

Windscreen Wiper Triggered Neural Responses as Causes and Predictors of Driver Drowsiness

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Introduction

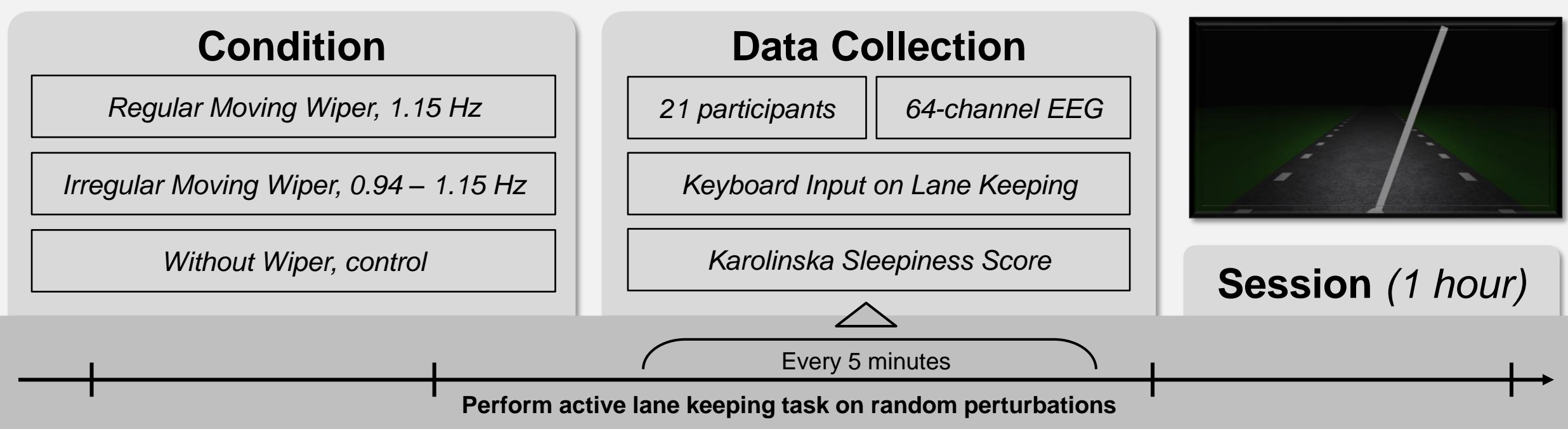
- Driver drowsiness is a major threat to road safety.
- Repeated rhythmic visual stimulus can trigger Steady-state Visual Evoked Potential (SSVEP) at the same frequency as the stimulus appears to formulate brain oscillation entrainment. The Signal-to-noise Ratio (SNR) can be used to quantify such neural responses.
- Power from the Electroencephalogram (EEG) delta frequency band is strongly associated with drowsiness states.
- Windscreen wipers are known to be obstructing the driver's view, potentially compromising driving safety. However, their influence on driver drowsiness has yet to be thoroughly examined.

Hypothesis

- Windscreen wipers, as a low-frequency rhythmic visual stimulus, may induce SSVEP and brain oscillation entrainment at the same or multiples of wiper frequency.
- Windscreen wipers may affect the development of driver drowsiness, through their entrainment effect on the EEG delta power band which matches the wiper moving frequency.
- Moving patterns of windscreen wipers may have different effects on the development of drowsiness.
- SNR of the neural responses triggered by windscreen wipers may serve as a good predictor for self-reported subjective drowsiness levels.

Method

Experiment Setup



Data Analysis

Correlation Analysis with Mixed Effect Model

Null Hypothesis: $kss \sim (1 \mid \text{participant_id})$

Alternative Hypothesis: $kss \sim \log(\text{snr}) + (1 \mid \text{participant_id})$

We adopted the likelihood ratio test to examine the effect on model fitness of having SNR at harmonic frequencies as predictors.

