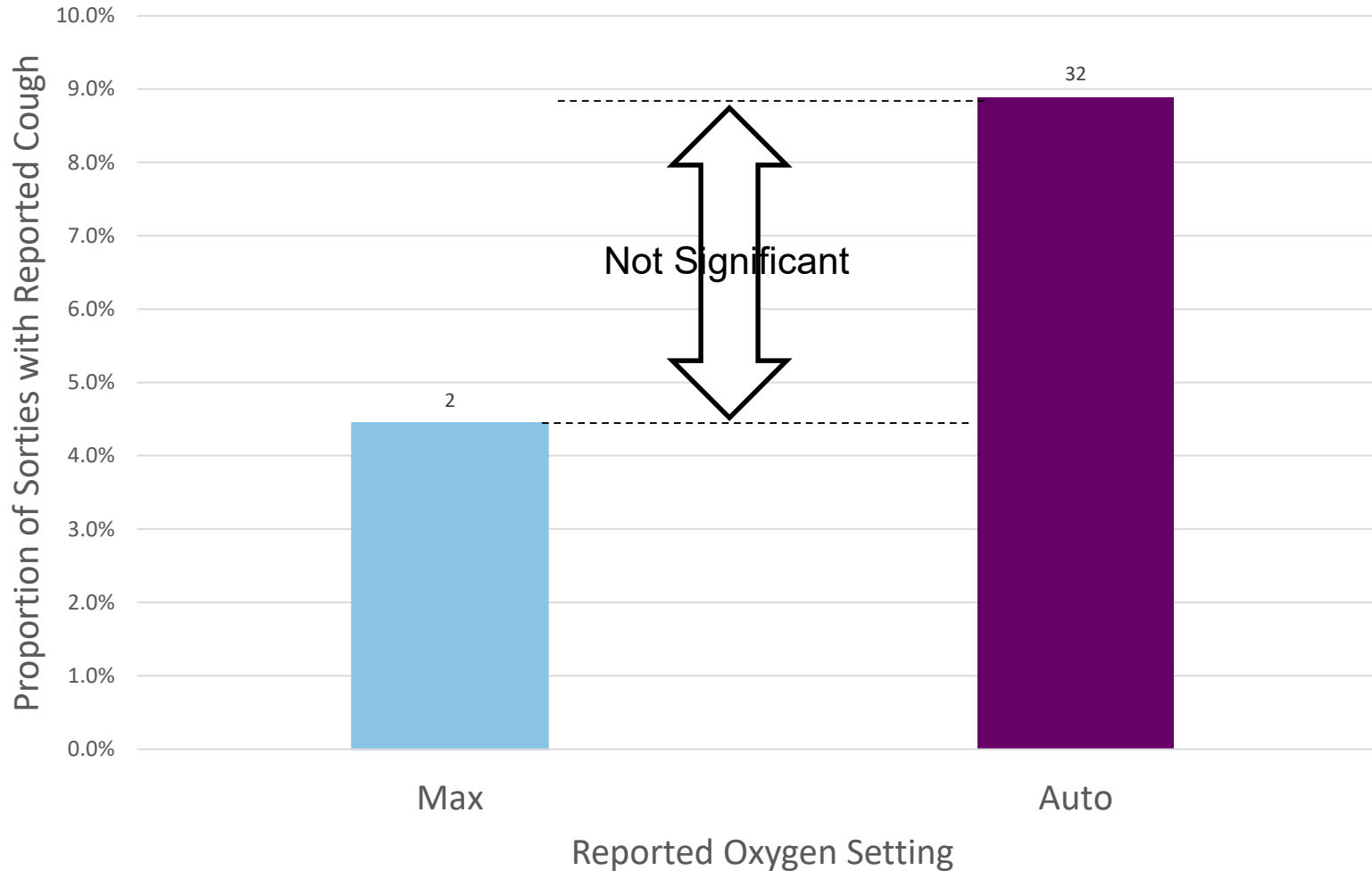
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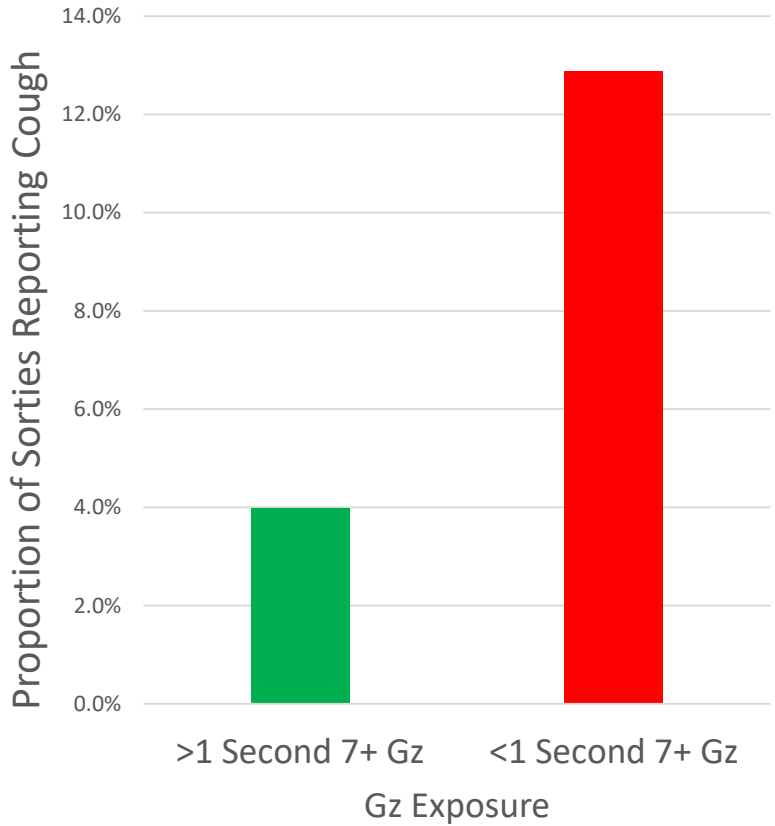
Oxygen Setting and Cough



