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Behavioural and Electrophysiological Predictors of Subjective Alertness / Sleepiness during Human-Computer Interaction in a Simulated Driving Task

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Introduction

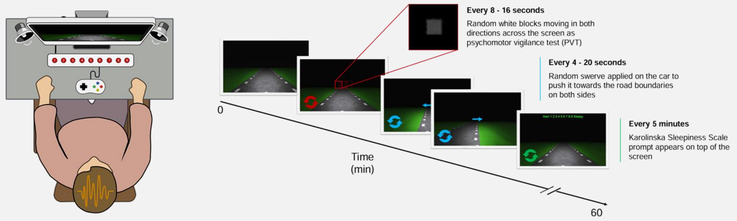
- ❑ Alertness refers to a state of readiness and vigilance, covering physical fatigue (sleep-wake) and mental fatigue (cognitive performance, controlled to be minimum in this study).
- ❑ Assessing alertness fluctuation is critical for ensuring safety, efficiency and satisfactory of the computer users.
- ❑ Our study focused on early signals of alertness alternations occurring within temporal windows on the scale of seconds to minutes.
- ❑ The direct comparison and integration of alertness indices remain largely unexplored.

Assumptions & Hypothesis

- ❖ The simulated driving task requires minimal level of cognitive workload. Therefore, the alternation of alertness is largely attributed to the fluctuations in physical fatigue (sleepiness).
- ❖ The self-reported sleepiness metrics can represent the true internal states of the physical fatigue, with significant individual differences.
- ➢ There exists optimal temporal patterns for the association between different modality of sleepiness measurements.
- ➢ Different modality of sleepiness indices have different predictive power against self-reported sleepiness levels.
- ➢ The combination of these modalities can help improve the overall predictive power of the model.

Method

Experiment Setup



Data Analysis

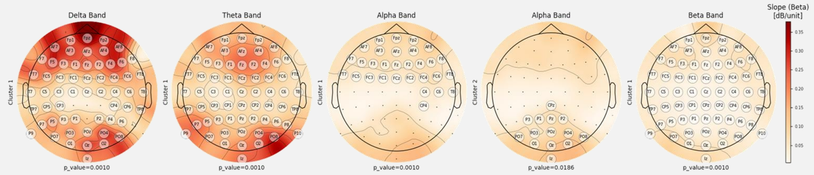
Correlation Analysis with Mixed Effect Model

Null Hypothesis: `subjective ~ (1 | participant_id)`

Alternative Hypothesis: `subjective ~ objective + (1 | participant_id)`

We adopted the likelihood ratio test to examine the effect on model fitness of objective measurements as predictors.

Grouped EEG Clusters for Multiple Comparisons



We used non-parametric cluster-level permutation test to identify significant electrode clusters from each EEG power band. F-values from all electrodes obtained by Ordinary Least Squares regression model were used for grouping, with model slopes drawn on the graph.

Result

Temporal Association of Subjective Sleepiness

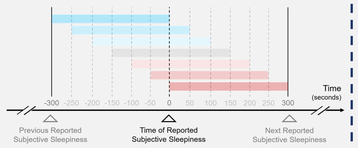


Figure 1: Illustration of temporal window settings for association between objective and subjective measurements. Temporal windows of association are evenly distributed within the effective time domain. Future and past time windows are coloured in red and blue separately.

