Female driver lower extremity injury in front crashes

Contributing factors and crash test relevance

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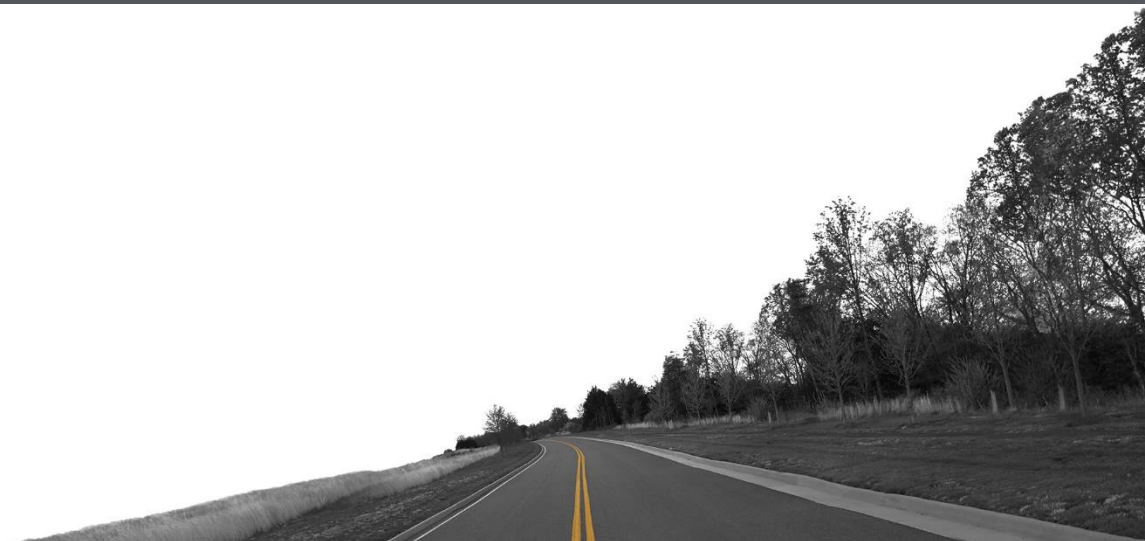
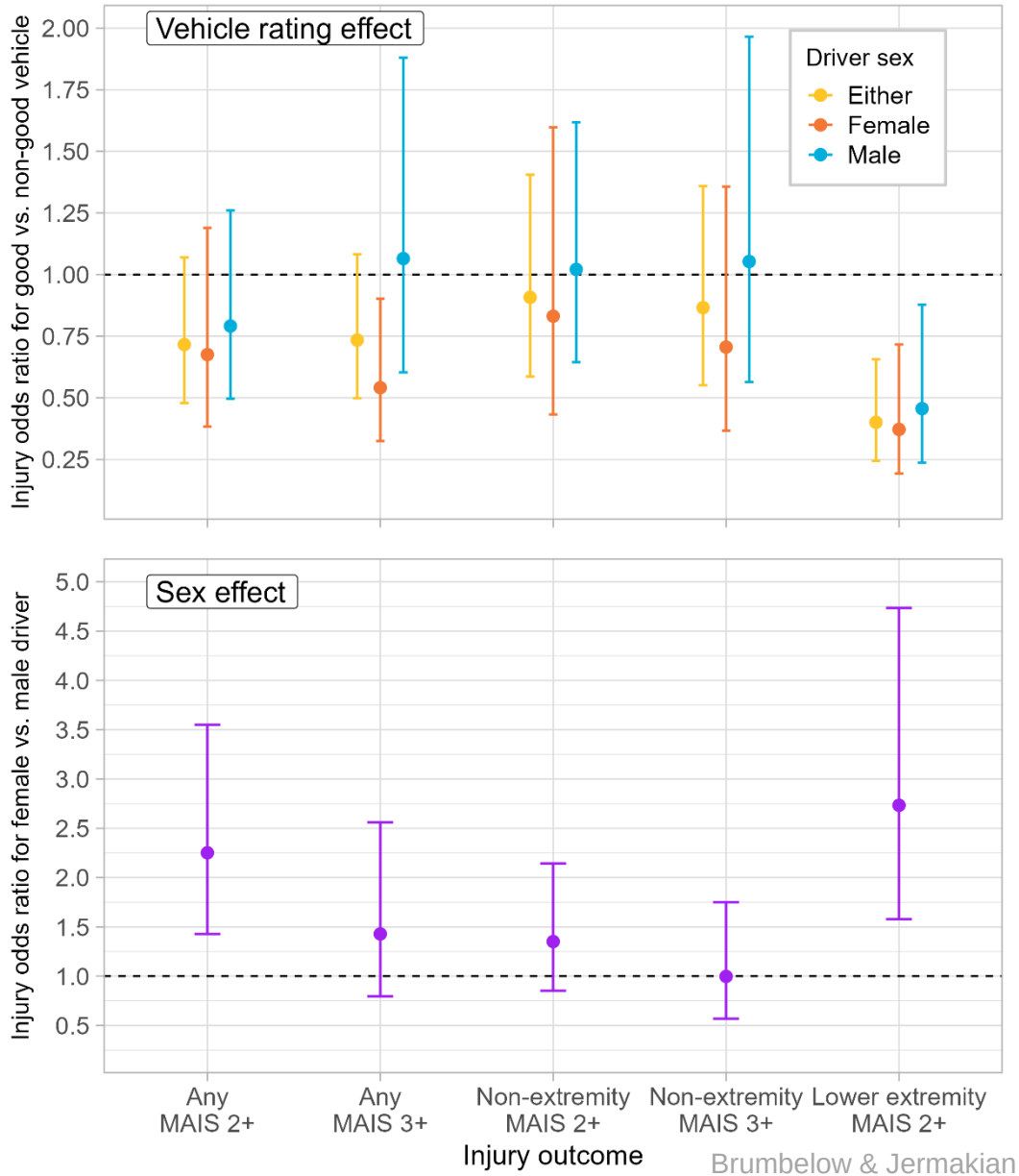