- ✧ Oxygen setting analysis based upon self-report of setting in F-22 (All)
- ✧ No significant association between O2 setting and cough was found
- ✧ Not a controlled experiment, treat results with caution
 - Individual variability important
 - Self-selected population may explain reduced cough



F-22 Flight Data: Time above 7 Gz vs. Cough



As 7+ Gz exposure increases¹, cough rate decreases

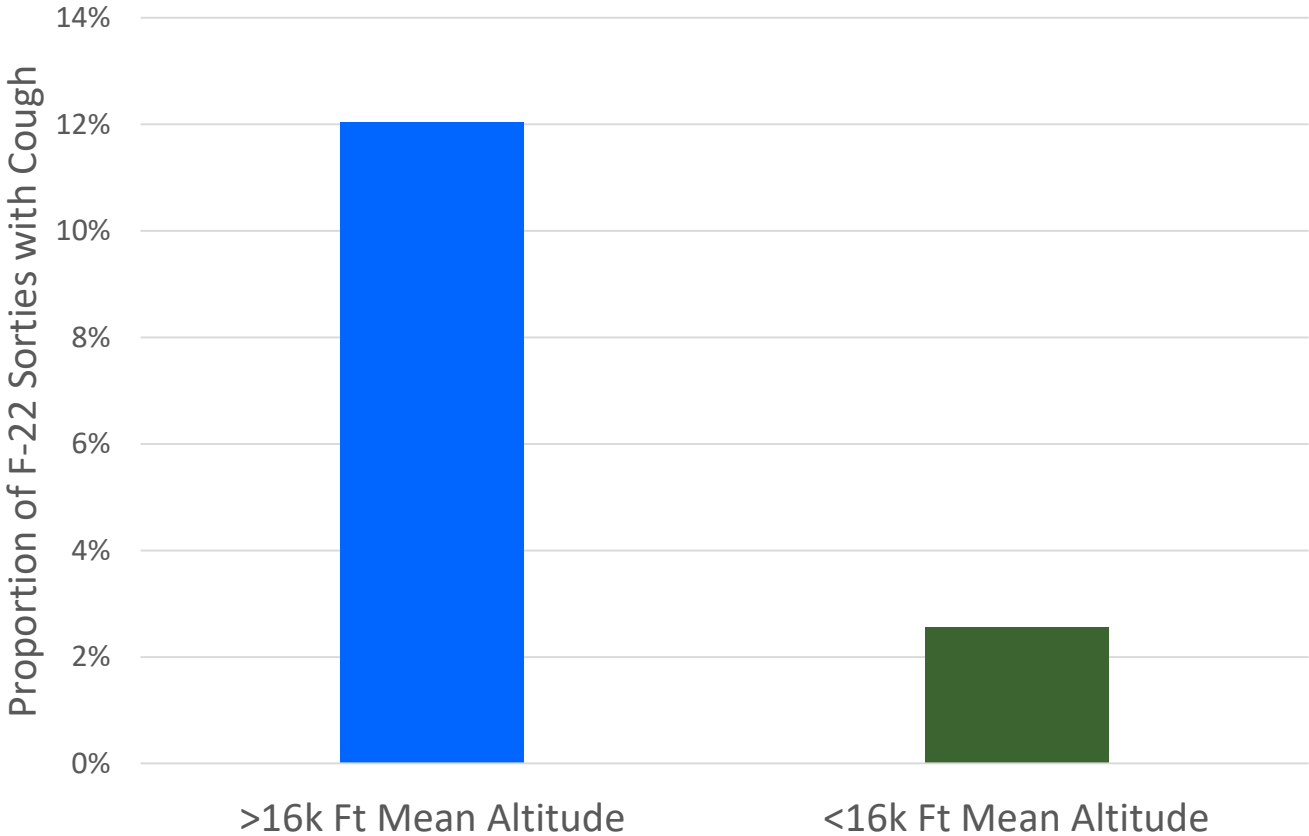
– Most significant drop from <1 second to >1 second²

