



Time-on-Task Fatigue During Prolonged Dual-Task Simulated Driving

Behavioral and Oculomotor Markers as a Reference for In-Ear EEG Detection

Introduction:

Losing attention during driving is a major contributor to road accidents, whether due to distraction or fatigue. We recently demonstrated that single-channel in-ear EEG can provide a temporally precise, low-burden neural marker of cognitive distraction during prolonged simulated driving. Within the present dataset, and as a basis for subsequent neural analyses, we evaluated three complementary behavioral and oculomotor markers associated with time-on-task fatigue-related performance decline.

Methods:

Twenty-seven participants* performed a dual-task driving paradigm in a highly immersive driving simulator with motion cues and near-360° visual coverage. The task combined continuous vehicle control with low- and high-load arithmetic tasks presented on an in-vehicle display. Standard deviation of lane position (SDLP), blink duration (BD), and total time eyes closed (TTEC) were analyzed across ten equally spaced modules of a 40-minute monotonous nighttime drive conducive to time-on-task fatigue.

Results:

From Module 1 to Module 10, SDLP increased from 23.3 cm to 27.4 cm ($\Delta = 4.1$ cm; +17.9%; $p = 0.004$, paired t-test M1-M10). Until Module 9, TTEC and BD increased with TTEC rising from 5.5 s to 8.35 s ($\Delta = 2.85$ s; +51%; $p = 0.001$) and BD increasing from 68.2 ms to 80.9 ms ($\Delta = 12.9$ ms; +18.9%; $p = 0.011$), before dropping in Module 10 due to premature termination of the arithmetic task.

Conclusions:

The concurrent increases in SDLP, BD, and total time eyes closed indicate a convergent pattern across independent behavioral and physiological markers and are consistent with moderate time-on-task fatigue toward the end of the drives. These findings provide a behavioral and physiological reference framework for subsequent analyses of single-channel in-ear EEG-based fatigue detection in this driving paradigm. They may help refine operating points for wearable EEG-based driver monitoring systems.

Take home messages

Behavioural and oculomotor markers all get worse over 40 minutes of monotonous night driving, a convergent sign of time-on-task fatigue.

Outlook

Two independent measurements establish that fatigue is present. This justifies examining the in-ear EEG signal and provides the reference against which it can be evaluated.