Elevated female driver lower extremity injury risk in frontal crashes

Vehicle crashworthiness improvements have reduced lower-extremity injury risk for both female and male drivers

However, females remain at higher risk of lower-extremity injury than male drivers in similar crashes

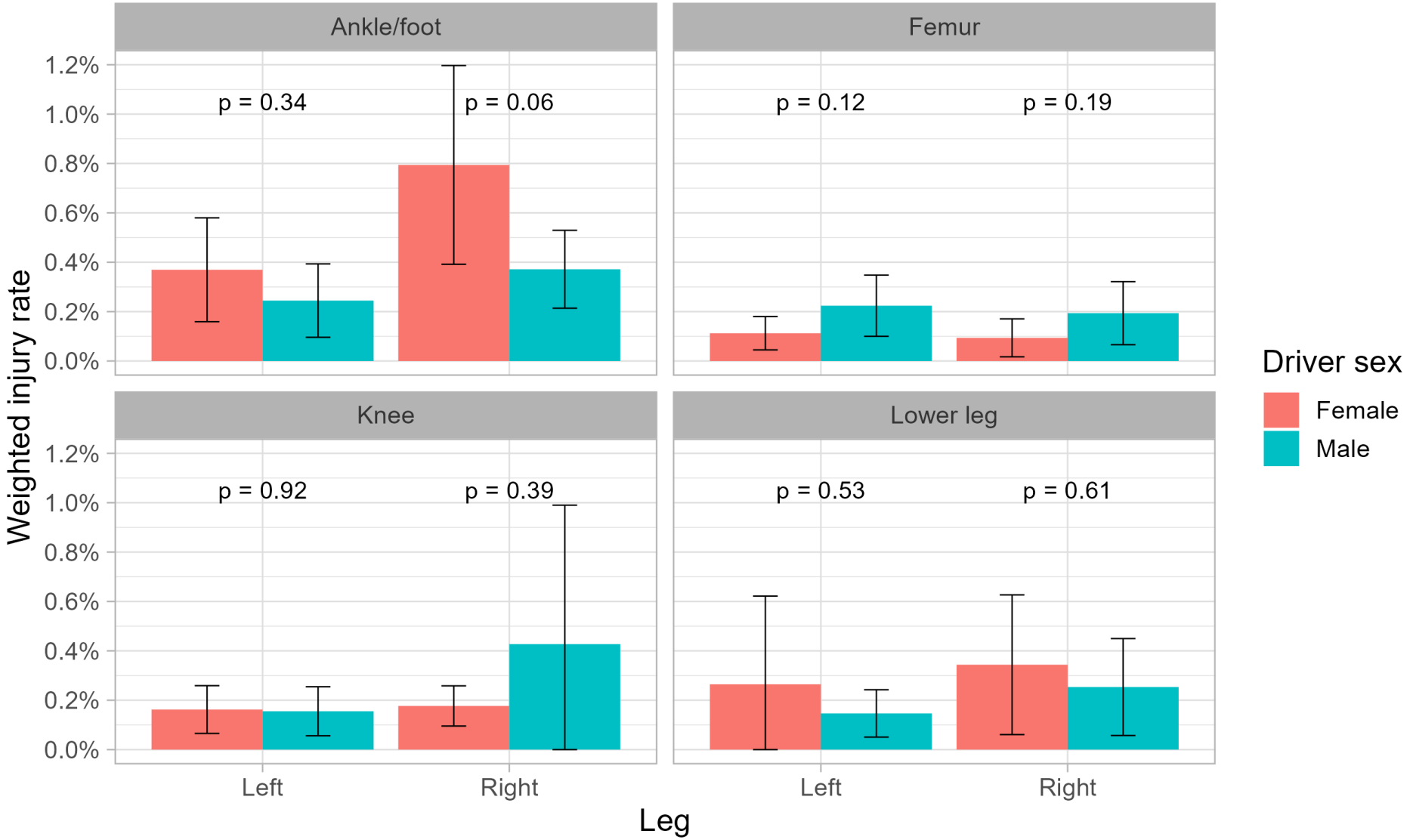


Brumbelow & Jermakian 2021

Right ankle/foot shows biggest injury rate difference

CISS 2017-2022 driver AIS2+ injury rates by sex and p-value for weighted t-test

Belted, front AB deployed, MY 2005+ (median 2013) front crashes with PV or object; n = 4489