17/23 instances of cough occurred in sorties with <1 second at 7+ Gz

No association based on when Gz occurred during sortie



F-22 Flight Data: Mean Altitude vs. Cough



F-22 Cough related to mean altitude during sortie

- Above 16k mean altitude, 12.0% cough (n = 166)¹
- Below 16k, 2.6% (n=117)²

20/23 instances of cough occurred in sorties with >16k mean altitude



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Multivariable Model Methods



✧ Generalized Linear Model

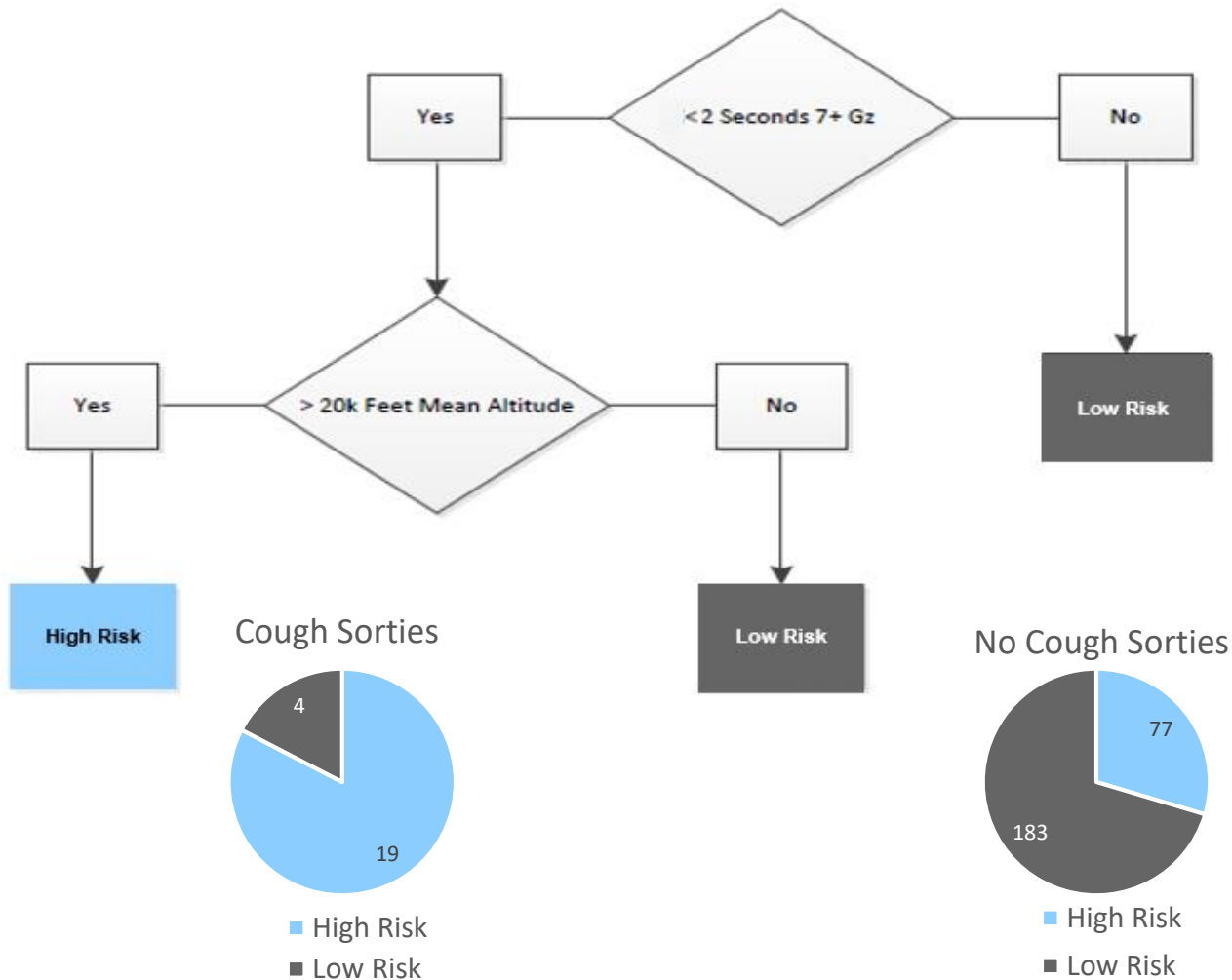
- Included maximum altitude, presence of cough on prior sortie, difference between mean and maximum altitude, and subjective heavy G-time
- Limited to pilots who reported cough on at least one sortie
- R-squared of 0.52

✧ Partition Model

- Simple discriminant-based classification system
- Based on high mean altitude, low 7+ Gz exposure risk profile
- Identifies high-risk exposures
- **Extension of partition model into other airframes was not predictive**
- **Partition model was not predictive for non-cough symptoms**



F-22 Partition Model



- ✦ Partition model effective at classifying F-22 cough
 - 83% of F-22 cough sorties as high risk (19/23)
 - 70% of non-cough sorties as low risk (183/260)
- ✦ High (>20k ft) low Gz (<2 seconds over 7+ Gz) F-22 sorties are 11.2x as likely to report cough
 - 2.1% of sorties classified low risk reported cough
 - 20.0% of sorties classified high risk reported cough
- ✦ Area under ROC:
 - 0.73 for altitude
 - 0.78 for Gz
- ✦ Partition model not predictive for other airframes

