EEG-Guided Sleep Enhancement and Embedded Impedance Monitoring with a Portable Wearable System

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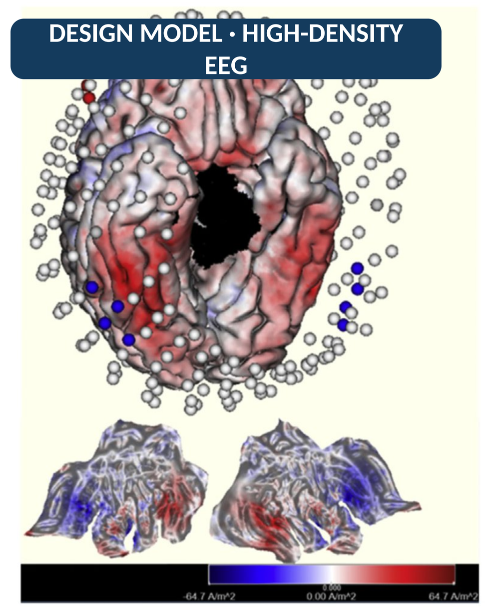
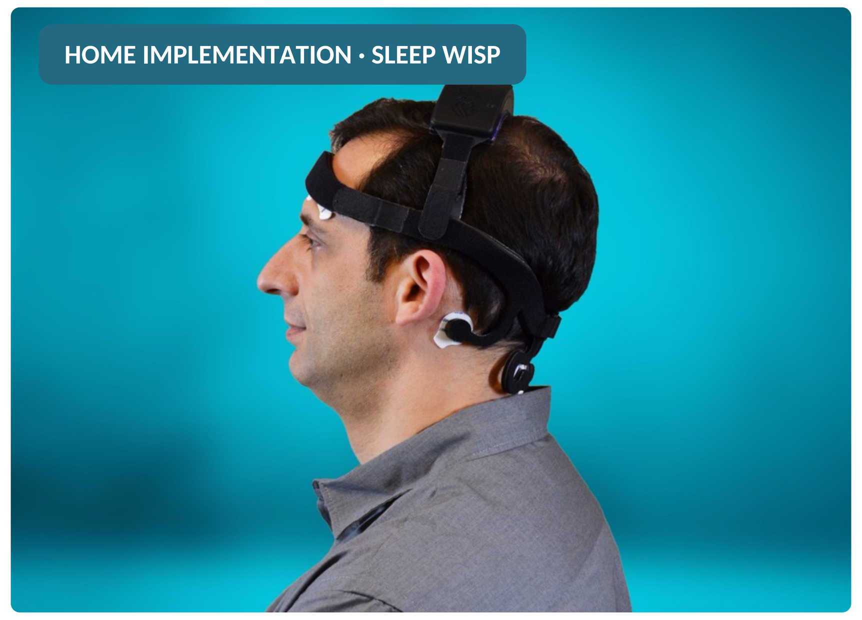
TAKEAWAY

Sleep WISP combines automated EEG-guided neuromodulation with embedded impedance sensing—supporting both sleep enhancement and field-deployable monitoring of physiological recovery.

RATIONALE

N3 slow oscillations support hippocampal–cortical communication and memory consolidation. Prior source modeling identified focal ventral limbic generators, motivating low-current stimulation optimized for these sources.

