

# Daily and hourly exposure to $PM_{2.5}$ and wildfire smoke and cognitive performance in a brain-training game: A longitudinal study of US adults

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# ACKNOWLEDGEMENTS



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# AGENDA

**1** Background & Objective

**2** Methods

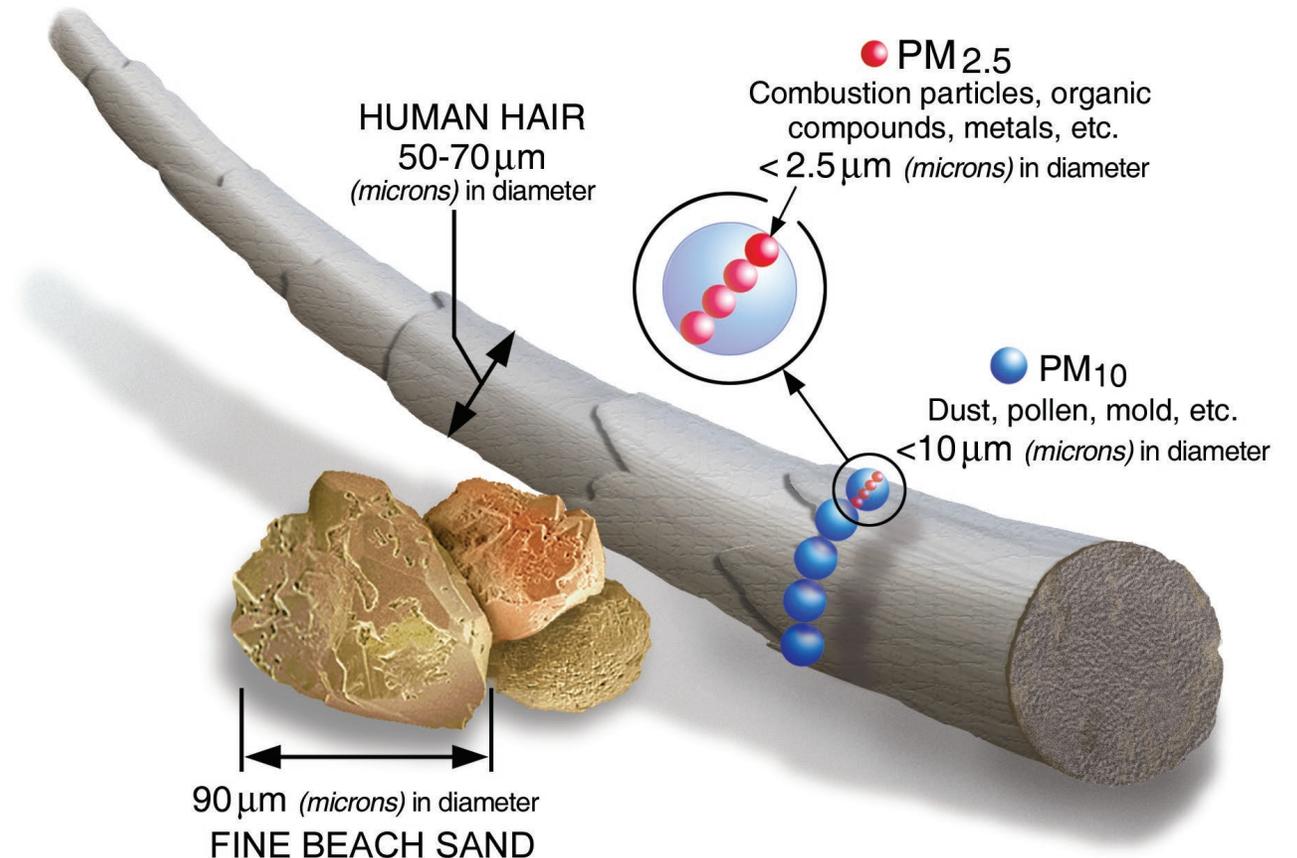
**3** Results

**4** Conclusions

# **BACKGROUND & OBJECTIVE**

# Fine Particulate Matter (PM<sub>2.5</sub>)

- PM<sub>2.5</sub> = particulate matter less than 2.5 microns in diameter
- Emitted from cars, power plants, fires, etc. and formed from chemical reactions
- Exposure is ubiquitous and continuous
- Inhaled into the deepest parts of the lungs, causing adverse health outcomes



# Wildfire Smoke

- Complex mixture of PM and toxic chemicals and gases  
→ PM<sub>2.5</sub> primary concern
- Wildfire PM<sub>2.5</sub> has different composition from typical ambient PM<sub>2.5</sub>
- Exposure may lead to different health effects compared with typical air pollution
- Exposure likely to increase with climate change



# Air Pollution & Cognitive Function

- $PM_{2.5}$  can reduce academic performance in children and accelerate cognitive decline in the elderly
- Agricultural fires and indoor fire usage can reduce performance on neurocognitive tests
- Most epidemiologic evidence is for long-term exposure (1 or more years)



# Knowledge Gaps



Limited evidence of PM<sub>2.5</sub> associations at the daily and hourly level

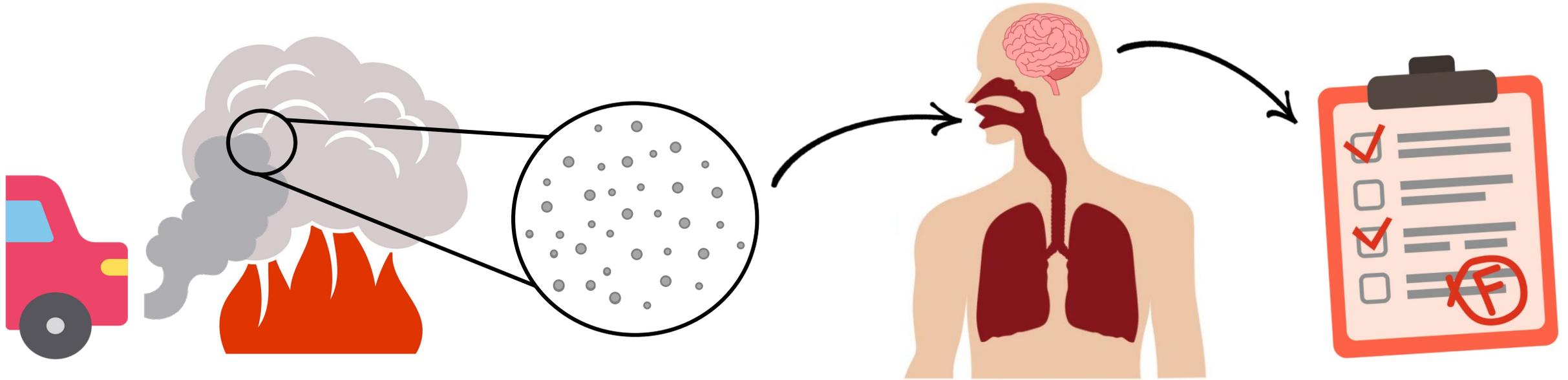


No evidence of associations with wildfire smoke exposure



Limited evidence of associations in the working age population

# Objective



Evaluate the associations between daily and sub-daily exposure to PM<sub>2.5</sub> and wildfire smoke and cognitive performance in adults in the contiguous United States (US)