High Altitude and Low Gz Sorties Experienced >10x Cough



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Conclusions



Two distinct types of cough – during sortie onset and after sortie onset

- During sortie onset cough not easily predicted / characterized

After sortie cough relatively well-characterized

- Often associated with other symptoms (chest tightness, SOB)
- After-sortie cough more likely to report discomfort
- After-sortie cough longer in duration than during-sortie cough (previous results)
- Clustered in F-22O
- Associated with features of flight; sorties with after-sortie cough more likely to be high altitude without high Gz
- Altitude predictive of cough, but oxygen setting not associated with cough



Conclusions



- ❖ **After sortie cough *not* consistent with classic acceleration atelectasis**
- ❖ **Prolonged shortness of breath post-sortie associated with reports of chest tightness**
- ❖ **Cannot easily distinguish airframe-specific differences from operational exposures**
 - **F-22O vs. F-22T differences suggest operational exposures (flight regime) may be more important than airframe**



Questions?



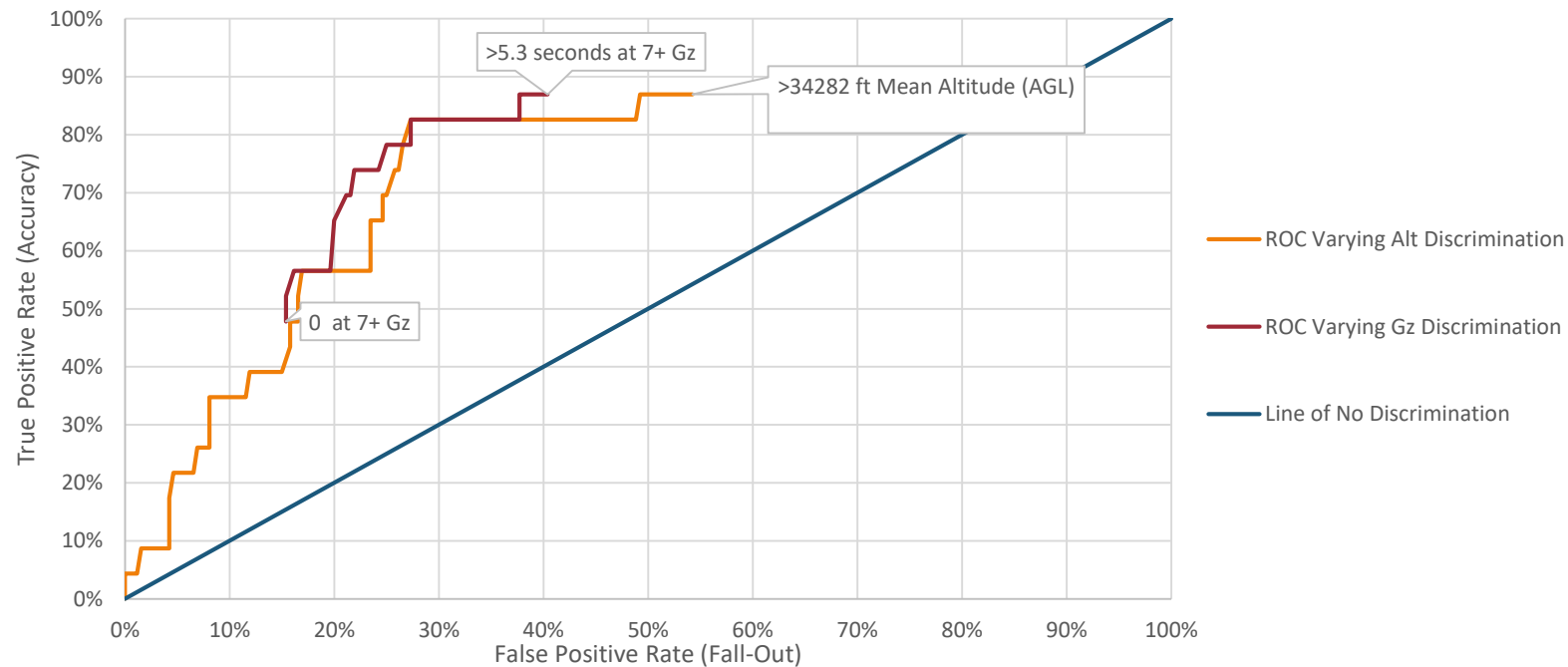
**Special
Thanks to:
Mr. Ben Clapp
& Mr. Chuck
Goodyear**



Contact: Ryan.Mayes.2@us.af.mil



Extended Multivariable Models



Partition model demonstrates specificity and accuracy at a range of discrimination thresholds