Strongest Model Observed at **[-300s, 0s] (Full Past)**

Predictor	Window	AIC	BIC	Log-likelihood	$p > (\lvert t \rvert)$	$p > (\chi^2)$	Estimates	CI
Reaction Time	[-300s, 0s]	874.99	888.67	-433.49	<0.001***	<0.001***	3.96	2.14 - 5.78
	[-250s, 50s]	875.90	889.59	-433.95	<0.001***	<0.001***	3.85	2.04 - 5.66
	[-200s, 100s]	876.62	890.30	-434.31	<0.001***	<0.001***	3.91	2.03 - 5.79
	[-150s, 150s]	878.64	892.32	-435.32	<0.001***	0.001**	3.58	1.74 - 5.42
	[-100s, 200s]	881.86	895.54	-436.93	0.001**	0.001**	3.23	1.33 - 5.13
	[-50s, 250s]	883.59	897.27	-437.80	0.002**	0.004**	2.95	1.06 - 4.84
	[0s, 300s]	885.31	898.99	-438.65	0.006**	0.009*	2.70	0.77 - 4.63
Percentage of Eyes Closed	[-300s, 0s]	878.61	892.29	-435.30	<0.001***	<0.001***	0.40	0.19 - 0.61
	[-250s, 50s]	878.75	892.43	-435.37	<0.001***	<0.001***	0.40	0.19 - 0.62
	[-200s, 100s]	879.19	892.88	-435.60	<0.001***	<0.001***	0.40	0.18 - 0.61
	[-150s, 150s]	881.37	895.05	-436.68	0.001**	0.001**	0.37	0.15 - 0.58
	[-100s, 200s]	884.24	897.92	-438.12	0.005**	0.005**	0.31	0.09 - 0.53
	[-50s, 250s]	885.81	899.49	-438.90	0.012*	0.012*	0.28	0.06 - 0.51
	[0s, 300s]	886.71	900.39	-439.35	0.021*	0.021*	0.27	0.04 - 0.49
EEG Alpha Band Power (Cluster 1)	[-300s, 0s]	839.52	853.00	-415.76	<0.001***	<0.001***	0.77	0.39 - 1.14
	[-250s, 50s]	837.41	850.89	-414.71	<0.001***	<0.001***	0.62	0.34 - 0.91
	[-200s, 100s]	838.02	851.50	-415.01	<0.001***	<0.001***	0.62	0.33 - 0.90
	[-150s, 150s]	838.88	852.37	-415.44	<0.001***	0.001**	0.60	0.31 - 0.89
	[-100s, 200s]	839.58	853.06	-415.79	<0.001***	0.001**	0.59	0.30 - 0.88
	[-50s, 250s]	840.71	854.19	-416.35	<0.001***	0.002**	0.57	0.28 - 0.86
	[0s, 300s]	842.14	855.62	-417.07	<0.001***	0.004**	0.54	0.25 - 0.83

Table 1: Likelihood ratio test of slope with Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Log-likelihood, significance of fixed effect predictors using T-Test, significance of likelihood ratio test using ANOVA, estimates and Confidence Interval (CI) for regression analysis between objective and subjective measurements. Objective measurements were associated with subjective measurements within the specified intervals of temporal window in seconds.

(.: p < 0.1, *: p < 0.05, **: p < 0.005, ***: p < 0.0005, ****: p < 0.00005)