# METHODS

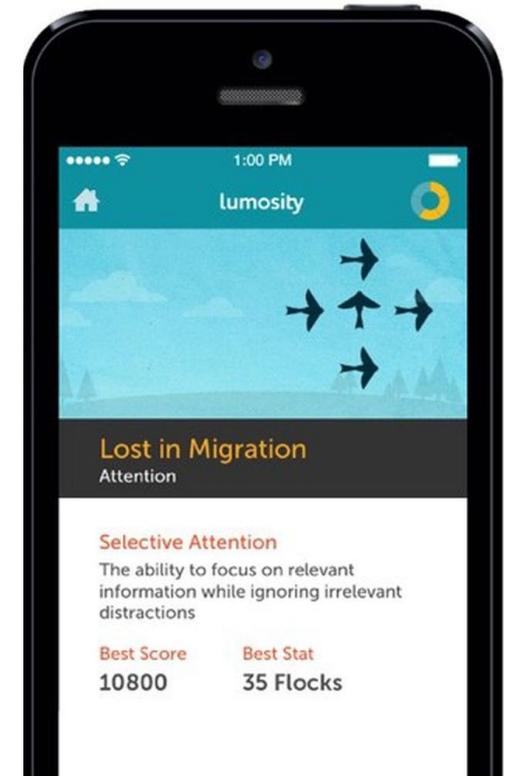
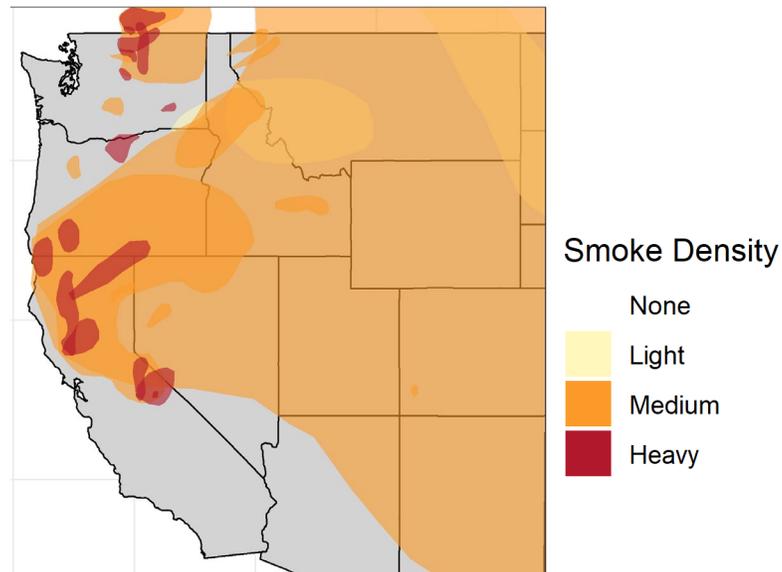
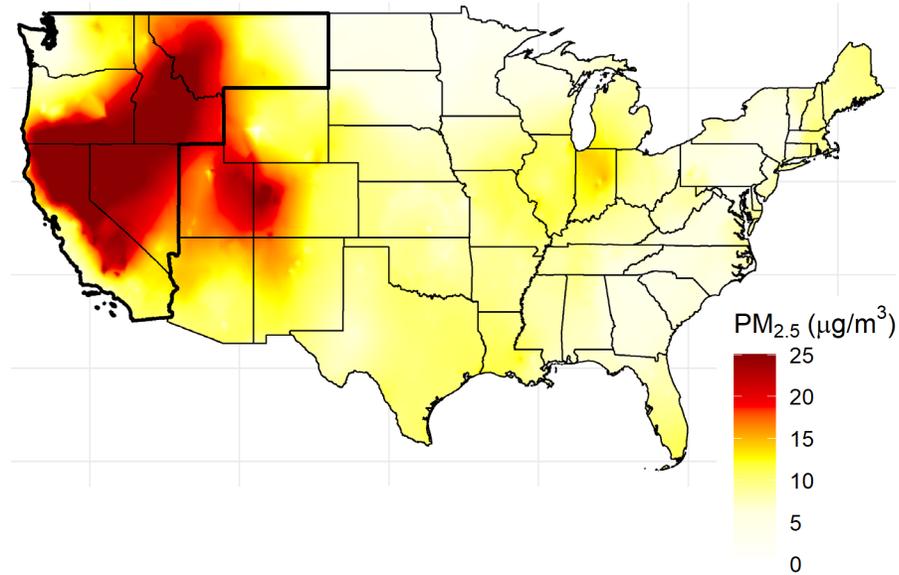
# Approach Overview

Daily and Sub-Daily  
 $PM_{2.5}$  & Smoke Exposure

Longitudinal study design with  
linear mixed effects models

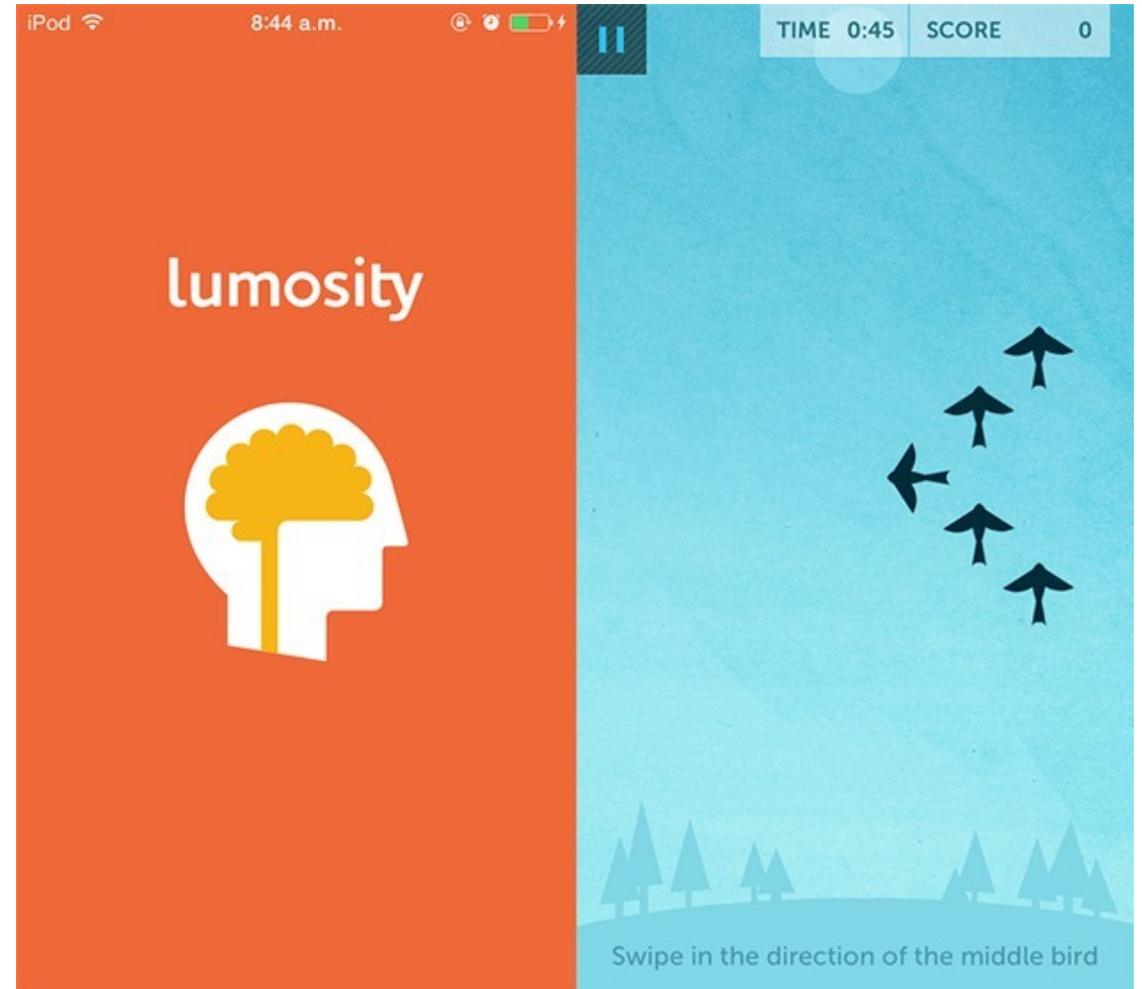


Cognitive Performance  
in Adults



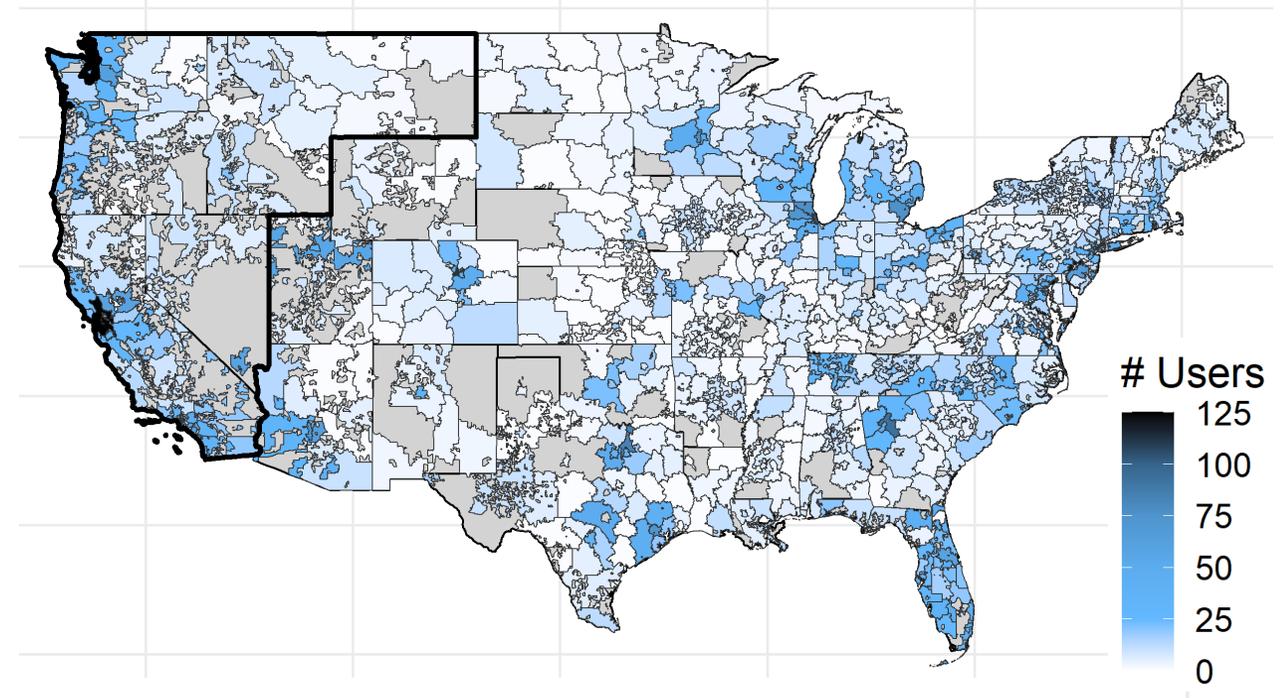
# Cognitive Performance Data

- Lumosity brain-training platform
- Data for 10,228 contiguous US users ( $\geq 18$ ) in a game designed to measure attention
- 20 timestamped scores per user for 2017-2018
- Information on user age, sex, education level, device used, and ZIP3 location
  - ZIP3: 27516