Future Work

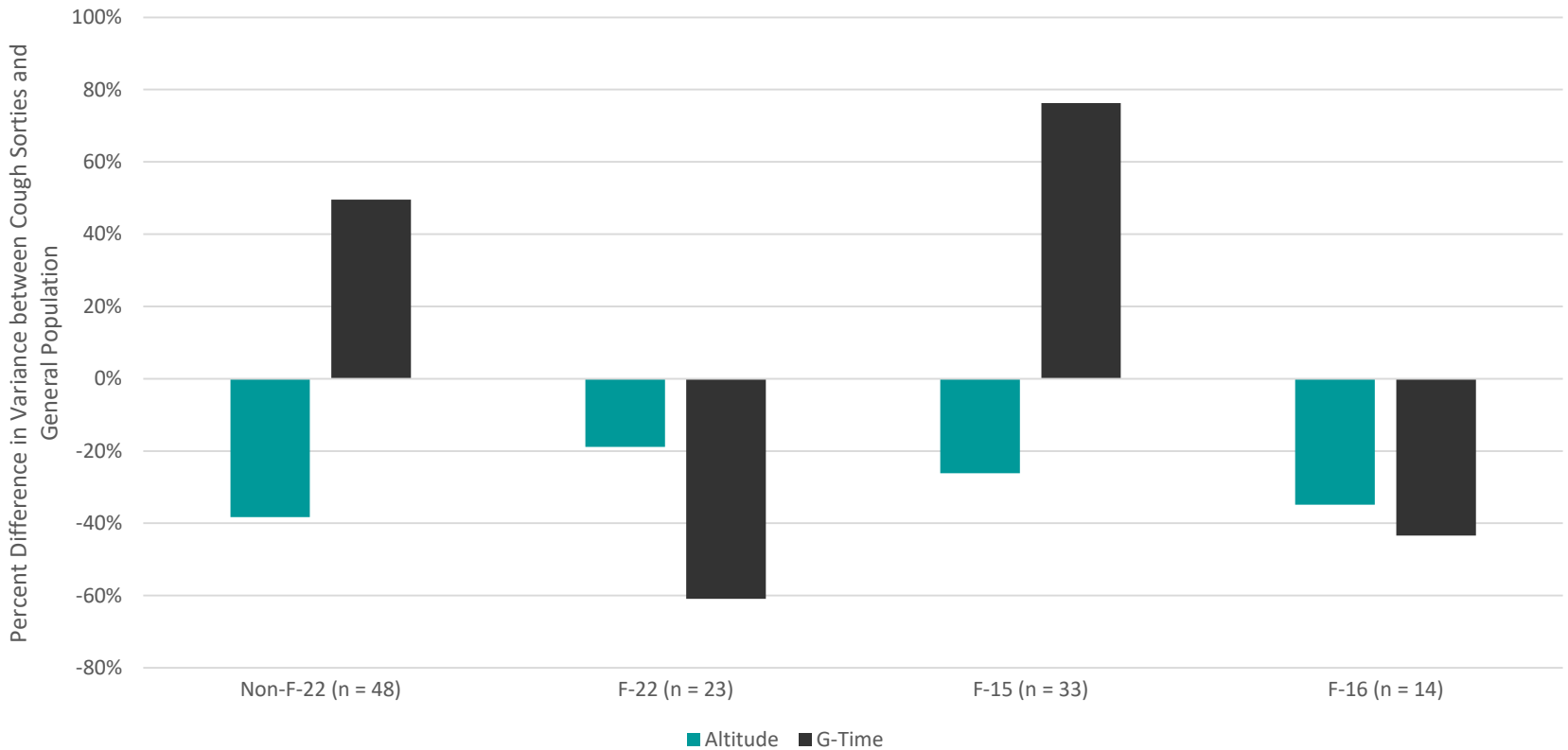
- **Multifactorial Modelling**
 - Further development of Simulation to Predict Impact of Multiple Factors on Respiratory Function
- **Investigate Gz-Cough Association**
 - Identify potential mechanisms for Gz to prevent/mitigate cough through deep dive in F-22 Integrity data and literature
- **Exhaled Breath & Ozone Data**
 - Analysis to be repeated with different software; IPA may be significant in cough analysis
 - Validate identity of chemicals
 - **Bigger Challenge: identify source(s), delivery, and mitigations for chemicals identified in study (in-line sensing)**

- **Future studies**
 - Further study on aircrew physiology using mask sensors
 - Follow-on study for symptom incidence?
 - 4 approved air quality studies
 - Legacy jet air sampling
 - Quantification, exposure reconstruction, tox assessment for significant peaks
 - Assess IPA uses and concentrations in MX activities
 - IPA specific sensor to be built





