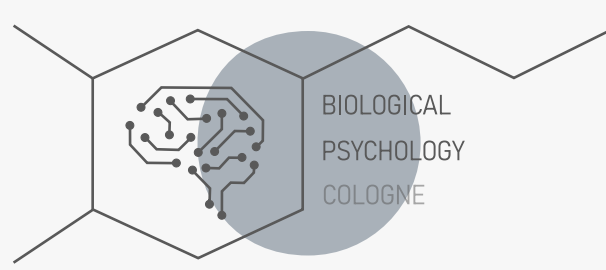


# Geolocation-based Ambulatory Assessment Reveals Urban Green Space Exposure Effects on Subjective and Physiological Stress Response

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## BACKGROUND

- Stress as a major risk factor for mental disorders, affecting psychological & physiological health<sup>1,2</sup>
- Urban green spaces (parks, trees, lakes) linked to reduced stress & improved mental health<sup>3</sup>
- We investigated subjective stress & physiological arousal in relation to urban green space exposure via geolocation-based assessment

## METHODS

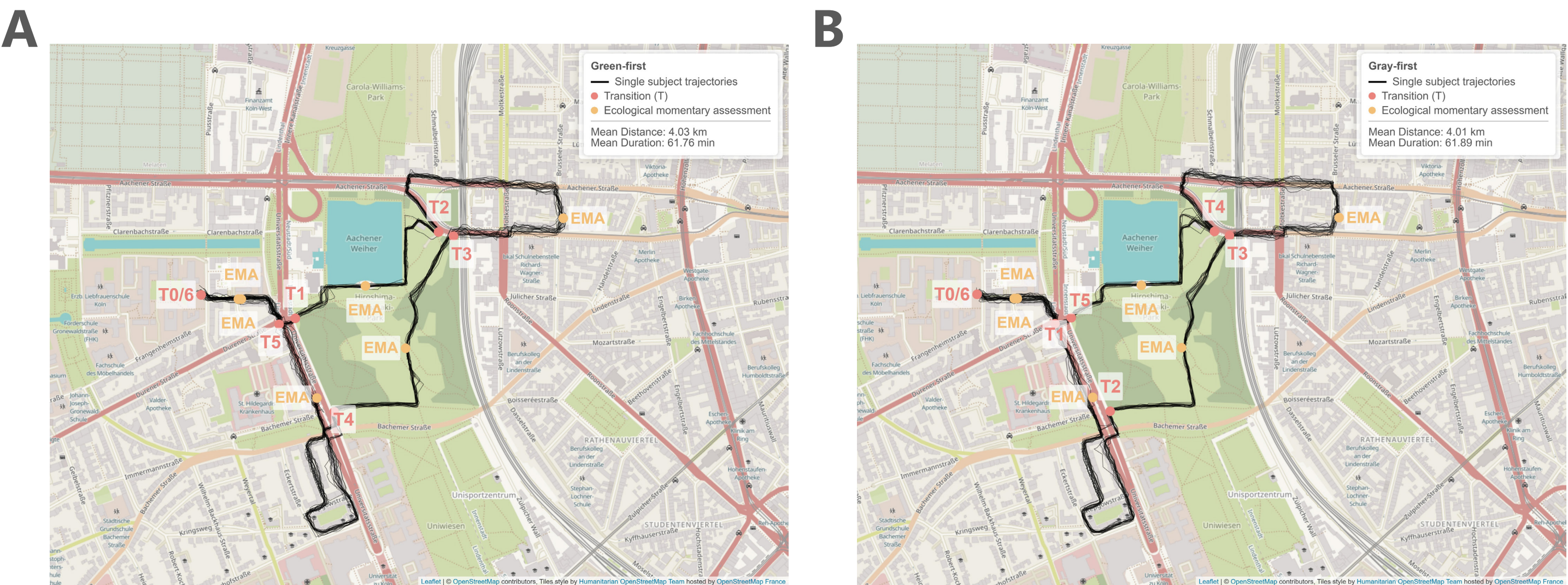
### Sample

- $N=36$  ( $n=8$  male,  $M_{\text{age}} = 21.97$ ,  $SD = 2.88$ )
- Circular ~4 km walking route in Cologne, Germany
- Counterbalanced within-subject design
- 6 sequential segments: baseline, 2x green, 2x gray, post-exposure