# Cognitive Performance Data

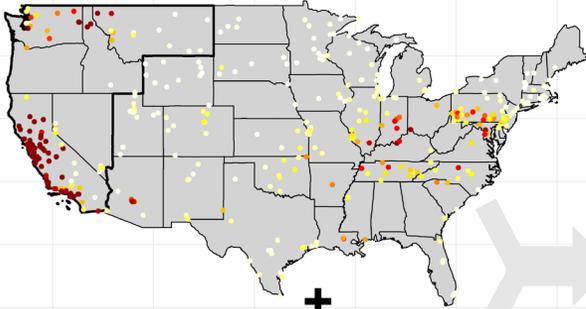
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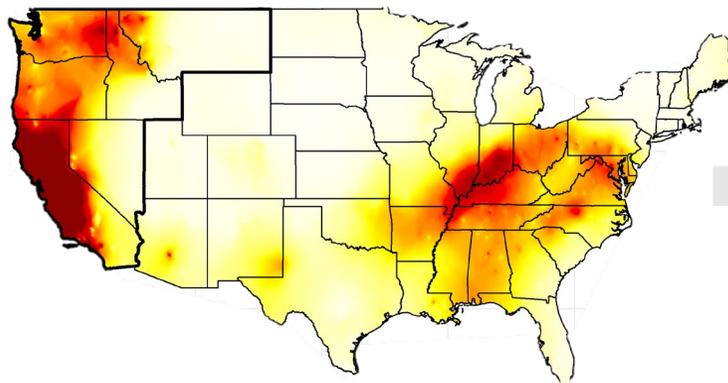
# PM<sub>2.5</sub> Data

- Bayesian Maximum Entropy (BME) Data Fusion of observations from US EPA FRM/FEM and PurpleAir monitors
- Population-weighted daily and hourly average BME estimates to ZIP3 level

FRM/FEM Observations

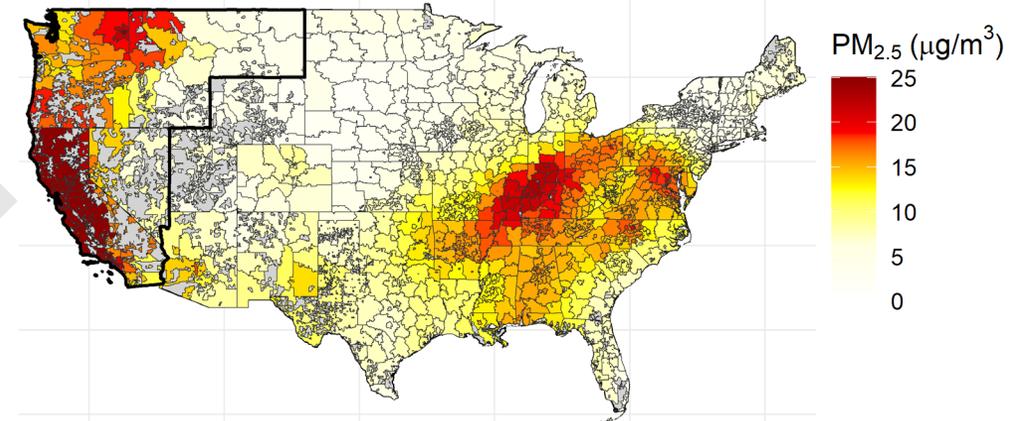


BME Data Fusion

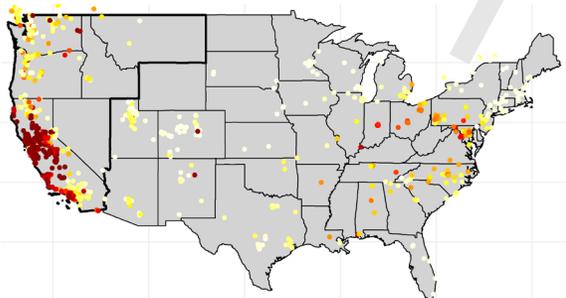


$R^2 = 0.815$

ZIP3-Level Population Weighted



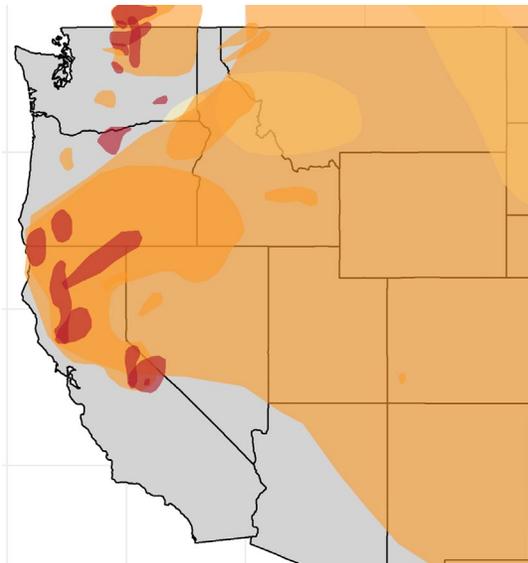
PurpleAir Observations



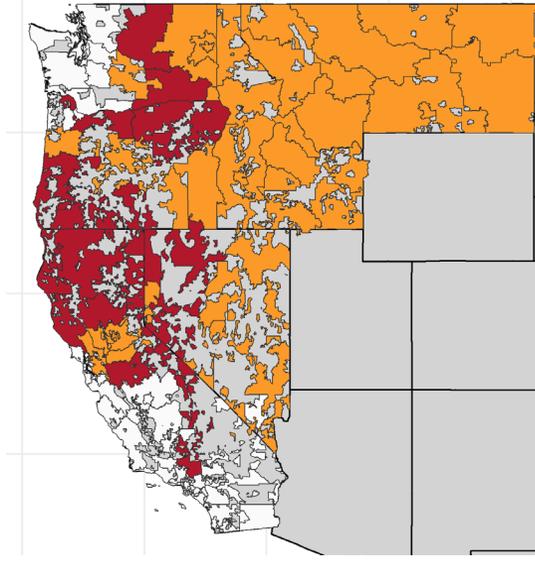
# Wildfire Smoke Data

- Smoke plumes from NOAA's Hazard Mapping System
  - Plumes classified into 3 densities: light, medium, heavy
- Limited data to western US (CA, OR, NV, ID, MT)
- Calculated maximum daily smoke density observed in a ZIP3

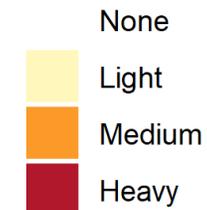
NOAA's HMS Smoke Plumes



ZIP3-Level Maximum



Smoke Density



# Statistical Analyses

Longitudinal repeated measures design with linear mixed effects models

$$Score_{n,i,s,t} = \beta_0 + u_{0,i} + \beta_1 \log(n) + \beta_2 Score_{i,n-1} + \beta_3 Score_{i,n-2} + \beta_4 Score_{i,n-3} + \beta_5 Exposure_{s,t} + covariate_{n,i,s,t} + \varepsilon_{n,i,s,t}$$

# Statistical Analyses

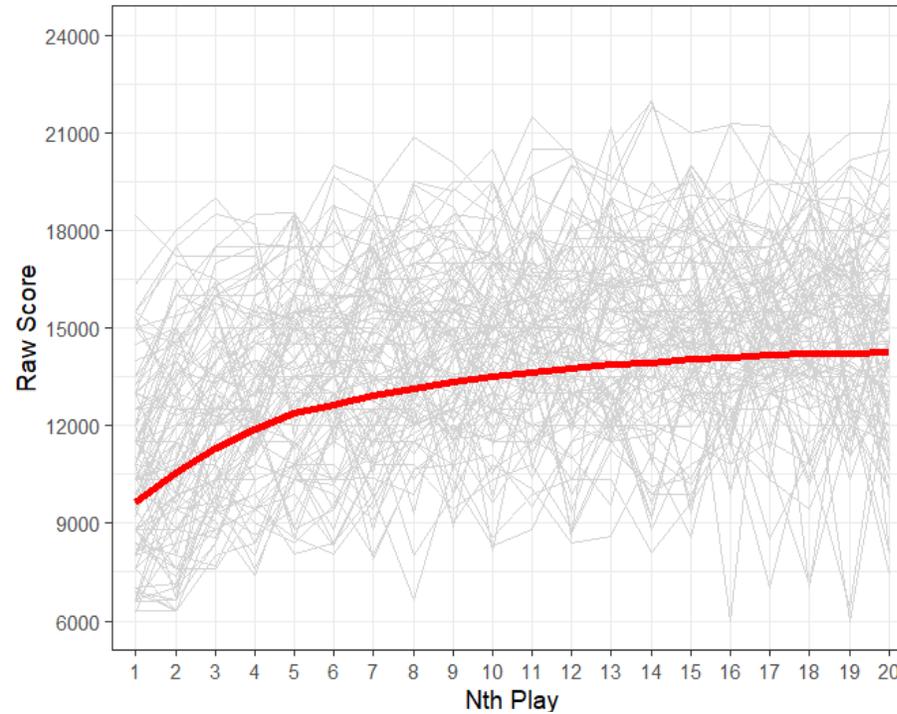
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**Score** on  
play  $n$  for  
user  $i$  in  
ZIP3  $s$  on  
day/hour  $t$