Discussion: Indexed Relative Variance



Separated presentations into distinct populations suggests distinct etiology

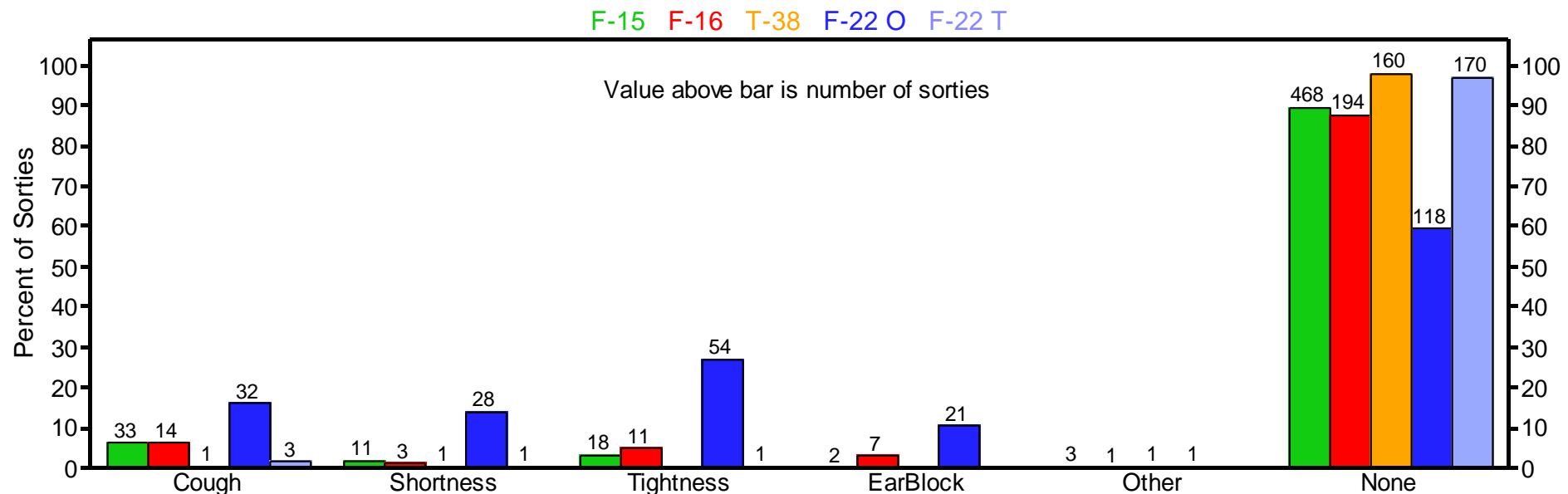
Different environment in F-22 (All)

- **F-22 flew higher and generally faster, especially F-22O**
- **Cough occurs higher and generally faster in combined populations**
- **Within F-22 (All), cough occurs higher and slower**



Previous Results Overview

- **13% of high-performance aircraft sorties associated with one or more respiratory symptoms**
 - Most common symptoms: cough and chest tightness
- **F-22 symptoms improved compared to previous studies**
 - Operational F-22 pilots report more symptoms than other high-performance aircraft pilots
- **Symptom etiology unclear: likely multifactorial**
 - Cough not consistent with classic acceleration atelectasis
 - Cough and chest tightness related

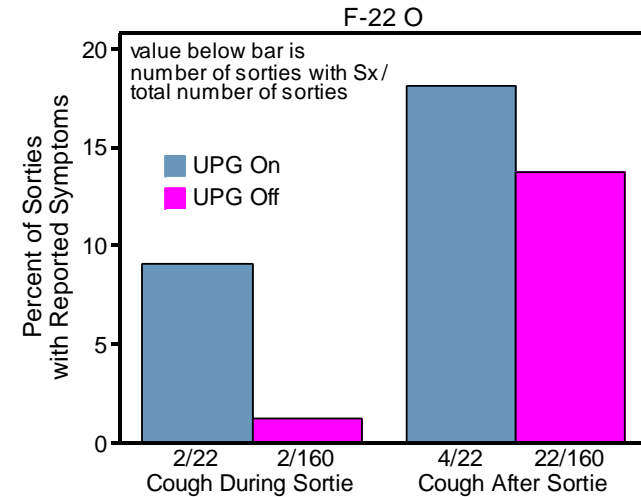
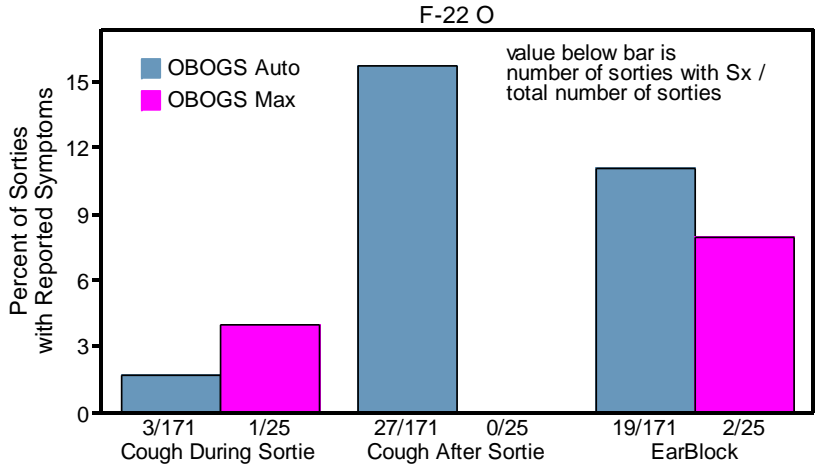