Research questions

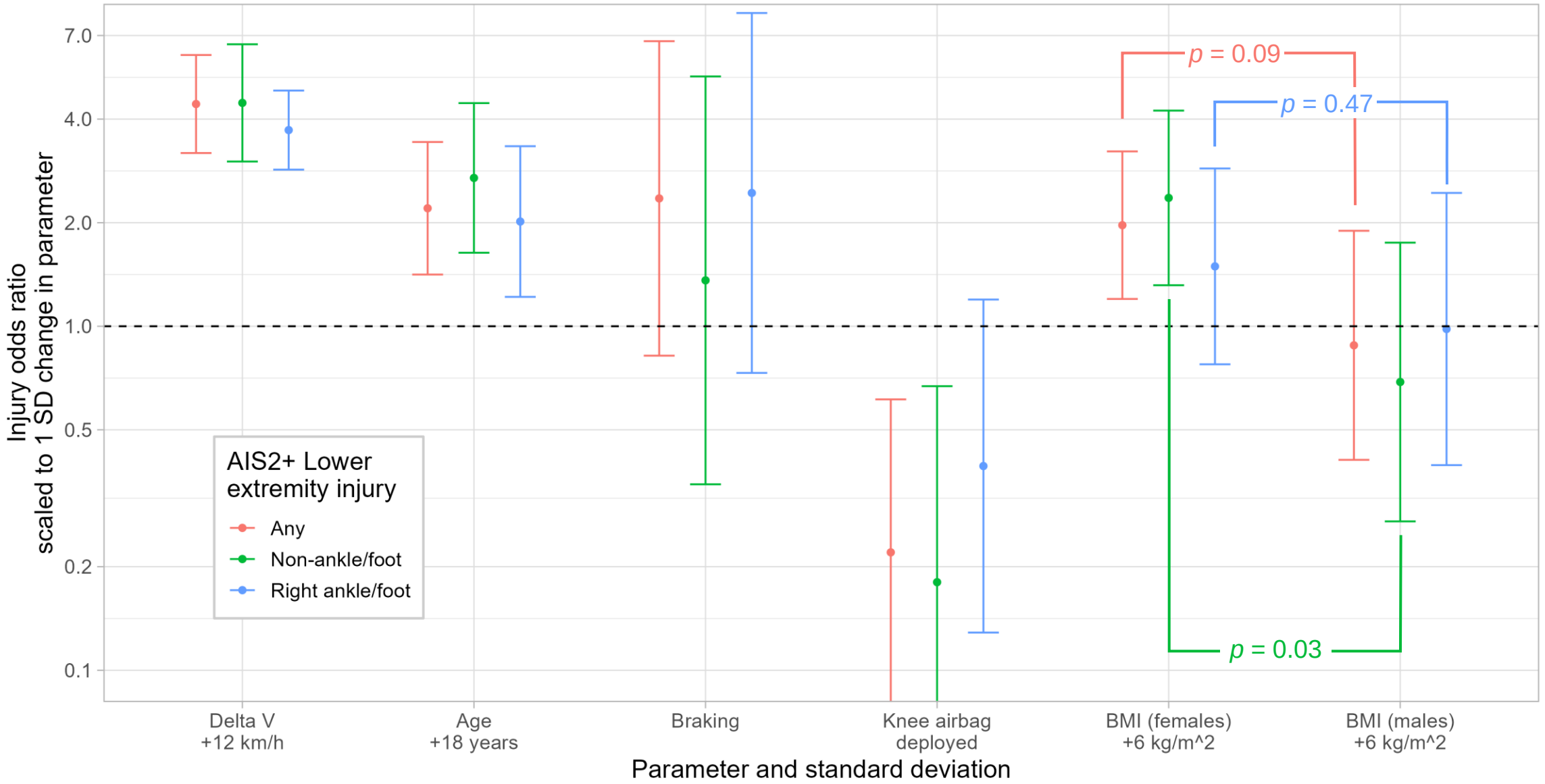
1. Do any driver or crash factors help explain sex-related differences in risk?
2. Are IIHS moderate overlap crash test metrics related to female injury risk? If so, should rating boundaries be adjusted?