# Statistical Analyses

Learning over 20 plays

$$Score_{n,i,s,t} = \beta_0 + u_{0,i} + \beta_1 \log(n) + \beta_2 Score_{i,n-1} + \beta_3 Score_{i,n-2} + \beta_4 Score_{i,n-3} + \beta_5 Exposure_{s,t} + covariate_{n,i,s,t} + \varepsilon_{n,i,s,t}$$



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## **PM<sub>2.5</sub>**

Daily: 7 lags of daily average PM<sub>2.5</sub>

Hourly: Max hourly PM<sub>2.5</sub> in 3, 6, and 12 hours prior to play

## **Wildfire Smoke**

Daily: Max smoke density at lags 0 and 1

Weekly: Max smoke density in 1 week prior to play

# Statistical Analyses

$$Score_{n,i,s,t} = \beta_0 + u_{0,i} + \beta_1 \log(n) + \beta_2 Score_{i,n-1} + \beta_3 Score_{i,n-2} + \beta_4 Score_{i,n-3} + \beta_5 Exposure_{s,t} + covariate_{n,i,s,t} + \varepsilon_{n,i,s,t}$$

Covariates	
Time of day	Age group
Day of week	Gender
Month	Education
Days since last play	Device
Relative humidity	% poverty
Temperature	% HS graduation
Annual PM <sub>2.5</sub>	RUCC level

User & ZIP3-level characteristics

Meteorologic & temporal variables

# Primary Results

## PM<sub>2.5</sub>

Change in attention score associated with a 10  $\mu\text{g}/\text{m}^3$  increase in daily or sub-daily PM<sub>2.5</sub>

- For both contiguous and western US users
- Overall and by age, sex, and habitual behavior

## Wildfire Smoke

Change in attention score associated with light, medium, or heavy density smoke at the daily or weekly level, relative to no smoke

- For western US users only
- Overall and by age, sex, and habitual behavior

# Primary Results

## PM<sub>2.5</sub>

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## Wildfire Smoke

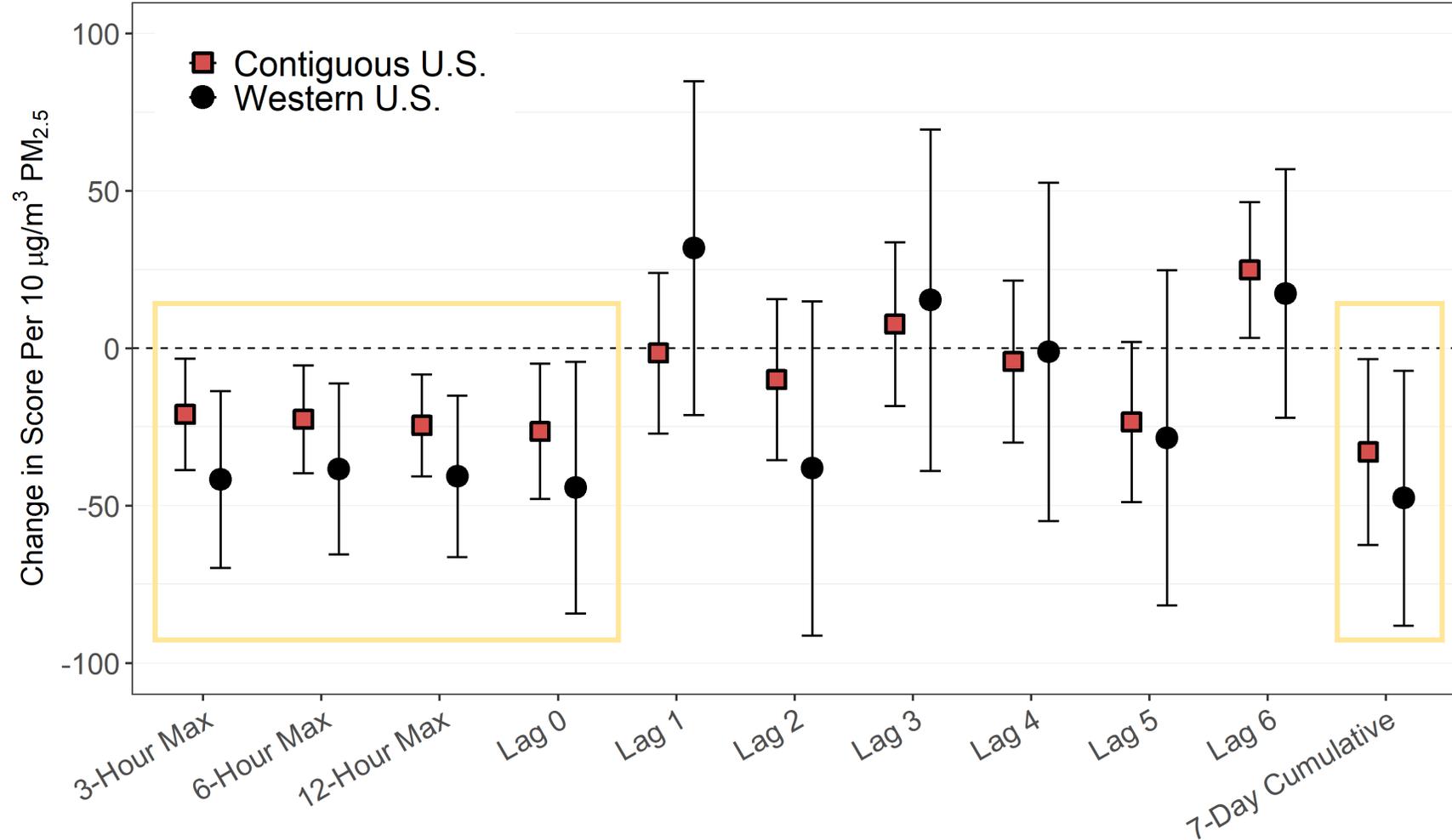
Change in attention score associated with light, medium, or heavy density smoke at the daily or weekly level, relative to no smoke

- For western US users only
- Overall and by age, sex, and habitual behavior

**RESULTS**

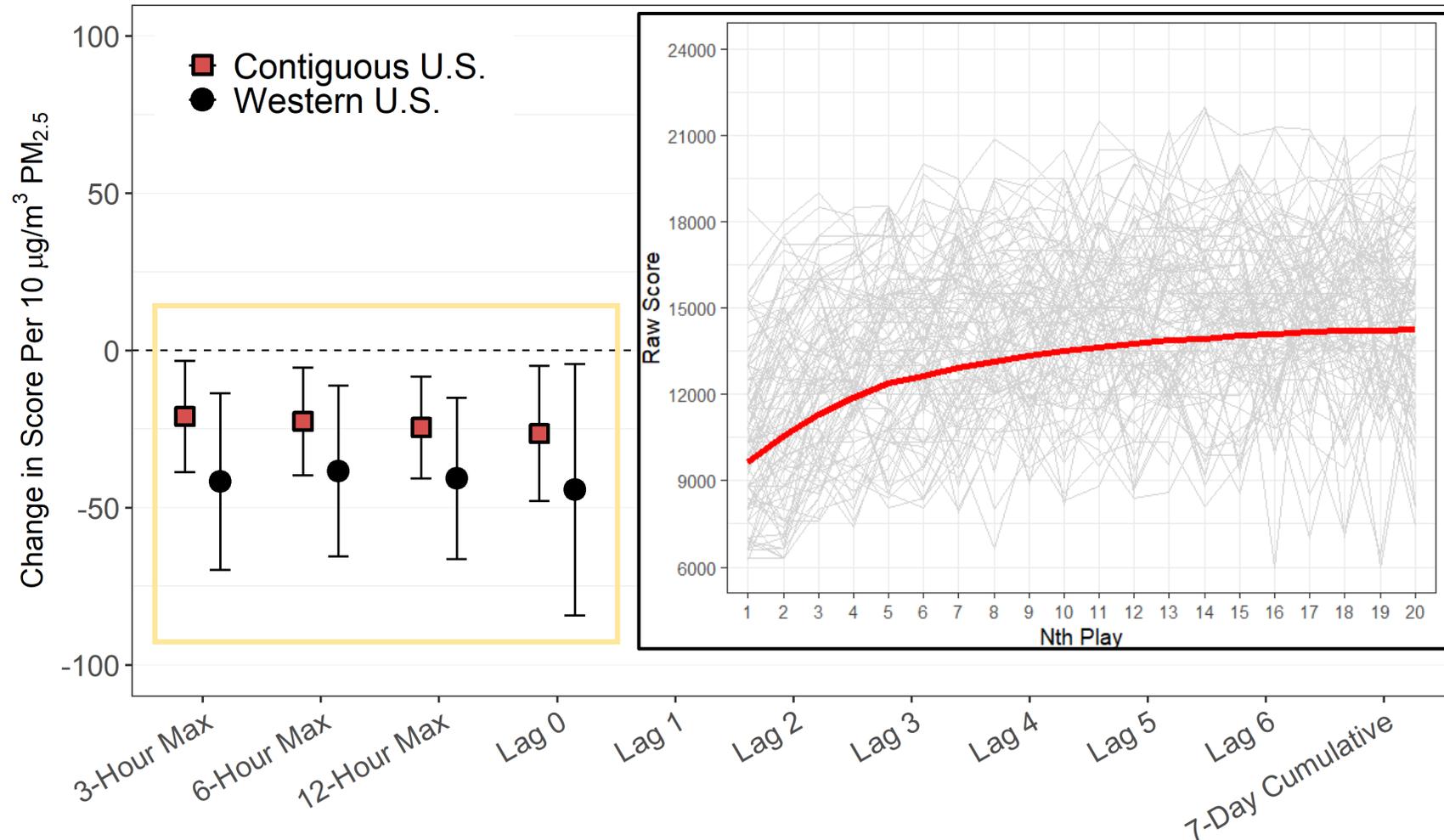
# Results – PM<sub>2.5</sub>

- Significant negative associations for both sub-daily and daily exposures
- Associations more pronounced in western US