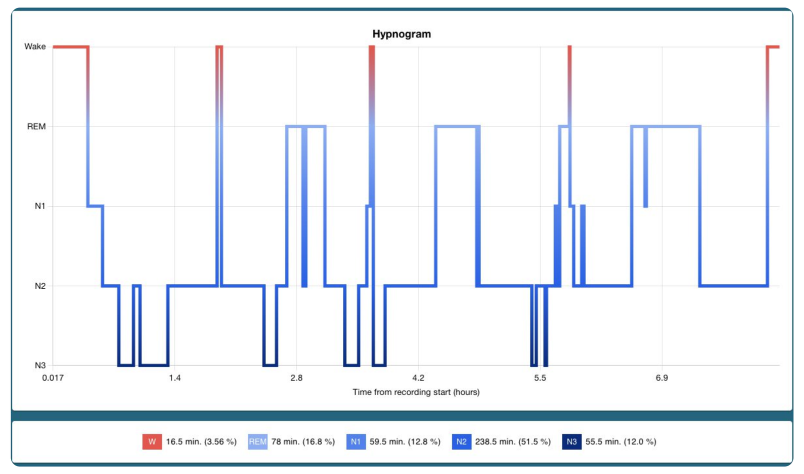




High-density EEG/FDM head modeling predicted current distribution and informed the reduced WISP stimulation montage. The model electrodes shown are not WISP recording channels.

AT-HOME PROTOCOL

1. 17 healthy adults enrolled; 16 retained after prespecified outlier screening
2. Adaptation night followed by active TES and Off nights in counterbalanced order
3. One-week washout; participants and instruction staff blinded by coded conditions
4. Automated staging initiated TES ≈4 min after stable N2 onset