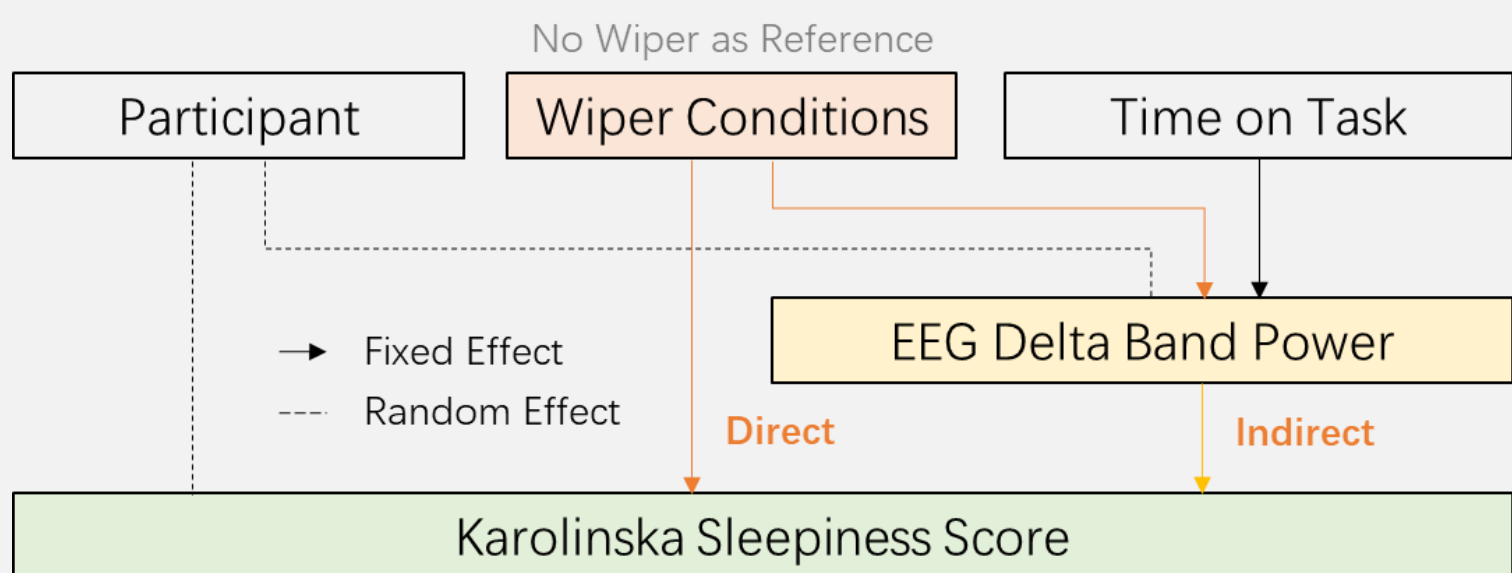
Causal Mediation Analysis with Mixed Effect Model

Mediator:

$\log_eeg_band_power \sim \text{block} + \text{condition} + (1 \mid \text{participant_id})$

Outcome:

$kss \sim \log_eeg_band_power + \text{condition} + (1 \mid \text{participant_id})$



We used causal mediation analysis to examine the effect of wiper conditions on sleepiness score mediated by EEG delta band power.

Correlation of Wiper Neural Responses to Drowsiness

$kss \sim \text{numerator} + (1 \mid \text{participant_id})$, $p=0.327$, $\text{beta}=0.09$
 $kss \sim \text{denominator} + (1 \mid \text{participant_id})$, $p=0.003$, $\text{beta}=0.31$
which explains an overall decrease since $\text{snr} = \text{numerator} / \text{denominator}$

Predictor	Model	AIC	BIC	Log-likelihood	$p > (\chi^2)$	Estimates	CI	ICC	Marginal/Conditional R^2
SNR [1.15 Hz]	H_0	534.74	545.00	-264.37	-	-	-	-	- / -
	H_1	534.61	548.29	-263.30	0.144	-0.09	-0.22 - 0.03	0.54	0.008 / 0.540
SNR [2.31 Hz]	H_0	534.74	545.00	-264.37	-	-	-	-	- / -
	H_1	532.20	545.89	-262.10	0.033*	-0.12	-0.22 - -0.01	0.54	0.014 / 0.547
SNR [3.46 Hz]	H_0	534.74	545.00	-264.37	-	-	-	-	- / -
	H_1	531.87	545.55	-261.94	0.027*	-0.11	-0.21 - -0.01	0.54	0.011 / 0.548
SNR [4.62 Hz]	H_0	534.74	545.00	-264.37	-	-	-	-	- / -
	H_1	532.92	546.61	-262.46	0.051	-0.10	-0.20 - 0.00	0.53	0.011 / 0.539

Table 1: Likelihood ratio test of slope with Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Log-likelihood, significance of ANOVA, estimates, Confidence Interval (CI), Intraclass Correlation Coefficient (ICC) and coefficient of determination (R^2) for paired correlation analysis between Karolinska Sleepiness Score and SNR from SSVEP at harmonic frequencies for regular wiper condition. (.: $p < 0.1$, *: $p < 0.05$, **: $p < 0.005$, ***: $p < 0.0005$, ****: $p < 0.00005$)