Authors

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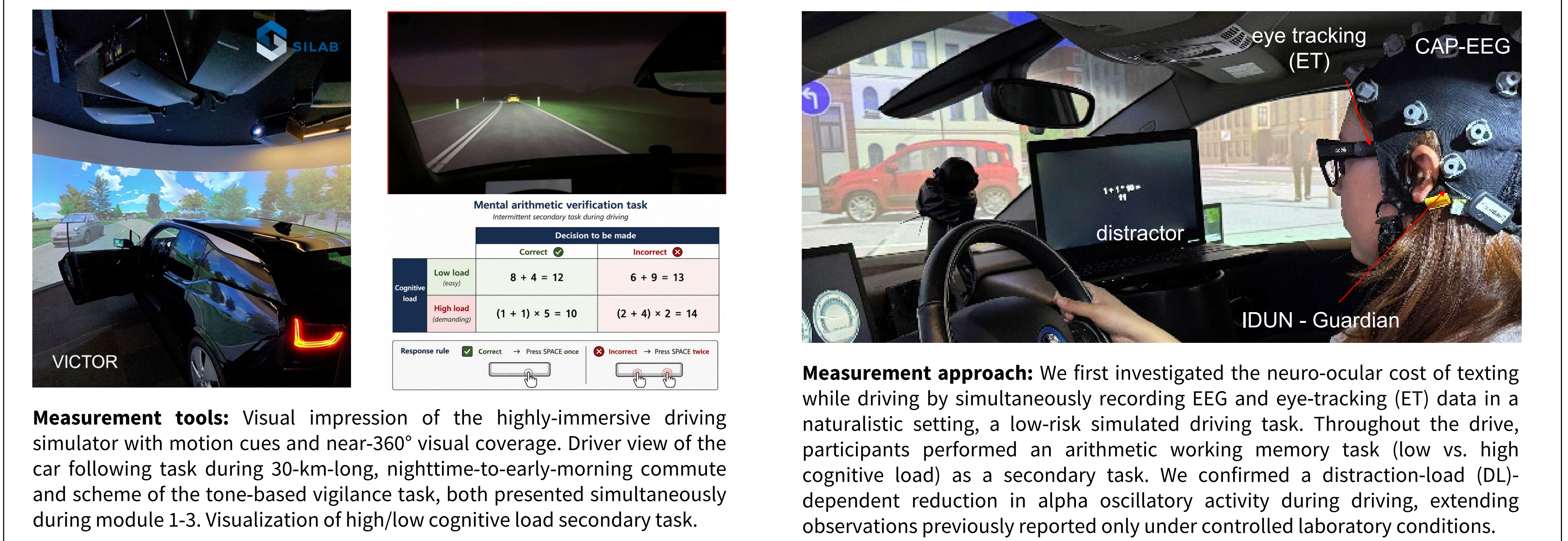
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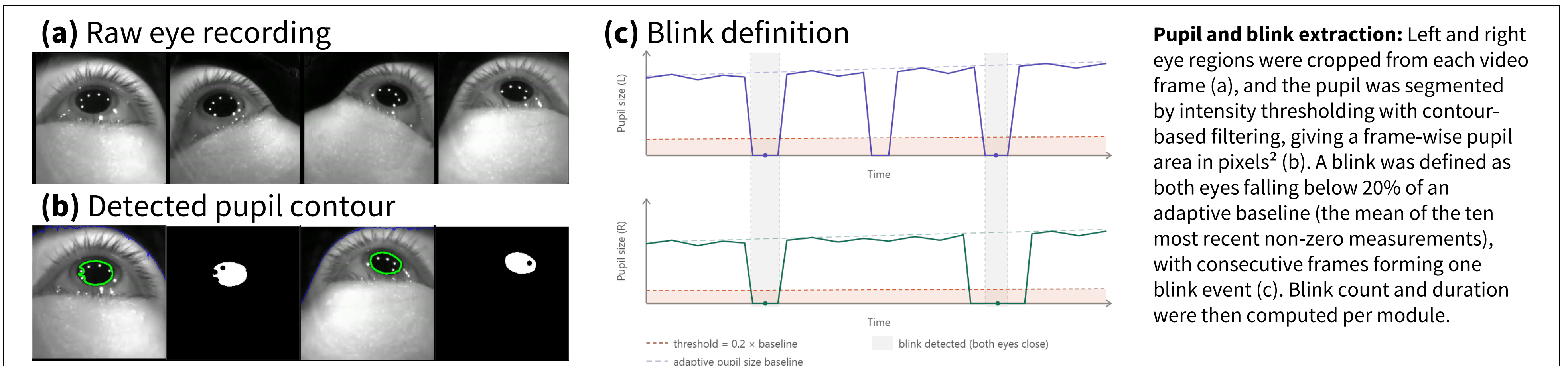
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Measurement tools and approaches