Symptom Characterization: F-22O Cough



- **F-22O: highest cough rate of any squadron sampled (included F-15E, F-16, and T-38)**
 - No difference in cough by sustained Gz; sorties with higher maximum Gz less likely to have cough
 - Sorties with UPG more likely to result in cough (note: sorties were all high-altitude) – statistically higher than sorties without UPG
 - Sorties with OBOGS MAX resulted in cough half as often than sorties with OBOGS Auto
 - Sorties with mean altitude >27k not statistically different for cough than sorties with mean altitude ≤27k
 - **Caveat: some association with max altitude above vs. below 27k; higher max altitudes associated with more cough (only 21 sorties with max<27k)**
 - For F-22, cough typically begins after sortie, lasts 30+ minutes, and has some level of discomfort
- **F-22 cough not consistent with classic acceleration atelectasis (high O₂ + Gz)**
 - Symptoms predominantly began after flight
 - Symptoms typically last 30+ minutes
- **Cough at other squadrons more consistent with acceleration atelectasis**
 - Began during sortie, lasted <2 minutes
 - Less discomfort than F-22 cough

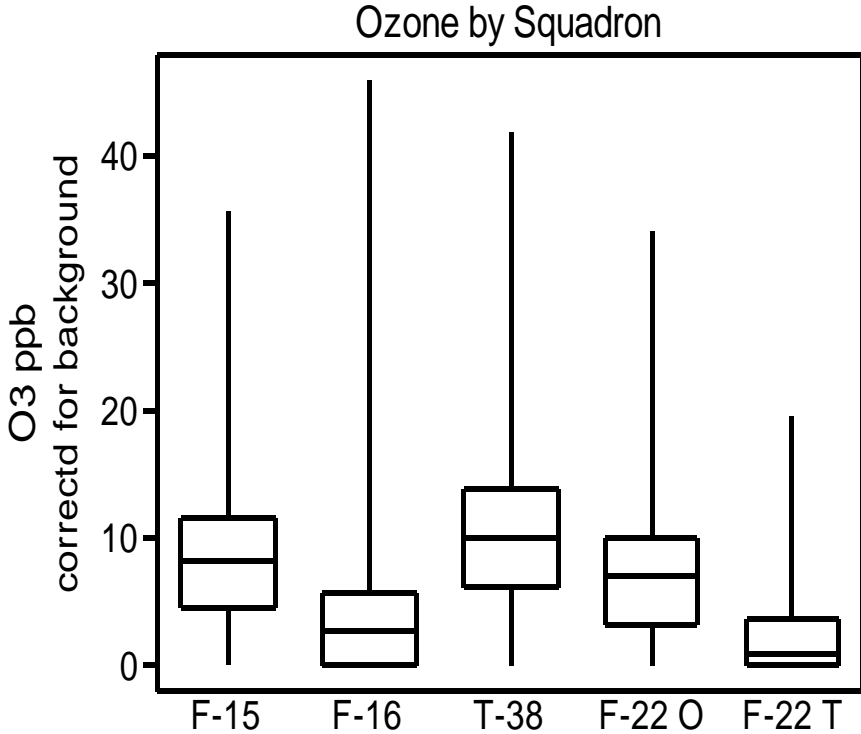




Ozone



- **Cockpit ozone results largely unremarkable; readings were below levels associated with respiratory symptoms**
- **Highest ozone measurements were found with long-duration sorties (>2.8 hours)**
- **Planned work will investigate whether there is any relationship between ozone and symptoms; null findings expected**





Individual Susceptibility

- **Individual susceptibility a significant factor: single best predictor of major symptoms is whether pilot reported symptoms in past**
 - 4 pilots account for 25% of all reported symptoms
 - However, most pilots reporting symptoms only did so occasionally (<100% of sorties)
 - Most pilots (68.5%) did not report any symptoms
- **Symptoms not randomly distributed across individuals; rates partially driven by susceptible individuals**