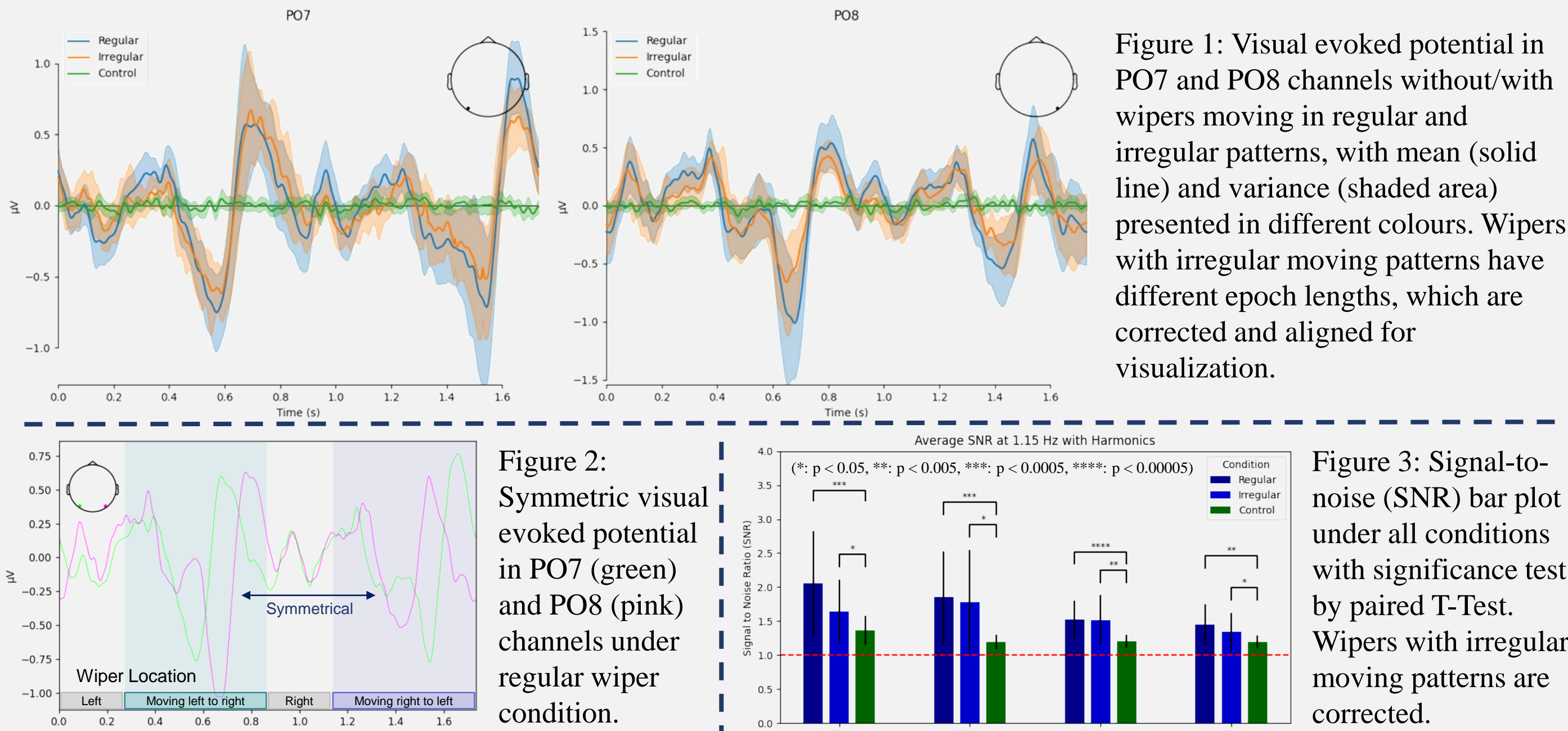
Causal Effect of Wiper on Drowsiness through Entrainment

Condition	Measurements	Estimate	95% CI Lower	95% CI Upper	p-value
Regular Wiper	ACME	0.0693	0.0102	0.14	0.012*
	ADE	-0.0364	-0.3622	0.31	0.840
	Total Effect	0.0329	-0.2912	0.39	0.874
No Wiper	Prop. Mediated	0.1852	-5.6463	4.53	0.866
Irregular Wiper	ACME	0.08208	0.02105	0.16	0.008**
	ADE	0.31672	-0.00543	0.64	0.056
	Total Effect	0.39880	0.08377	0.71	0.014*
No Wiper	Prop. Mediated	0.20072	0.03927	0.89	0.022*

Table 2: Causal mediation analysis of wiper moving pattern on drowsiness with Average Causal Mediation Effect (ACME), Average Direct Effect (ADE), Total Effect, Proportion Mediated based on no wiper condition as reference. (.: $p < 0.1$, *: $p < 0.05$, **: $p < 0.005$, ***: $p < 0.0005$, ****: $p < 0.00005$)

Result

Frequency Tagging of Wiper Triggered Neural Responses



Conclusion

- Wiper-triggered SSVEP and brain oscillation entrainment effect is **significant for regular and irregular moving patterns**.
- The existence of wipers shows a **significant indirect effect on drowsiness** mediated through EEG delta band power.
- Wipers with irregular patterns **contribute significantly to the increased drowsiness levels**, with most of the contribution coming from the **direct effect**.
- SNR triggered by regular windscreen wipers has a **significant negative correlation** with subjective drowsiness levels.