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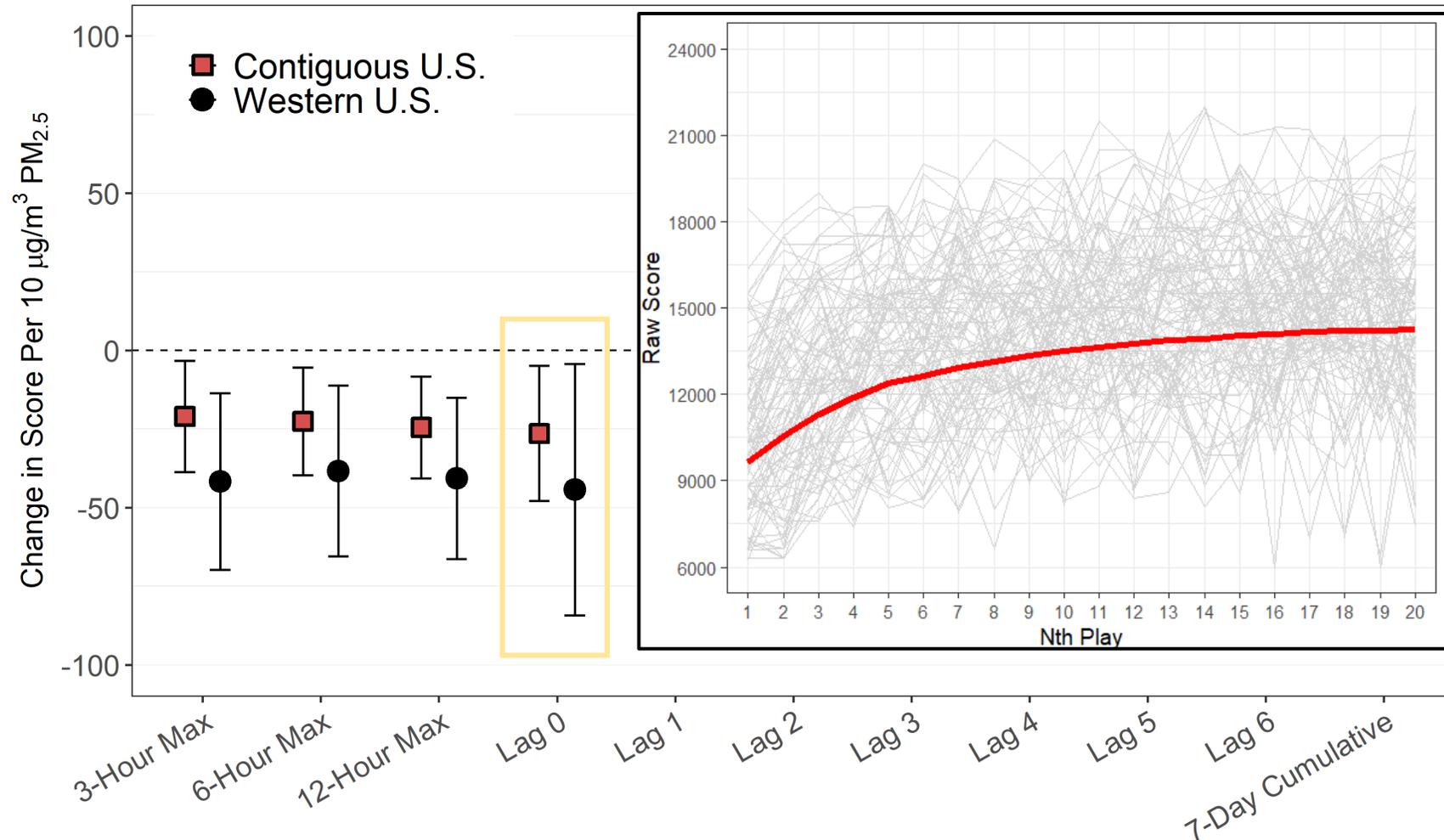
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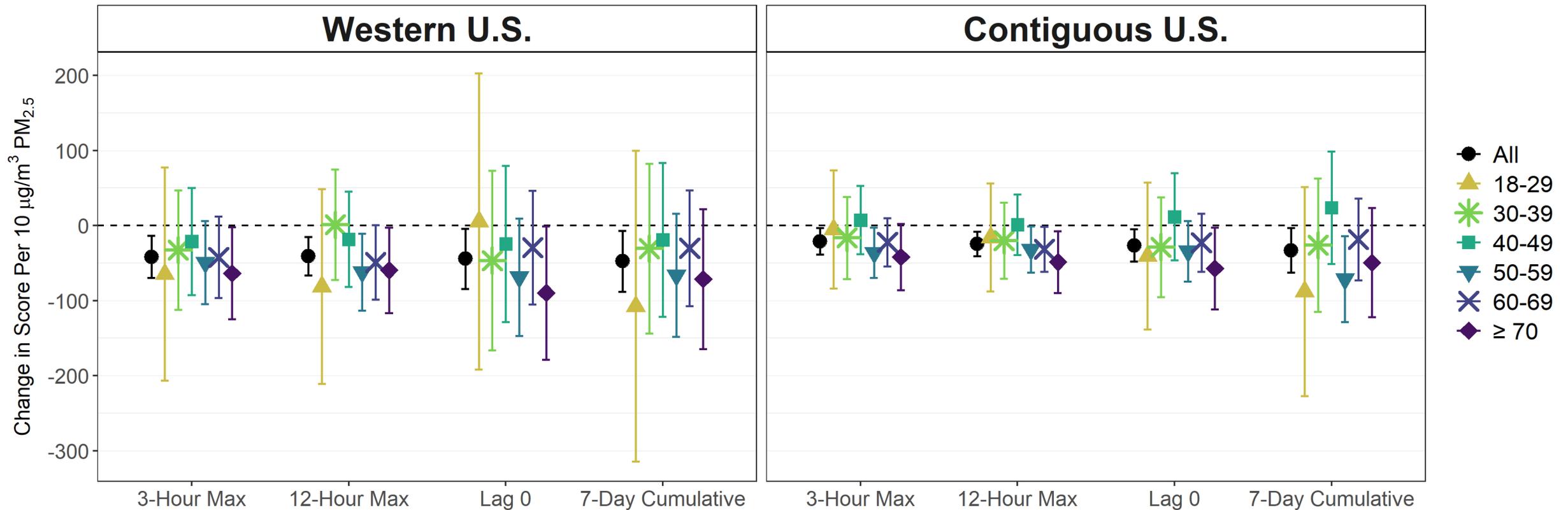
Exposure over 20 plays associated with:

- 3.7% reduction in final score (529 points, ~11 fewer correct answers) in contiguous US
- 6.2% reduction (882 points, ~18 fewer correct answers) in western US