### Ambulatory Assessment

#### Location Tracking

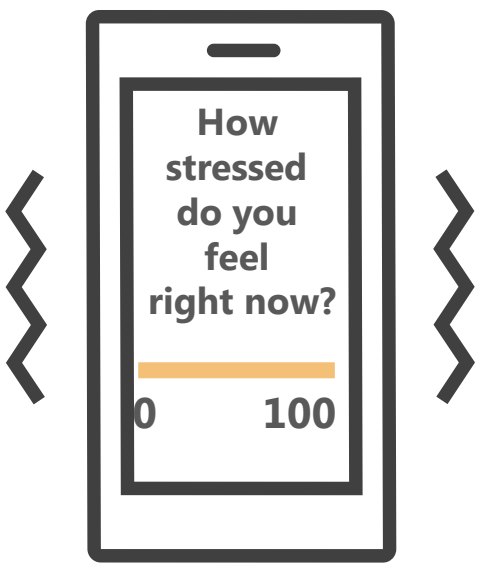
- Continuous GPS recording via study smartphone
- Walking distance  $M = 4.02$  km,  $\pm SD = 0.06$ ; duration  $M = 61.82$  min,  $\pm SD = 3.62$ ; temperature  $M = 7.97^{\circ}\text{C}$ ,  $\pm SD = 5.45$ , Range =  $-1^{\circ}\text{C} - 20^{\circ}\text{C}$ )



**Figure 1.** Illustration of the urban walking route in Cologne, Germany. Individual participant movement trajectories derived from GPS-based location tracking are depicted by black lines, separately for green-first (panel A,  $n = 18$ ) and gray-first participants (panel B,  $n = 17$ ; one participant excluded due to unusable GPS data). Visualization created using Leaflet (<https://leafletjs.com/>)<sup>4,5</sup>, © OpenStreetMap contributors, CC-BY-SA (<https://creativecommons.org/licenses/by-sa/2.0/>), tiles style by Humanitarian OpenStreetMap Team (<https://www.hotosm.org/>) hosted by OpenStreetMap France (<https://www.openstreetmap.fr/>).