Driver and crash factors

- Dataset: 2017-22 CISS with EDR, belt+AB restrained drivers in front crashes, limited intrusion
- Logistic regression models estimating odds of three different AIS ≥ 2 lower extremity injury outcomes: any, non-ankle/foot, right ankle/foot
- Covariates
  - Longitudinal EDR ΔV
  - Any EDR braking from $-2 \leq t < 0$ seconds
  - Knee airbag deployment
  - Driver sex
  - Driver age
  - Driver BMI
- Included interaction between driver sex and BMI; other interactions with driver sex evaluated initially but dropped in final models ($p > 0.5$)

Results: driver and crash factors

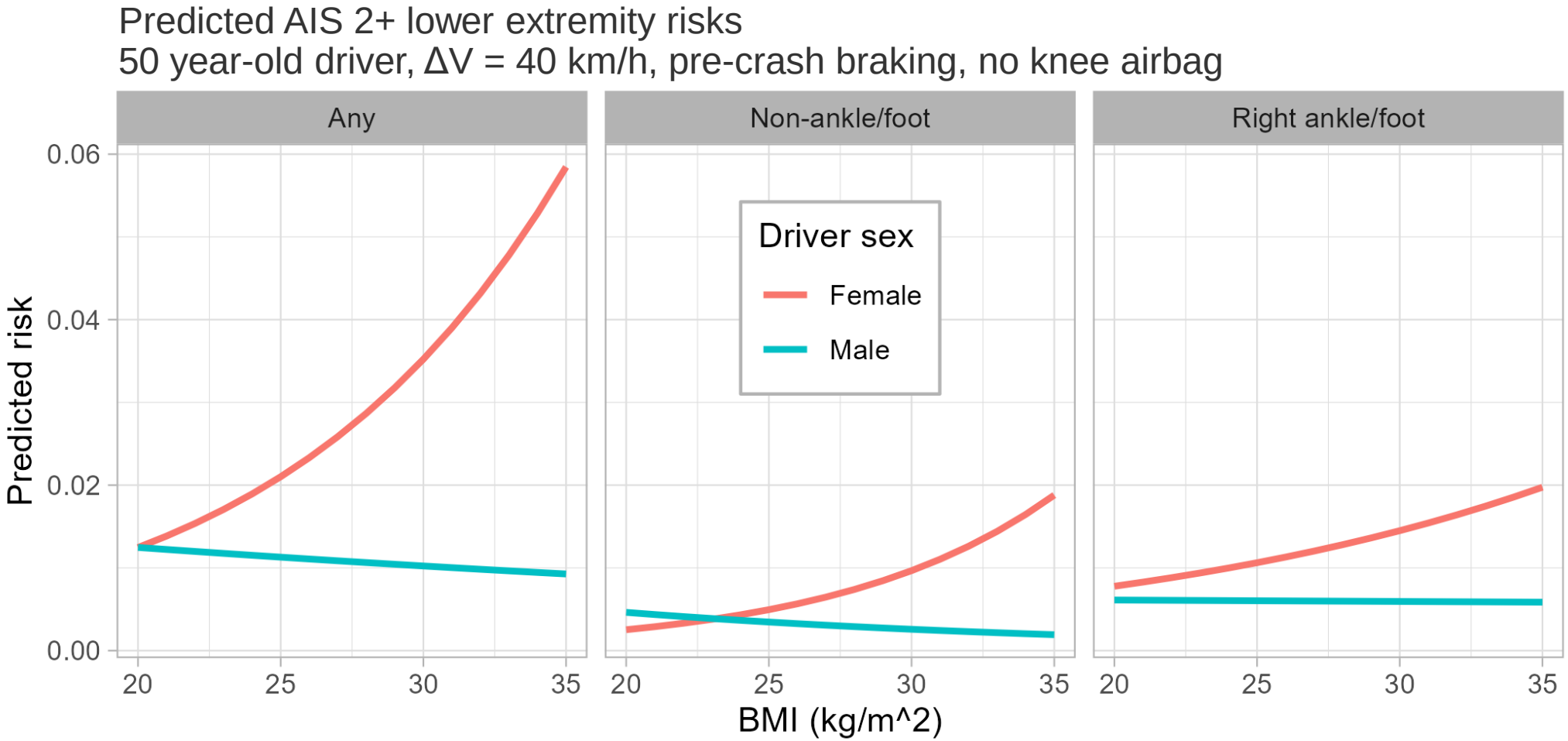
2017-22 CISS EDR cases



IIHS HLDI

Results: driver and crash factors

Sex-based differences vary with BMI



Summary: driver and crash factors

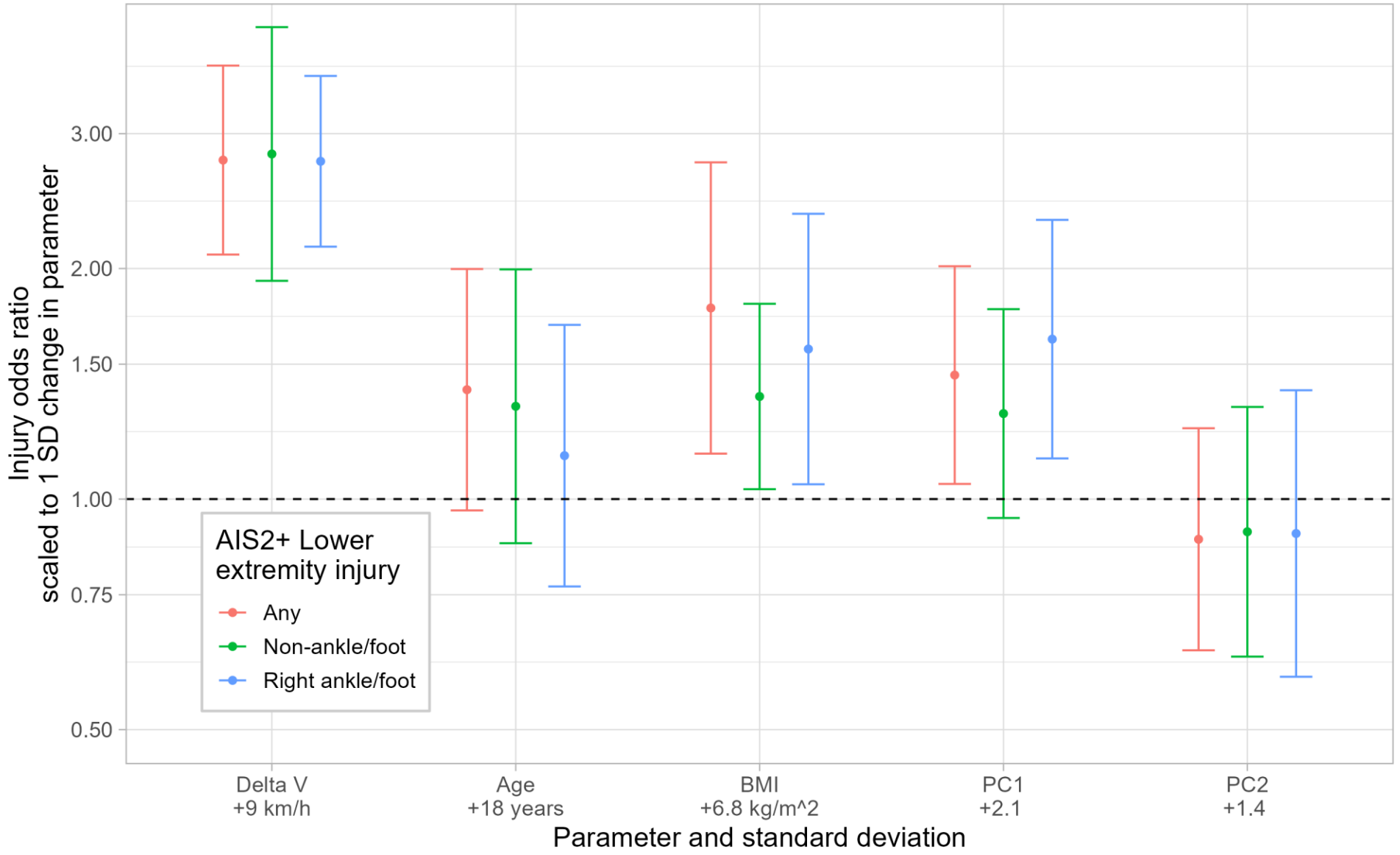
- Pre-crash braking
  - Increases right foot/ankle injury risk ~2.5x; equivalent to ΔV increase of 8 km/h
  - Minimal effect on non-foot/ankle injuries
- Knee airbags
  - Possibly reduces foot/ankle injury risk ~60%
  - Reduces non-foot/ankle injury risk ~80%
  - Opposite of previous NASS-CDS result; needs more data / further investigation
- BMI sex interaction: female risk generally increases with BMI while male risk does not
  - At lower BMI, females have similar or lower predicted injury risk than males
  - Dischinger et al. (2016) reported elevated risk for females at BMI ≥ 25, males only ≥ 40
  - Possible explanations include belt fit (e.g. Jones et al. 2021) or pre-impact leg and foot position (e.g. Boyle et al. 2020) but further investigation is needed

IIHS moderate overlap test metric analysis

- Dataset: 2000-15 NASS-CDS, belt+AB restrained drivers in front crashes, limited intrusion, *females only*
- Logistic regression models estimating odds of three different AIS ≥ 2 lower extremity injury outcomes: any, non-ankle/foot, right ankle/foot
- Covariates
  - WinSMASH longitudinal ΔV
  - Driver age
  - Driver BMI
  - Test metrics expressed as 1st and 2nd principal components (PC1 and PC2) of all lower extremity test metrics
    - PC1 was a linear positive combination of all peak measures (all measures had a positive loading, most with a similar magnitude)