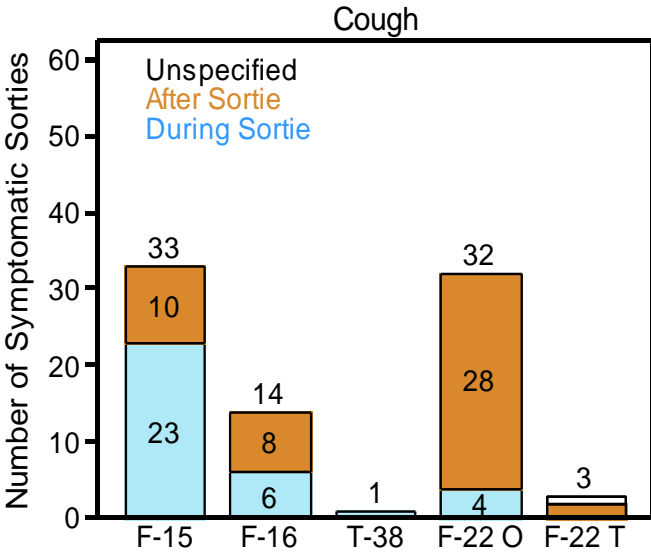




Symptom Characterization: Cough

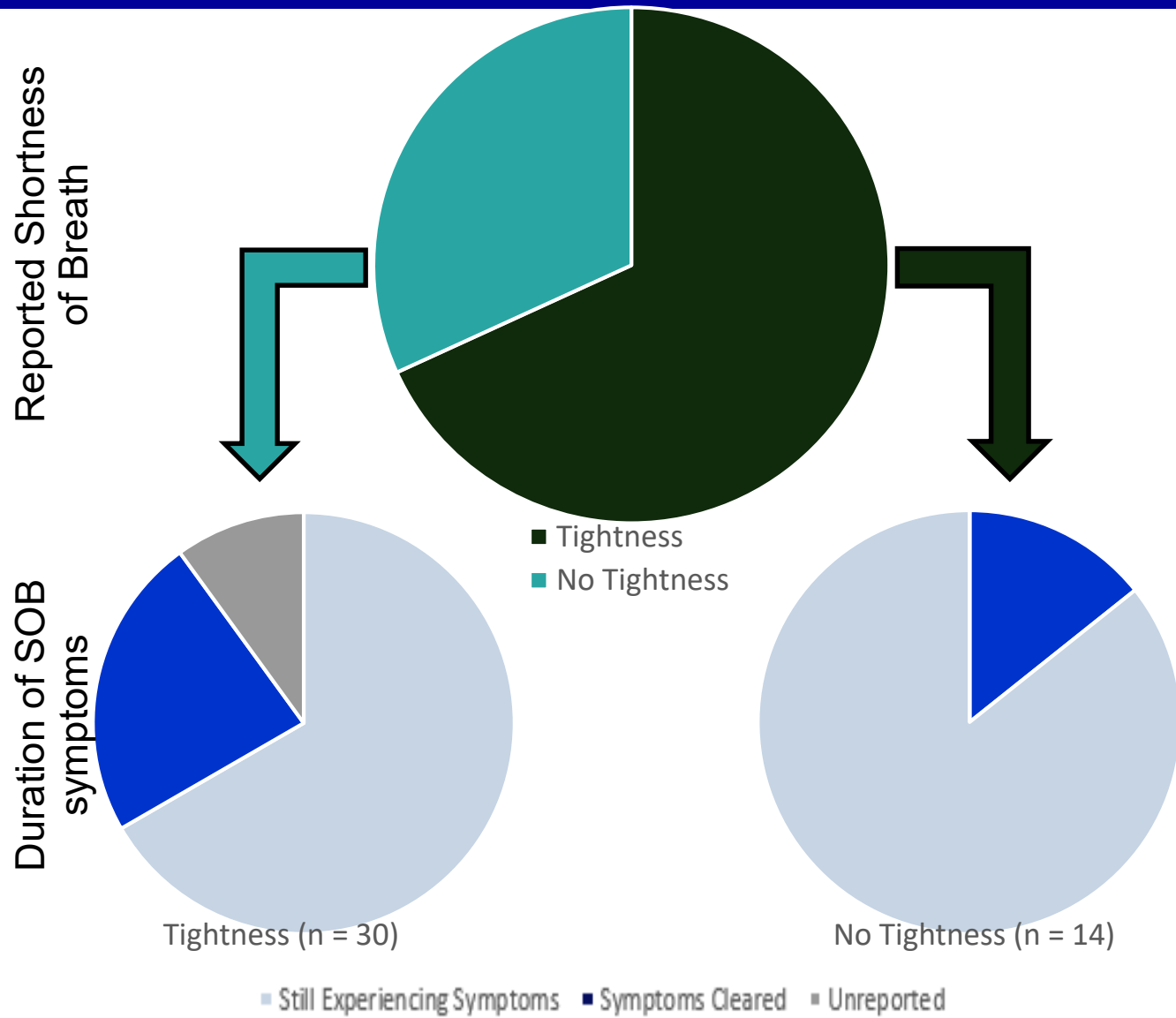


- **Cough for F-22O is predominantly after sortie and more frequent than other bases**
 - F-15E predominantly during sortie
 - F-16 about even
- **Individual susceptibility important**
 - F-22O: 3 pilots reported 20/32 instances of cough
 - F-15E: 3 pilots reported 15/33 instances of cough
- **Cough during sortie**
 - Mostly short in duration (1-5 minutes)
 - 67% of those reporting cough during sortie reported no discomfort
 - However, some cough lasted through time of survey (30-60+ minutes)
 - 8/23 for F-15E
 - 5/6 for F-16
 - 0/4 for F-22O (1 unspecified)
 - Unusual observation for F-15E: more cough with PBG than with regulator set to “on” (no PBG)
- **Cough after sortie**
 - Long in duration: 30+ minutes (still occurring at time of survey)
 - 25% reported no discomfort (75% reported little or some discomfort)
 - 26/40 for F-22O were 30+ minutes
 - However, only 2/10 for F-15E were 30+ minutes (7/10 were ≤ 10 minutes)





Extended Shortness of Breath and Chest Tightness



Of those who experienced prolonged Shortness of Breath (SOB), the majority also had comorbid chest tightness

Most reports of SOB were accompanied by reports of chest tightness

SOB with chest tightness: more likely to have prolonged SOB

- Statistically significant