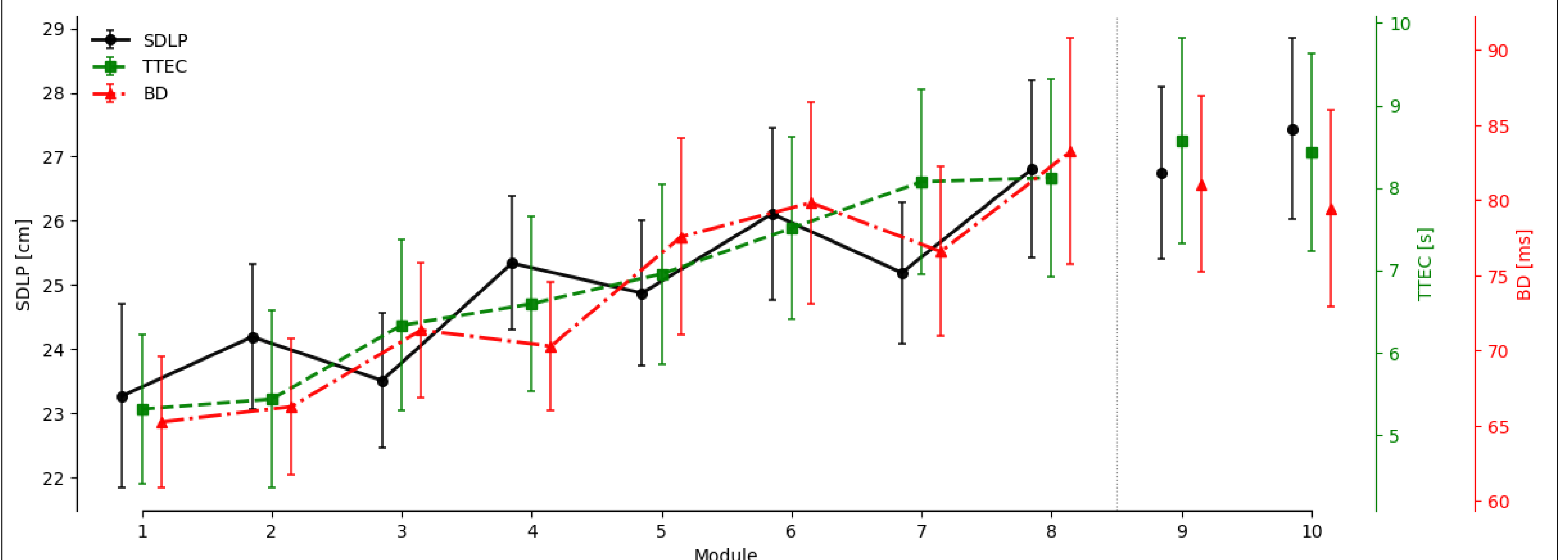
Oculomotor feature extractions



Behavioral and oculomotor markers of time-on-task after synchronization correction

Analysis set	Metric	n	1st module	Last module	Δ abs	Δ %	Δ % / module	p	d_z
Completed 8 full modules	SDLP[cm]	5	25	25.4	0.4	1.8	0.3	0.914	0.05
	TTEC[s]	4	8.1	12	3.9	48.1	6.9	0.104	1.16
	BD[ms]	4	80.9	107.5	26.5	32.8	4.7	0.093	1.22
Completed 9 full modules	SDLP[cm]	18	21.2	26.5	5.3	25	3.1	0.004	0.77
	TTEC[s]	12	4.9	7.4	2.5	51.2	6.4	0.026	0.74
	BD[ms]	12	58.4	77.9	19.5	33.5	4.2	0.018	0.80
Completed 10 full modules	SDLP[cm]	20	24.7	27.6	2.9	11.6	1.3	0.201	0.30
	TTEC[s]	11	4	7.1	3.1	75.9	8.4	0.014	0.90
	BD[ms]	11	63.5	75.5	12	18.8	2.1	0.104	0.54
Common window (M1-8)	SDLP[cm]	43	23.3	26.8	3.5	15.2	2.2	0.005	0.46
	TTEC[s]	28	5.4	8	2.6	47.7	6.8	<0.001	0.89
	BD[ms]	28	64.6	81.7	17.1	26.4	3.8	0.023	0.45

First versus last module: Change in Standard Deviation of Lane Position (SDLP), Total Time Eyes Closed (TTEC), and Blink Duration (BD) from the first to the last module. Modules are 10 identical 4-min segments of the drive. Upper block: participants grouped by how many modules the arithmetic task covered in full; those who finished mid-module contribute the preceding modules only, so observation length differs (32/36/40 min). Bottom row: all participants pooled over the common window M1-M8. n = participants with data in both tested modules, which is lower for TTEC and BD because eye-tracking data are unavailable for the early modules in some recordings. Paired t-tests (uncorrected); Cohen's d_z = mean difference / SD of differences. *Numbers differ from the submitted abstract, which was based on an unsynchronized dataset (18.03.2026); shown here is the synchronized dataset (12.08.2026). For the 43 participants, 27 of whom wore the in-ear EEG.



Time-on-task: Group means $\pm$ SEM of SDLP (black, round, left axis), TTEC (green, square, inner right axis), and BD (red, triangle, outer right axis) across the ten 4-min modules. Lines connect M1-M8; M9 and M10 are shown as unconnected points since some participants finished the arithmetic task before M9 or M10. Means and errors include all available data per module.

All three markers increased over the common window (M1 to M8), and every completion cohort showed the same direction of change, although the between-participant variability was substantial. In participants whose arithmetic task covered all ten modules, the increase continued to the end of the drive. Lane keeping and eyelid behaviour were recorded by separate systems and respond to different immediate causes, so their parallel deterioration is hard to attribute to a single measurement artefact or to a shift in how participants handled the arithmetic task.

The pattern is consistent with a gradual loss of alertness over time on task. The size of the effect differed considerably between participants, which is the situation where an individually referenced continuous signal has the most to offer. Drawn from two independent measurements, these markers provide the behavioural reference for the planned in-ear EEG analysis: a fatigue related change is present in this paradigm and is measurable behaviourally within a 40-minute drive.