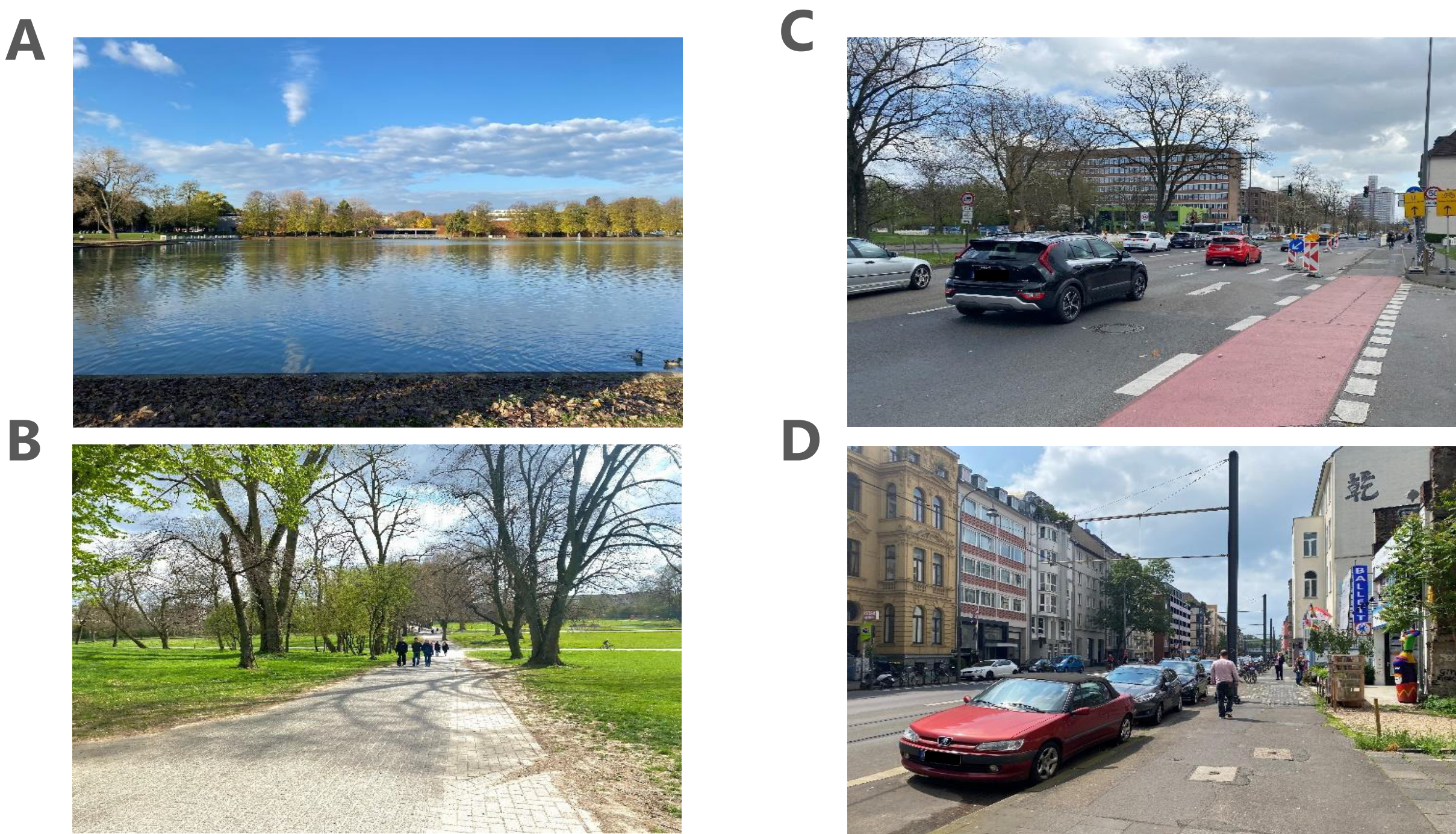
### Ecological Momentary Assessment

- Subjective stress, affective well-being & physical exertion rated 6× during the walk (single-item measures)



### Physiological Recording

- Electrodermal & cardiovascular activity recorded via Movisens sensors (EDAmove4, ECGmove4)<sup>6,7</sup>
- Outcome indices: HR, HRV (RMSSD), SCL, SCR peak, SCR amplitude



**Figure 2.** Representative visual depiction of the green and gray urban segments traversed during the study. Panels A and B depict typical scenes from the green segments, and panels C and D depict typical scenes from the gray segments. All photographs were taken during data collection period and are representative of the environmental conditions encountered by participants between October 2024 and February 2025 in Cologne, Germany.