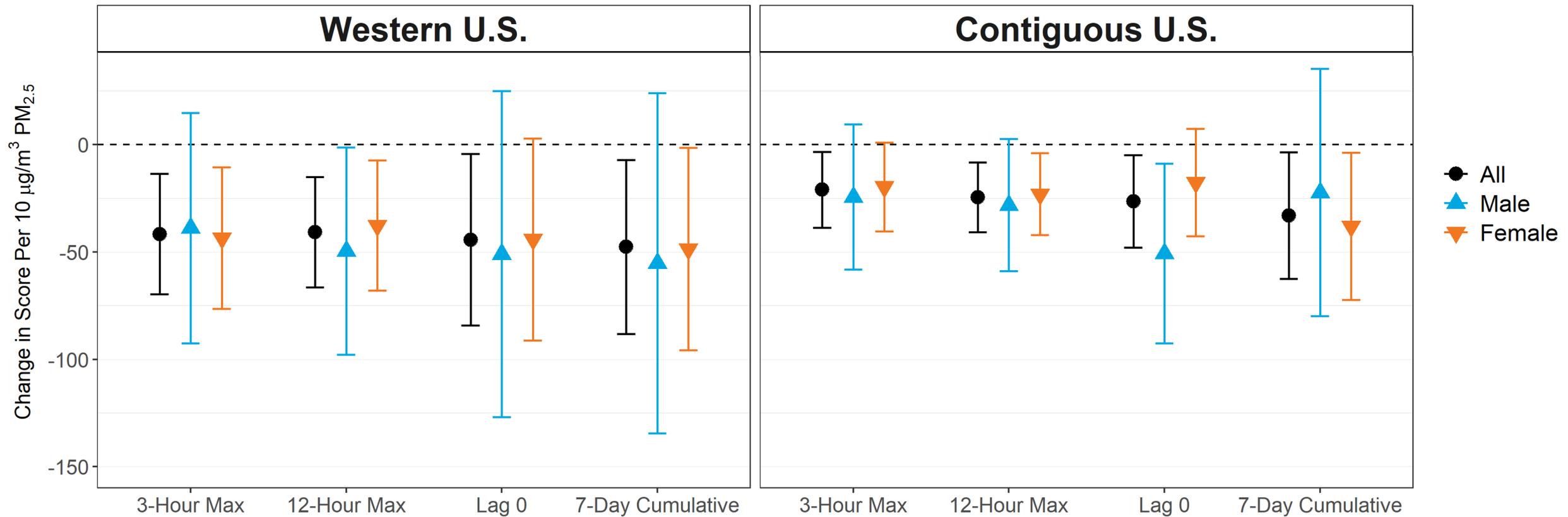
# Results – PM<sub>2.5</sub>

Youngest (18-29) and oldest (70+) users had strongest associations



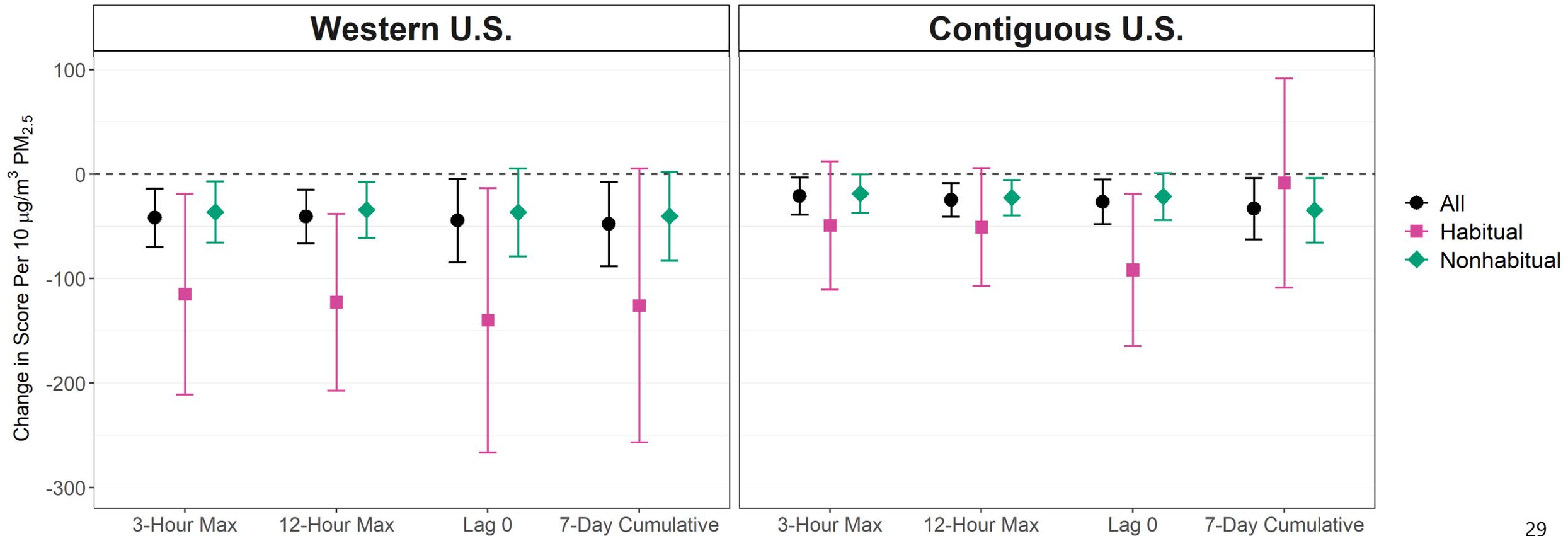
# Results – PM<sub>2.5</sub>

No observed differences by gender



# Results – PM<sub>2.5</sub>

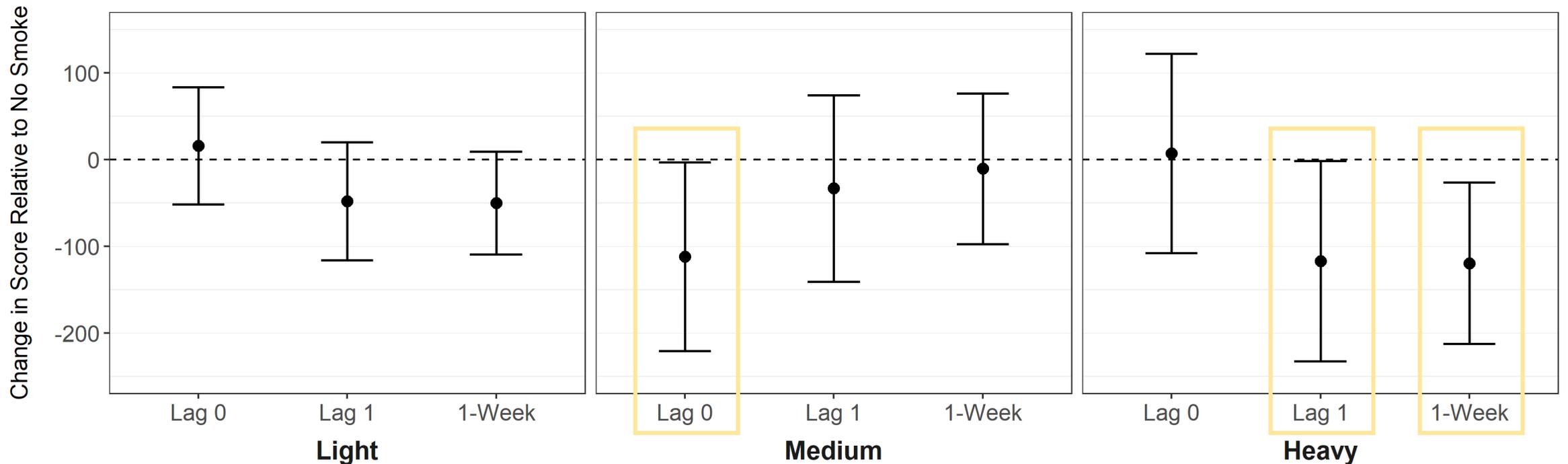
Associations more pronounced in habitual users



# Results – Wildfire Smoke

Significant negative associations for:

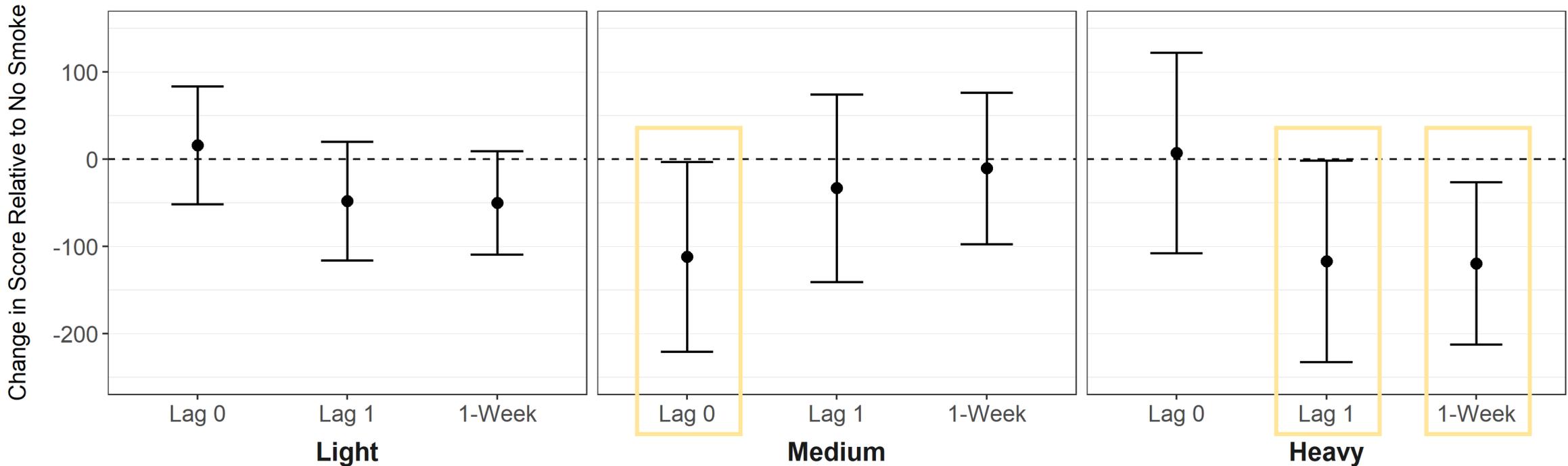
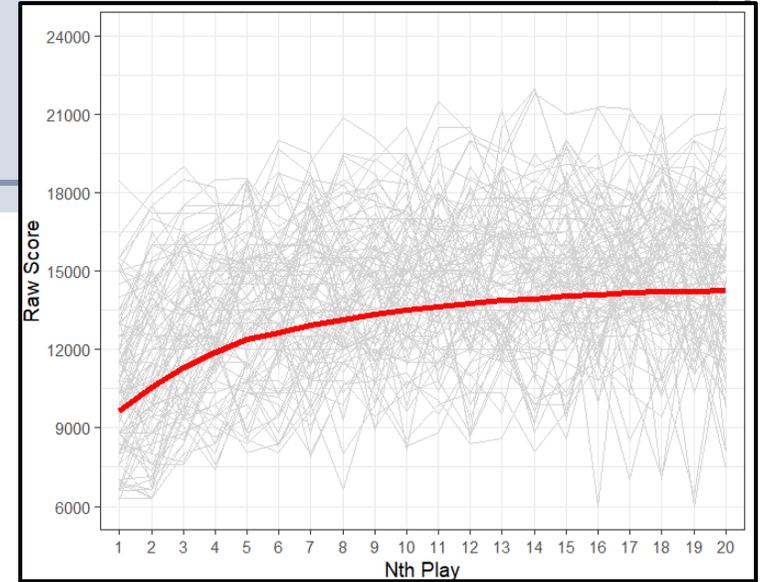
- Medium smoke density at Lag 0
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# Results – Wildfire Smoke