Results: test metrics for female drivers

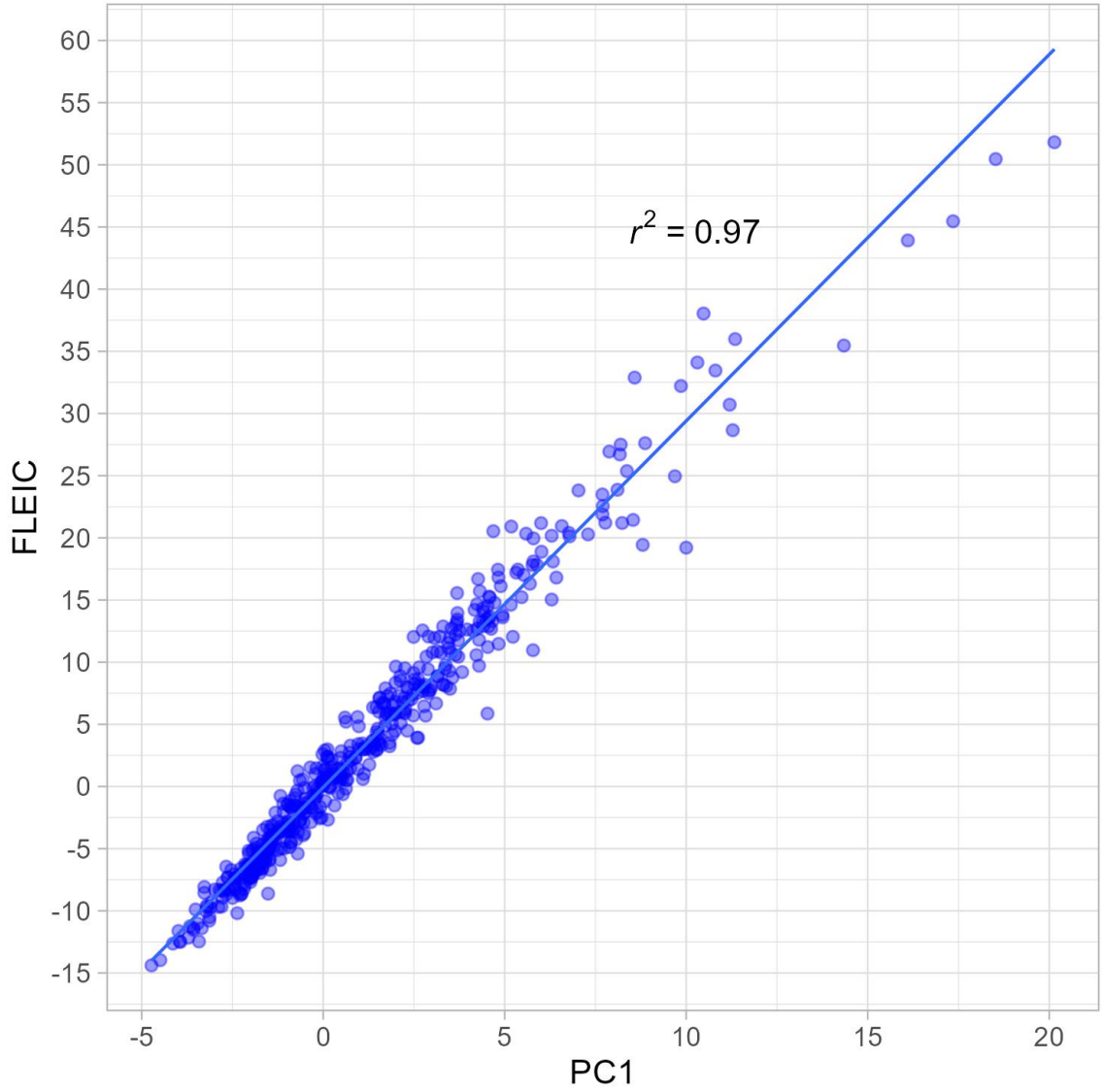
2000-15 NASS-CDS cases



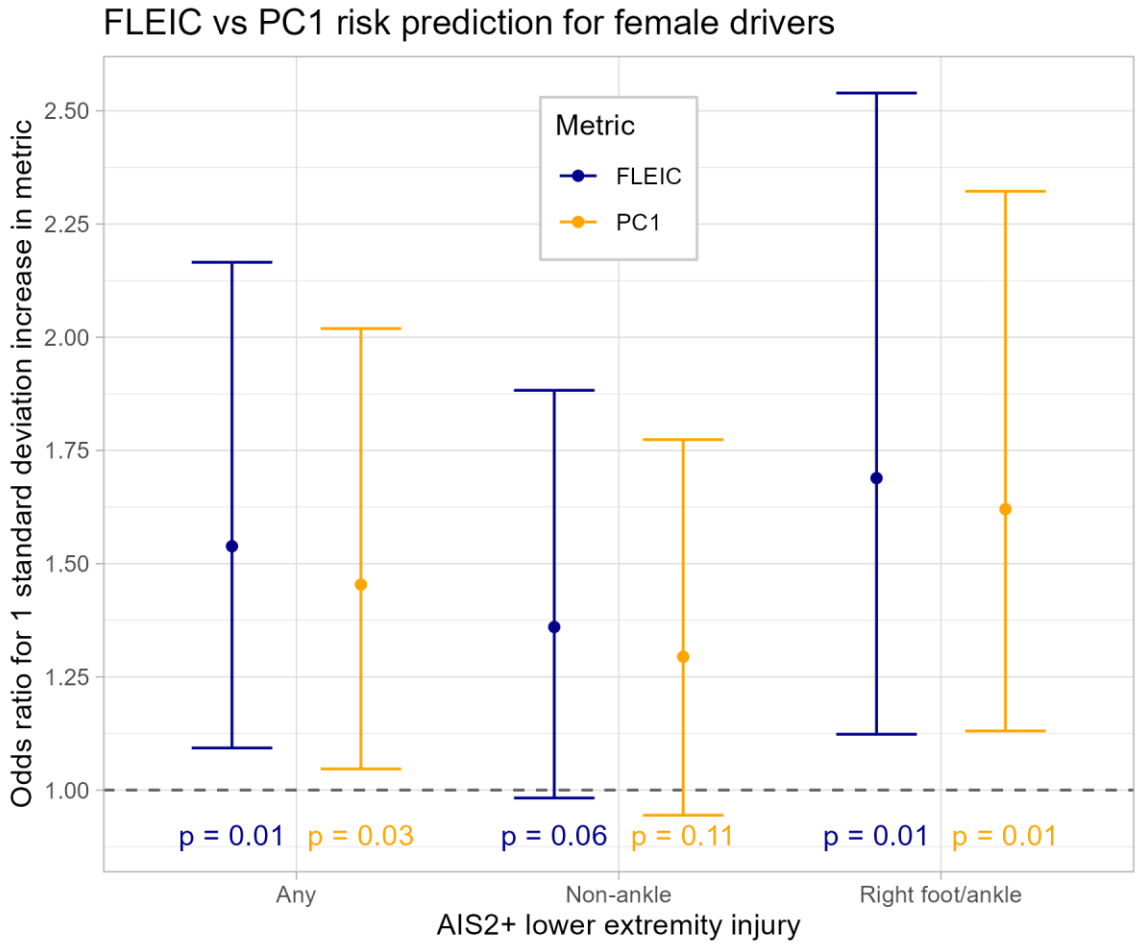
IIHS HLDI

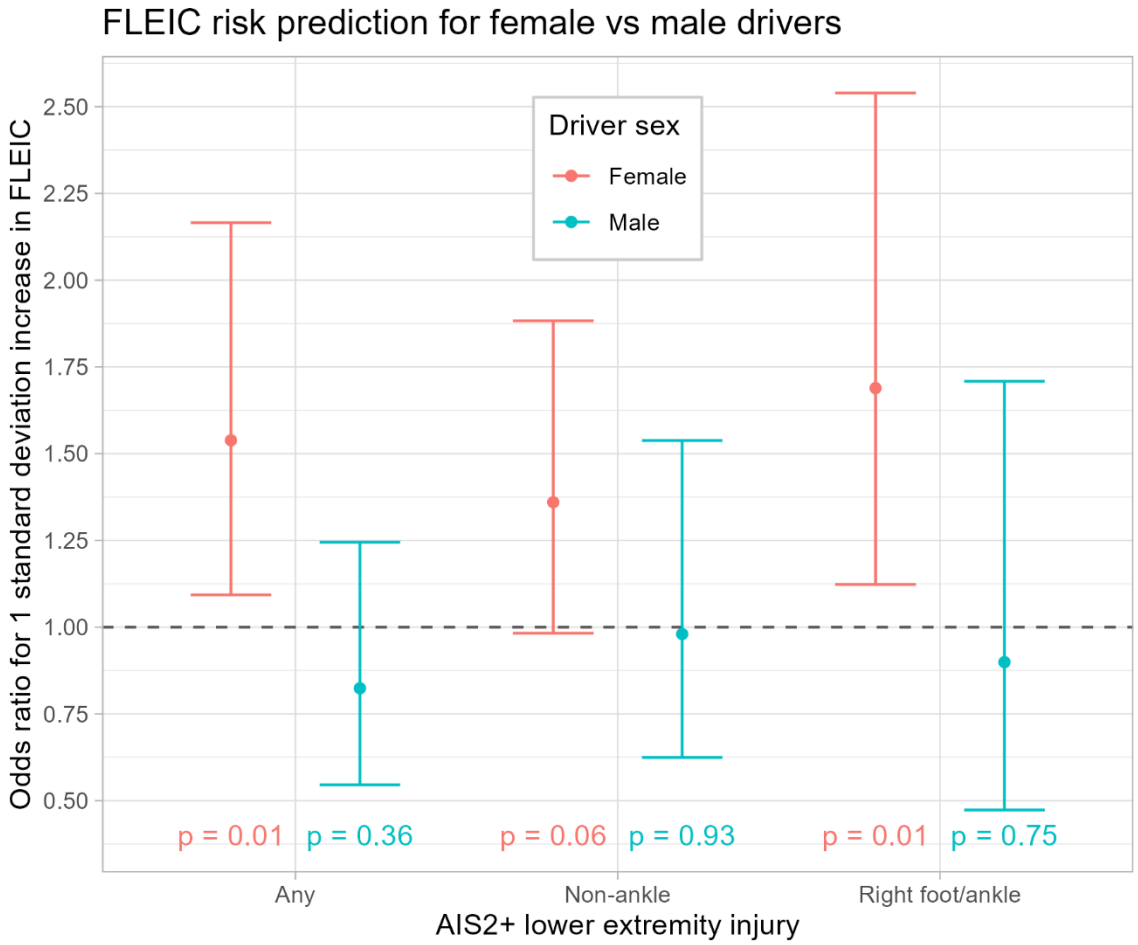
A simplified female lower extremity injury criterion (FLEIC) has minimal differences with PC1

- Simplified PC1 by:
  - Using resultant accelerations and moments instead of x/y/z components
  - Using the same centering and scaling values for both legs
  - Equal weighting for each measure
- Reduces data adjustment steps from 18 to 5



Simplified metric predicts female injury as well as PC1
It does not predict male injury (neither did PC1)





Summary: moderate overlap test metrics

- In good-rated vehicles, a linear combination of HIII-50M ODB test metrics is strong predictor of risk for female drivers in crashes with limited intrusion, especially for right foot/ankle injuries
- Adjusting IIHS rating criteria may be appropriate to further reduce risks for females
- Next steps
  - Continue development of female-specific rating metric
  - Footwell camera added to ODB tests
  - Industry engagement

    What countermeasures might be encouraged by more stringent HIII-50M rating boundaries?