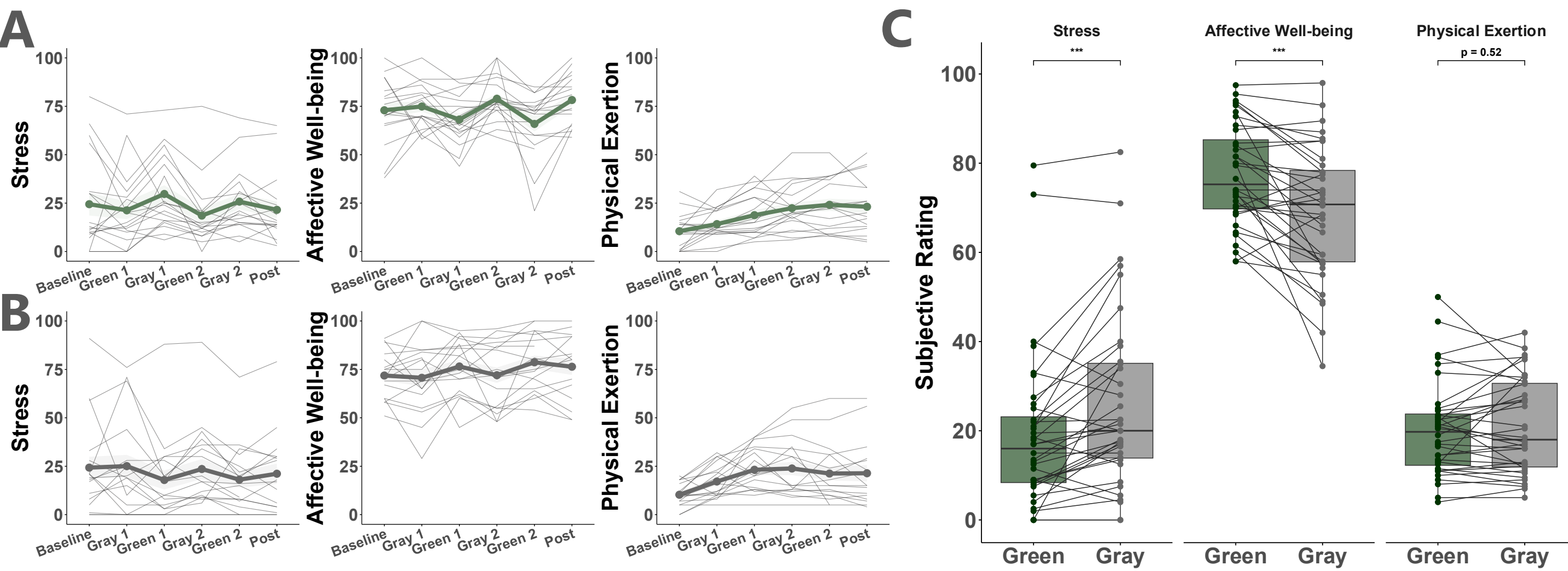
## RESULTS

### GPS-Based Location Tracking

| Route Segment | <i>N</i> | Distance (m)           |                | Time (min)             |             | Speed (km/h)           |           |
|---------------|----------|------------------------|----------------|------------------------|-------------|------------------------|-----------|
|               |          | <i>M</i> ( <i>SD</i> ) | Range          | <i>M</i> ( <i>SD</i> ) | Range       | <i>M</i> ( <i>SD</i> ) | Range     |
| Baseline      | 35       | 273.25 (32.41)         | 225.04-349.05  | 5.20 (1.05)            | 3.35-7.3    | 1.96 (.36)             | 1.37-2.93 |
| Gray          | 35       | 1064.26 (27.64)        | 945.54-1102.43 | 16.18 (1.23)           | 13.89-20.72 | 2.58 (.34)             | 1.8-3.17  |
| Green         | 35       | 651.91 (17.42)         | 621.57-705.82  | 9.22 (.48)             | 8.38-10.31  | 3.21 (.35)             | 2.57-3.88 |
| Post          | 35       | 288.61 (32.51)         | 214.4-359.01   | 5.45 (1.01)            | 3.38-8.05   | 1.96 (.45)             | 1.28-3.04 |

**Table 1.** Distance meters (m), time (min), and walking speed (km/h) reported as  $M$  ( $SD$ ) and range per segment, aggregated across both order groups. Green and Gray represent aggregated urban environment segments; Baseline and Post represent the start and end segments.  $N = 35$ ; one participant excluded due to unusable GPS data.