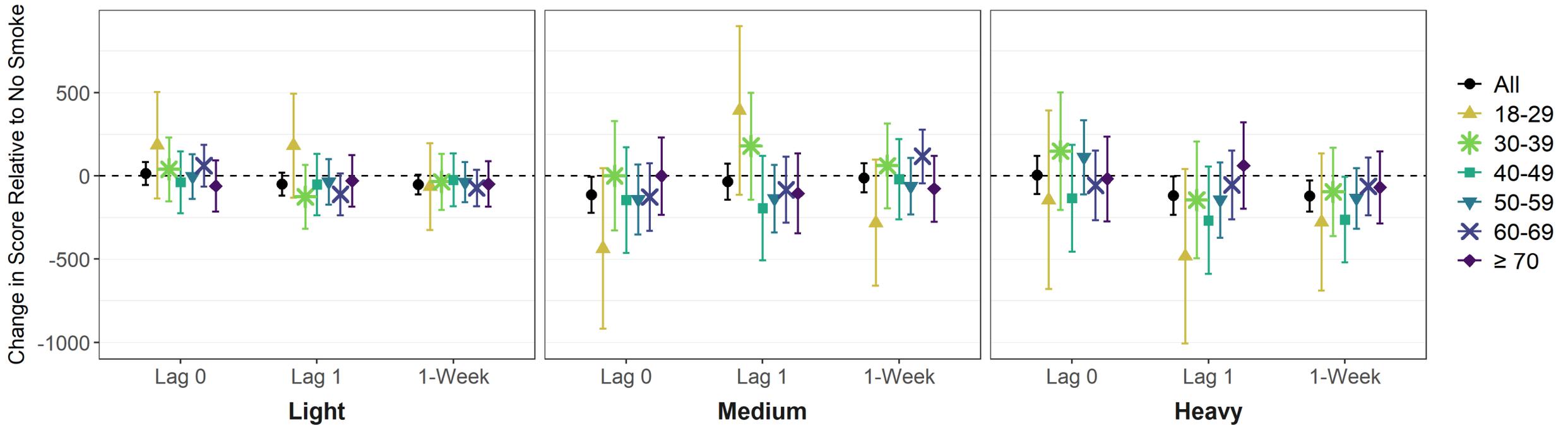
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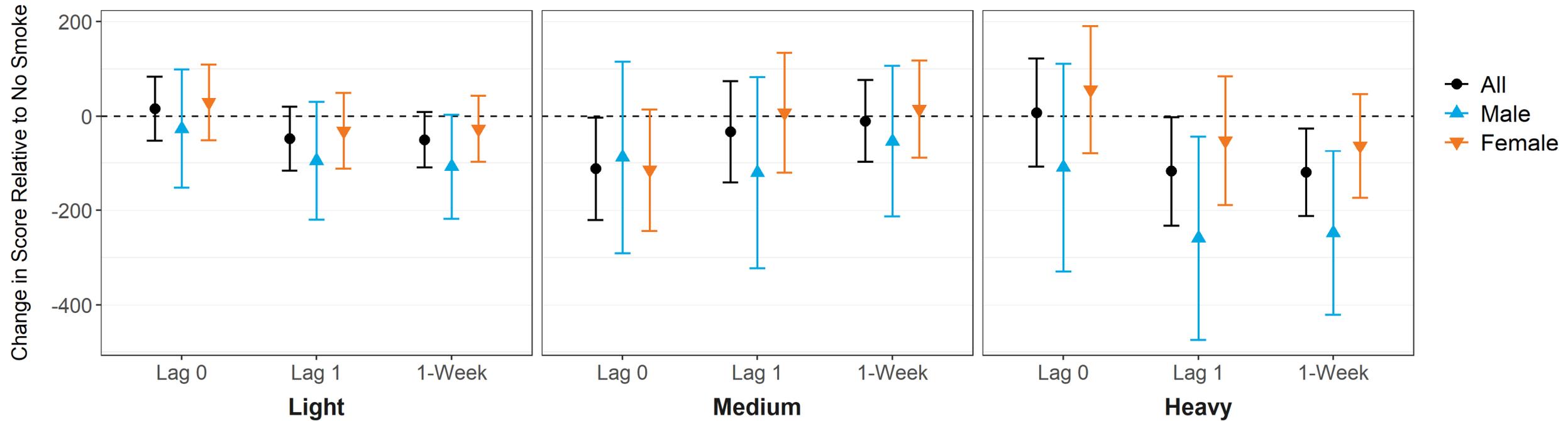
# Results – Wildfire Smoke

Users aged 18-29 and 40-49 had strongest associations



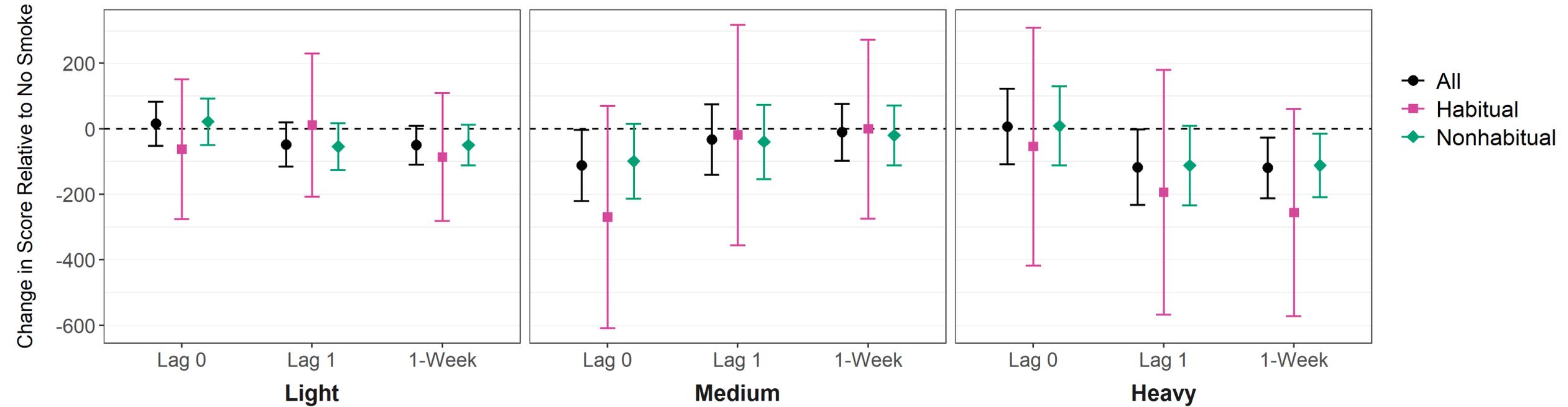
# Results – Wildfire Smoke

Males had more pronounced associations than females



# Results – Wildfire Smoke

Associations more pronounced in habitual users



**CONCLUSIONS**

# Primary Takeaways



Significant associations between short-term exposure to PM<sub>2.5</sub> and wildfire smoke and decreased attention in adults

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Significant associations between short-term exposure to  $PM_{2.5}$  and wildfire smoke and decreased attention in adults



Strongest associations with  $PM_{2.5}$  and wildfire smoke observed within a short exposure window

→  $PM_{2.5}$  within 3 hours of exposure, wildfire smoke within 1-2 days

# Primary Takeaways



Significant associations between short-term exposure to  $PM_{2.5}$  and wildfire smoke and decreased attention in adults



Strongest associations with  $PM_{2.5}$  and wildfire smoke observed within a short exposure window



$PM_{2.5}$  associations more pronounced in the wildfire-impacted western US  
→ Possibly due to different  $PM_{2.5}$  composition or other wildfire impacts