    Do these align with countermeasures suggested by other analyses (PMHS, HBM, other)?

    Any explanation for why newer knee airbags may be more effective?

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THANK YOU

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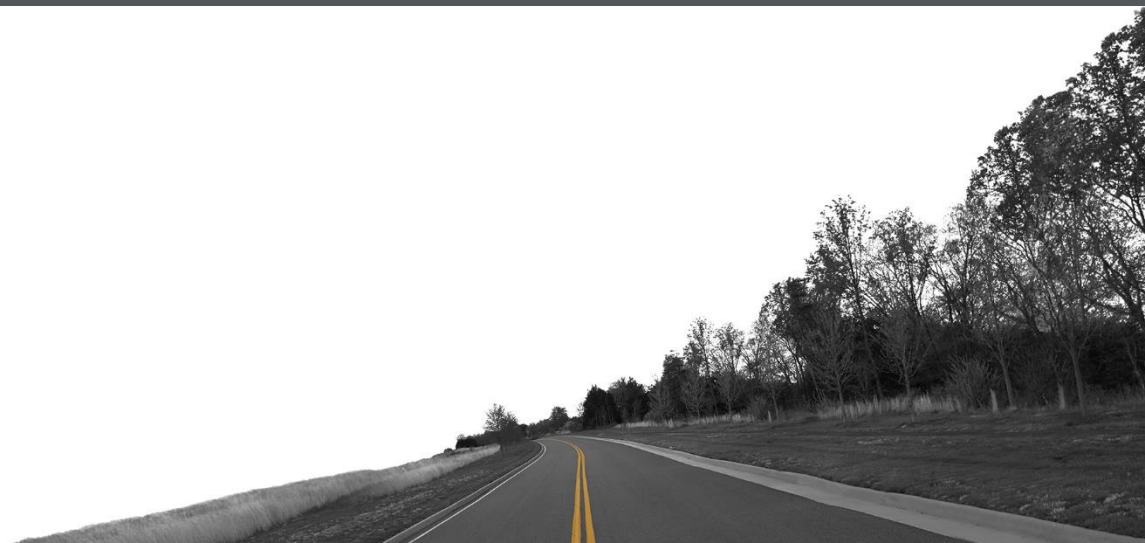

Development of simplified injury metric FLEIC

PC1					FLEIC				
Measure	Location	Loading	Mean	Std. dev.	Measure	Location	Multiplier	Center	Scale
Femur force (kN)	Left	0.115	2.08	1.63	Femur force (kN)	Left	1 (all scaled measures given equal weight)	2.1	1.5
	Right	0.276	2.26	1.37		Right			
Foot X acceleration (g)	Left	0.311	56.02	20.90	Resultant foot acceleration (g)	Left		75	25
	Right	0.273	67.04	29.00		Right			
Foot Z acceleration (g)	Left	0.284	48.29	16.27					
	Right	0.236	51.58	21.00					
Knee disp. (mm)	Left	0.234	1.94	3.05	Knee disp. (mm)	Left		2	3
	Right	0.252	2.21	3.08		Right			
Tibia force (kN)	Left	0.216	1.91	0.77	Tibia force (kN)	Left		2.3	1
	Right	0.283	2.82	1.12		Right			
Tibia X moment (Nm)	Left lower	0.088	48.37	29.34	Resultant tibia moment (Nm)	Left lower		90	40
	Left upper	0.200	48.86	20.19		Left upper			
	Right lower	0.206	91.22	48.73		Right lower			
	Right upper	0.195	68.73	30.30		Right upper			
Tibia Y moment (Nm)	Left lower	0.144	52.75	28.61					
	Left upper	0.245	70.35	32.03					
	Right lower	0.239	63.54	34.40					
	Right upper	0.304	76.21	34.06					

18 measures, each with unique center, scaling and weighting values

12 measures, 5 center/scaling values, equal weight

$$\text{FLEIC} = \frac{X_1 - c_{X_1}}{s_{X_1}} + \frac{X_2 - c_{X_2}}{s_{X_2}} + \cdots$$

where $X_1, X_2, \cdots$ are the peak values recorded for each of the measures, $c_{X_1}, c_{X_2}, \cdots$ are the "center" values for each measure shown in table, and $s_{X_1}, s_{X_2}, \cdots$ are the "scale" values for each measure shown in table

Peak values from both left and right legs are used.