Individual Predictors of Subjective Sleepiness

Predictor	Model	AIC	BIC	Log-likelihood	$p > (\chi^2)$	Estimates	CI	ICC	Marginal/Conditional R^2
Test Block	H_0	688.36	705.21	-339.18	-	-	-	-	- / -
	H_1	670.43	690.65	-329.22	<0.001***	1.40	0.93 - 1.86	0.83	0.190 / 0.861
Reaction Time	H_0	869.41	886.51	-429.70	-	-	-	-	- / -
	H_1	865.36	885.88	-426.68	0.014*	3.98	1.16 - 6.80	0.60	0.136 / 0.653
Eye Blinks per Minute	H_0	514.87	531.98	-252.44	-	-	-	-	- / -
	H_1	513.79	534.31	-250.89	0.079	0.18	-0.01 - 0.37	0.64	0.030 / 0.654
Percentage of Eyes Closed	H_0	514.93	532.03	-252.47	-	-	-	-	- / -
	H_1	510.81	531.34	-249.41	0.013*	0.18	0.05 - 0.30	0.60	0.031 / 0.610
EEG Alpha Band Power (Cluster 1)	H_0	814.55	831.40	-402.27	-	-	-	-	- / -
	H_1	799.79	820.01	-393.89	<0.001***	3.34	2.06 - 4.62	0.81	0.500 / 0.905
EEG Alpha Band Power (Cluster 2)	H_0	815.57	832.43	-402.79	-	-	-	-	- / -
	H_1	802.14	822.36	-395.07	<0.001***	3.24	1.88 - 4.59	0.84	0.480 / 0.915
EEG Beta Band Power	H_0	820.97	837.82	-405.48	-	-	-	-	- / -
	H_1	808.94	829.16	-398.47	<0.001***	2.63	1.53 - 3.73	0.70	0.422 / 0.827
EEG Theta Band Power	H_0	836.26	853.11	-413.13	-	-	-	-	- / -
	H_1	828.96	849.19	-408.48	0.002**	2.94	1.34 - 4.55	0.77	0.344 / 0.850
EEG Delta Band Power	H_0	830.40	847.26	-410.20	-	-	-	-	- / -
	H_1	826.66	846.89	-407.33	0.017*	2.42	0.68 - 4.16	0.80	0.202 / 0.838

Table 2: 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 regression analysis between objective and subjective measurements.
(.: p < 0.1, *: p < 0.05, **: p < 0.005, ***: p < 0.0005, ****: p < 0.00005)

Combined Predictors of Subjective Sleepiness

Predictor	Fixed Effects Linear Regression AIC	Log-likelihood	Original/Adjusted R^2	$p > (F)$	Mixed Effects Linear Regression AIC	Log-likelihood	Marginal/Conditional R^2	$p > (\chi^2)$
EEG Alpha Band Power (Cluster 1)	578.928	-286.464	0.155 / 0.151	-	447.342	-216.455	0.500 / 0.905	-
+ EEG Alpha Band Power (Cluster 2)	576.582	-284.291	0.172 / 0.164	0.039*	450.853	-214.030	0.484 / 0.904	0.303
+ EEG Beta Band Power	579.553	-285.776	0.160 / 0.152	0.245	444.091	-210.061	0.393 / 0.939	0.012*
+ EEG Theta Band Power	580.852	-286.426	0.155 / 0.147	0.785	450.812	-213.202	0.430 / 0.922	0.164
+ EEG Delta Band Power	580.751	-286.375	0.156 / 0.148	0.677	436.246	-207.283	0.410 / 0.957	0.001**
+ Percentage of Eyes Closed	572.952	-282.476	0.186 / 0.178	0.005**	441.665	-207.654	0.491 / 0.924	0.001**
+ Reaction Time	549.334	-270.667	0.270 / 0.264	<0.001***	442.395	-208.794	0.438 / 0.921	0.004**
+ Percentage of Eyes Closed + Reaction Time	544.934	-267.467	0.292 / 0.282	<0.001***	433.807	-197.588	0.431 / 0.938	<0.001***
+ EEG Beta Band Power + EEG Delta Band Power + Percentage of Eyes Closed + Reaction Time	544.249	-265.124	0.307 / 0.291	<0.001***	432.038	-182.334	0.387 / 0.970	<0.001***

Table 3: Model fitness for combined predictors with Akaike Information Criterion (AIC), Log-likelihood, significance of ANOVA and coefficient of determination (R^2) for linear regression with or without random effect.
(.: p < 0.1, *: p < 0.05, **: p < 0.005, ***: p < 0.0005, ****: p < 0.00005)

Conclusion

1. There exists **strong correlation** between subjective and objective sleepiness measurements.
2. Subjective sleepiness is best associated with objective sleepiness indices **in the past**, compared with other measurements obtained from the 5-minute sliding windows.
3. Electrophysiological predictors show **stronger predictive power** than behavioural predictors for subjective sleepiness.
4. Our findings support the integration of multiple objective sleepiness indices to substitute subjective measurements.

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