# Primary Takeaways



Significant associations between short-term exposure to PM<sub>2.5</sub> and wildfire smoke and decreased attention in adults



Strongest associations with PM<sub>2.5</sub> and wildfire smoke observed within a short exposure window



PM<sub>2.5</sub> associations more pronounced in the wildfire-impacted western US



Younger (18-29), older (70+), male, and habitual users most affected  
→ Highlights importance of user behavior in associations

# Strengths & Limitations

## Strengths

- First study to look at cognitive effects of daily and hourly PM<sub>2.5</sub> and smoke exposure in a large adult population
- Repeat measures for 10,000+ diverse users
- BME data fusion to estimate PM<sub>2.5</sub>
- Results largely consistent with existing research

## Limitations

- Lumosity is not a clinical measure of cognitive performance
- Possibility of exposure misclassification
- Differences between subgroups were not statistically significant
- Generalizability may be limited to populations like Lumosity cohort

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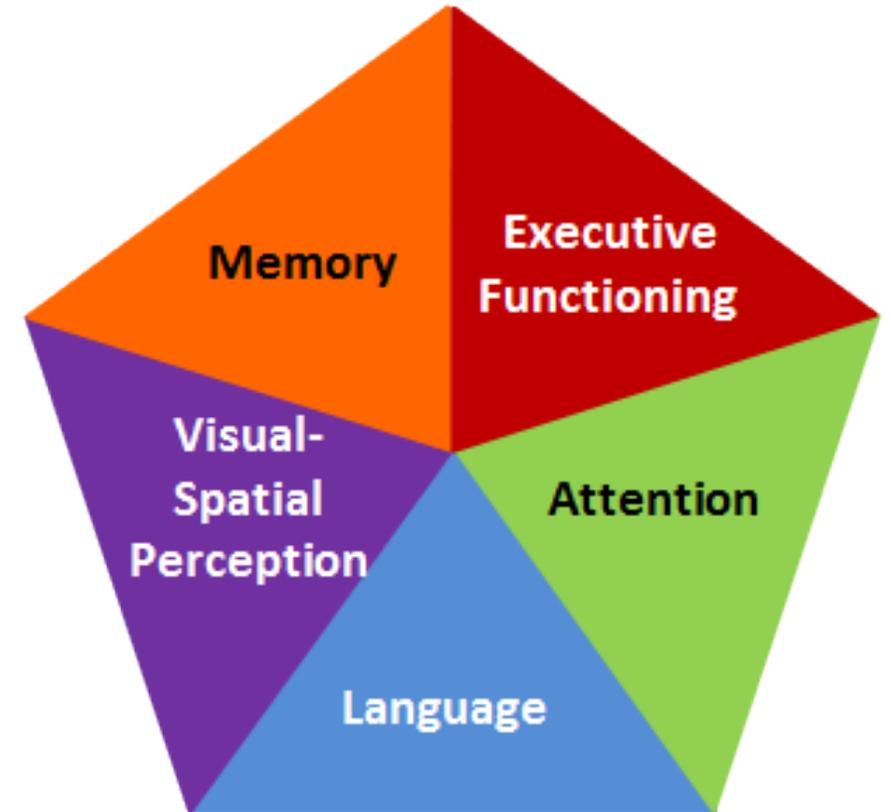
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# Future Work

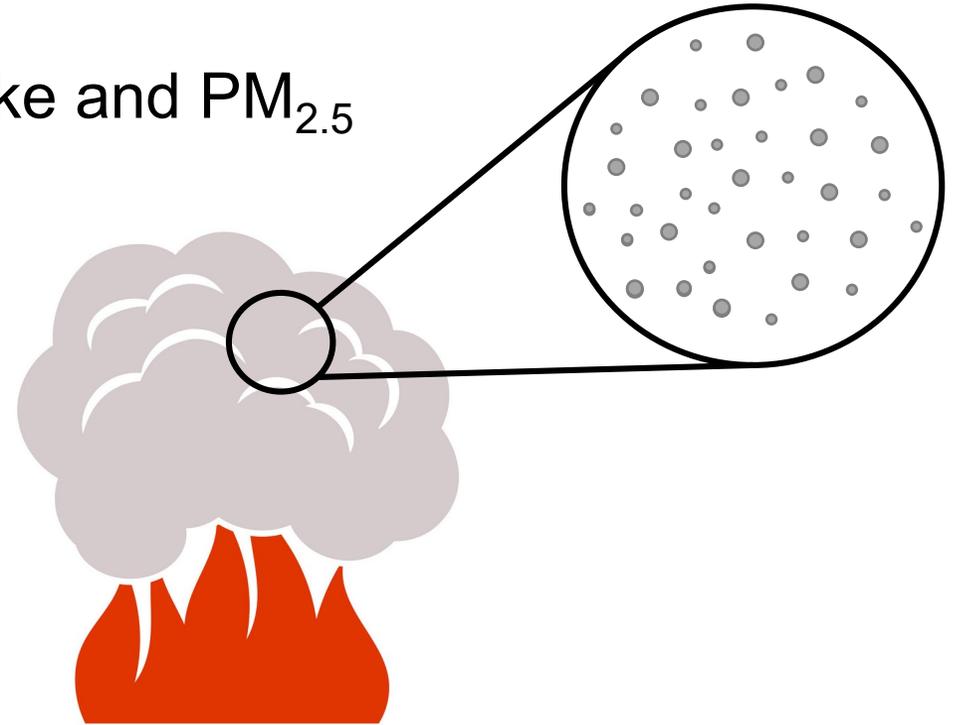
- Explore cognitive domains other than attention
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- Investigate the interaction between wildfire smoke and PM<sub>2.5</sub>



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- Explore cognitive domains other than attention  
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- Investigate the interaction between wildfire smoke and  $PM_{2.5}$
- Examine role of individual behavior in associations



# Future Work

- Explore cognitive domains other than attention
  - Lumosity may be a useful tool for this
- Investigate the interaction between wildfire smoke and  $PM_{2.5}$
- Examine role of individual behavior in associations
- Evaluate associations in other populations and regions and using different measures of cognitive performance
  - Validate findings and further elucidate relationships



# Additional Information

## Journal Article:

Cleland et al (2022). Short-term exposure to wildfire smoke and PM<sub>2.5</sub> and cognitive performance in a brain-training game: A longitudinal study of U.S. adults. *Environmental Health Perspectives*, 130(6).

<https://doi.org/10.1289/ehp10498>

## Interactive Dashboard:



[https://ehs-bccdc.shinyapps.io/PMSmoke\\_Attention\\_Dashboard/](https://ehs-bccdc.shinyapps.io/PMSmoke_Attention_Dashboard/)

**QUESTIONS?**

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# Dataset Characteristics

	Western US (n= 1,809)	Contiguous US (n=10,228)
<b>Female</b>	1,250 (69.1%)	7,214 (70.5%)
<b>Age Group</b>		
18-29	147 (8.1%)	859 (8.4%)
30-39	254 (12.0%)	1,238 (12.1%)
40-49	276 (15.3%)	1,530 (15.0%)
50-59	457 (25.3%)	2,752 (26.9%)
60-69	427 (23.6%)	2,614 (25.6%)
70+	248 (13.7%)	1,235 (12.1%)
<b>Education</b>		
Some High School	34 (1.9%)	152 (1.5%)
High School	203 (11.2%)	1,447 (14.1%)
Some College	375 (20.7%)	1,959 (19.2%)
Associates	178 (9.8%)	937 (9.2%)
Professional	91 (5.0%)	419 (4.1%)
Bachelors	576 (31.8%)	3,115 (30.5%)
Masters	278 (15.4%)	1,820 (17.8%)
PhD	29 (1.6%)	190 (1.9%)
Other	45 (2.5%)	189 (1.8%)
<b>Device</b>		
Android	606 (33.5%)	3,462 (33.8%)
iPad	264 (14.6%)	1,638 (16.0%)
iPhone	668 (36.9%)	3,858 (37.7%)
Web	271 (15.0%)	1,270 (12.4%)
<b>Habitual</b>	146 (8.1%)	873 (8.5%)

	Western US (n= 1,809)	Contiguous US (n=10,228)
<b>Attention Score, mean (SD)</b>		
All 20 plays	13,161.8 (4,202.5)	13,075.5 (4,108.7)
1 <sup>st</sup> play	9,721.5 (4,189.3)	9,645.7 (4,093.6)
20 <sup>th</sup> play	14,317.2 (3,928.0)	14,250.7 (3,795.7)
<b>Days Between Plays, mean (SD)</b>	8.4 (15.1)	8.3 (14.0)
<b>Hour of Day Played, mean (SD)</b>	13.8 (5.6)	13.7 (5.6)
<b>Daily PM<sub>2.5</sub> (µg/m<sup>3</sup>), mean (IQR)</b>	10.0 (6.2)	8.7 (5.0)
<b>Hourly PM<sub>2.5</sub> (µg/m<sup>3</sup>), mean (IQR)</b>	10.2 (6.2)	9.3 (5.2)
<b>Smoke Density, # (%) of observations</b>		
None	29,512 (81.6%)	-
Light	3,859 (10.7%)	-
Medium	1,318 (3.6%)	-
Heavy	1,491 (4.1%)	-