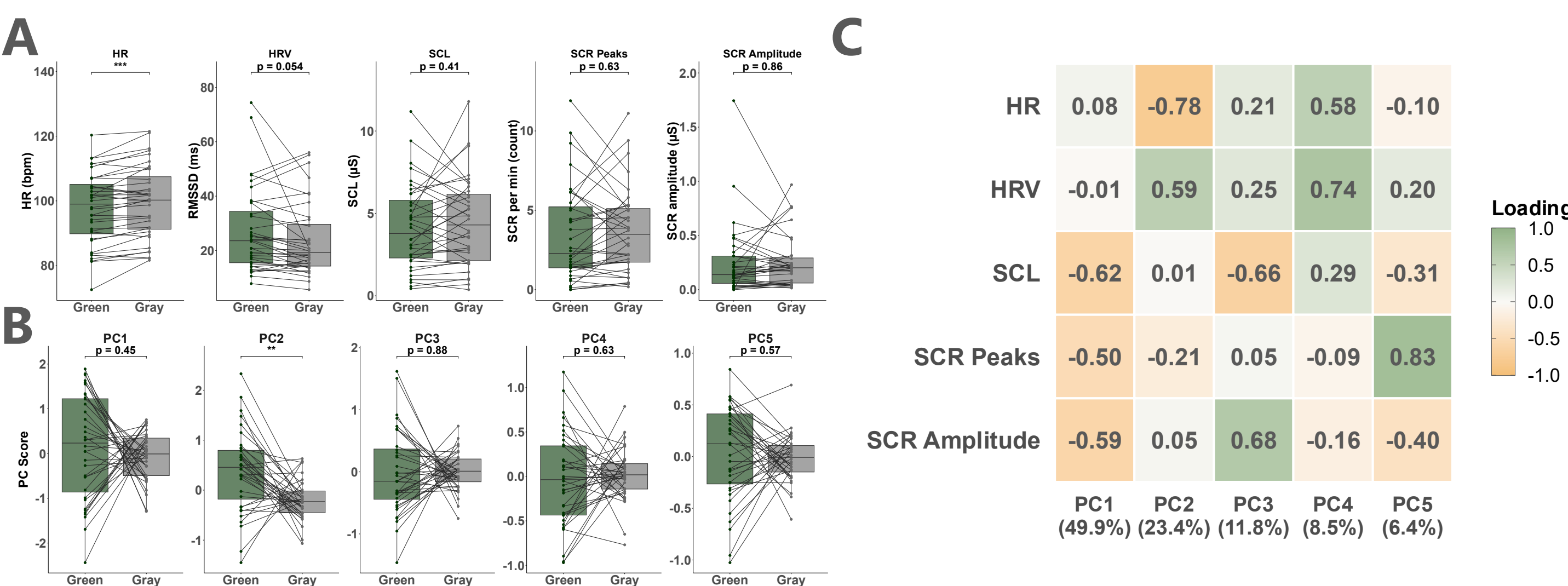
### Ecological Momentary Assessment



**Figure 3.** EMA trajectories for stress, affective well-being, and physical exertion (0–100) across six measurement points. Panel A: green-first ( $n = 18$ ); Panel B: gray-first ( $n = 18$ ); Gray lines = individual trajectories, bold lines = group means, ribbons =  $\pm 1$  SEM. Panel C: paired t-tests comparing aggregated green vs. gray ratings; lines connect individual observations. Paired t-tests: \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ .

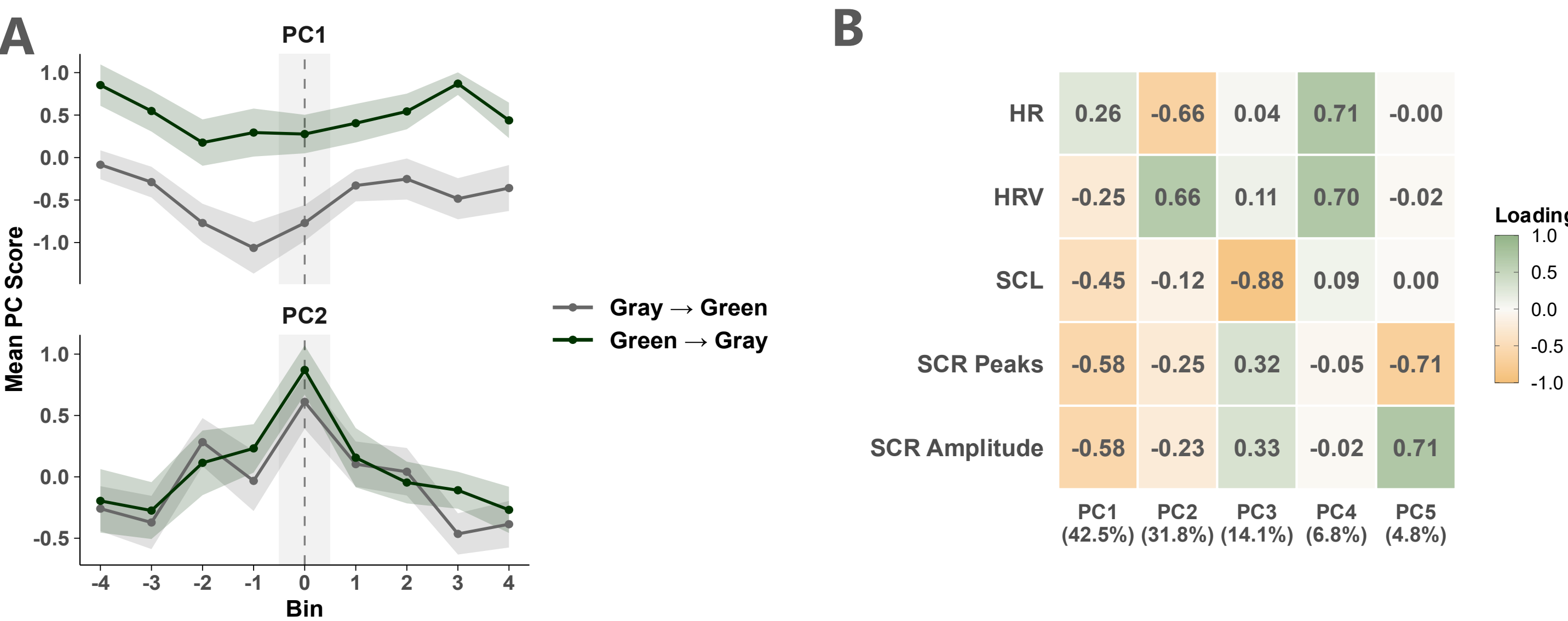
### Physiology

#### Segment-Based Analysis



**Figure 4.** Physiological responses across one green and two gray segments (one green excluded due to steep incline). Panel A: Bonferroni-corrected paired t-tests for HR, HRV (RMSSD), SCL, SCR peaks/min, and SCR amplitude. Panel B: PCA scores (within-subject z-scored) for green vs. gray; lines connect individual observations, boxplots show median and IQR. Panel C: PCA loadings and explained variance.  $N = 36$ .

### Transition-Based Analysis



**Figure 5.** PCA of five physiological indices across one green and two gray segments (one green excluded due to steep incline). Panel A: PC score time-courses across nine 60-second bins centered on environmental transition (0 = transition) for green-to-gray and gray-to-green transitions. Panel B: Heatmap of PCA loadings and explained variance.  $N = 36$ .

## CONCLUSION

- Brief, repeated urban green space exposure associated with lower subjective stress, improved well-being & reduced physiological arousal
- Findings highlight public health value of accessible urban green infrastructure
- Scalable strategy for stress reduction & mental health promotion in urban populations

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