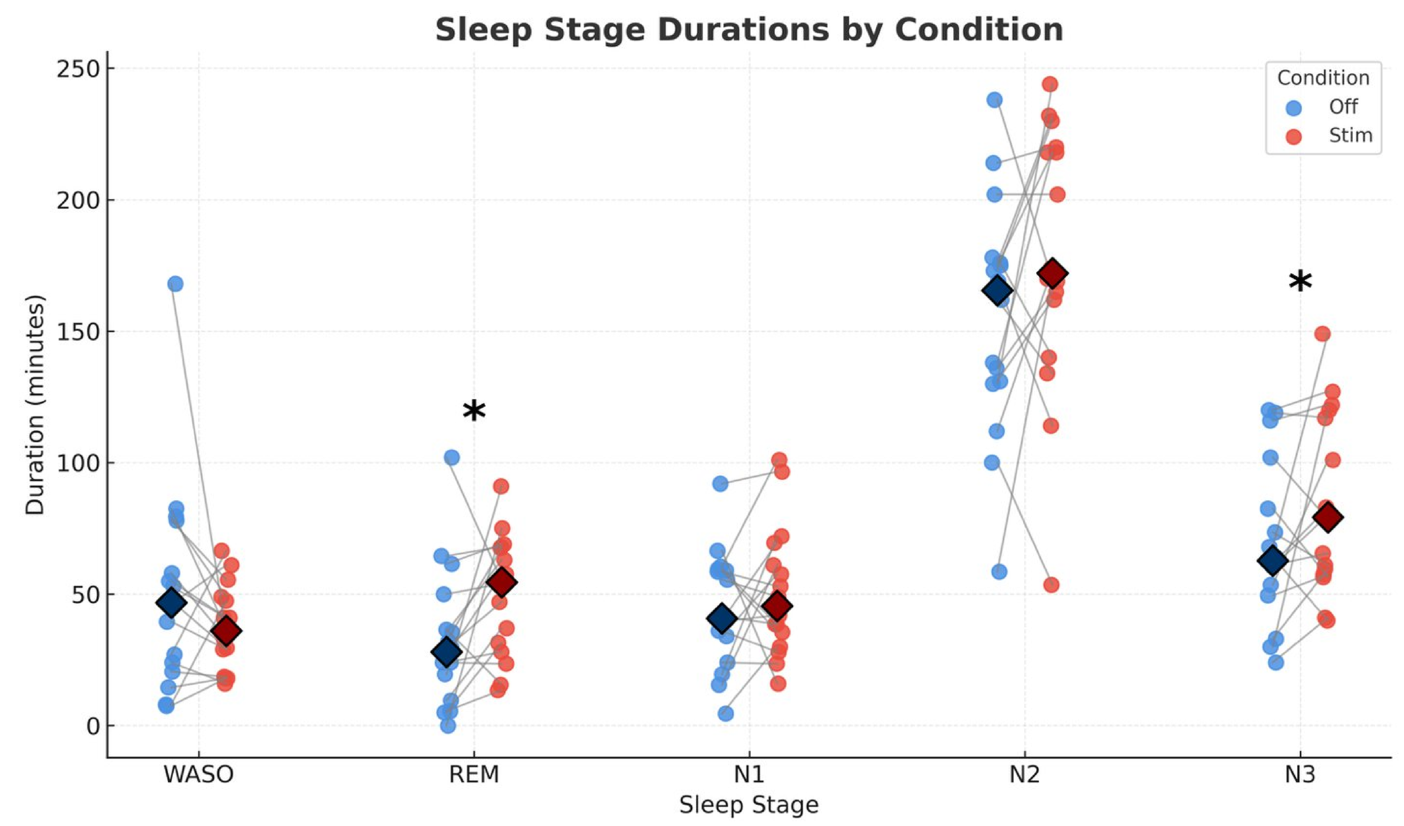


STIMULATION • 0.5 Hz sinusoidal AC • 0.5 mA maximum • five 5-min blocks separated by 1-min rests • 25 min total

AUTOMATED STAGING • NEAT CNN agreement: 90.3% (95% CI 90.1–90.6) against technologist consensus

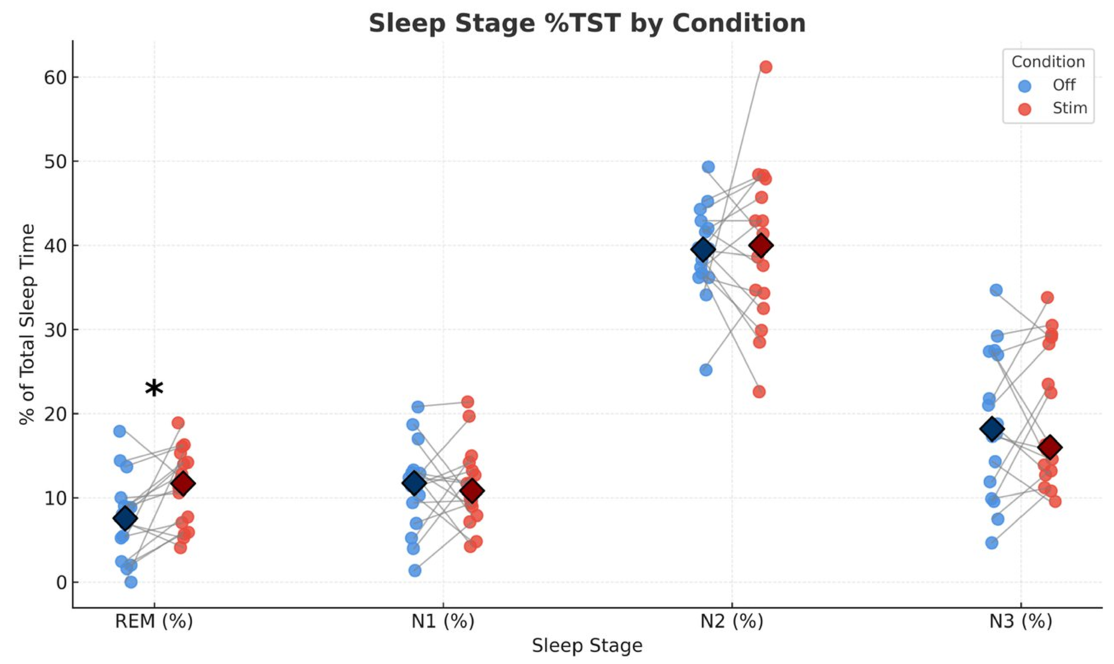
PRIMARY OUTCOMES

Paired within-subject comparison of TES vs Off nights. Directional one-tailed tests were prespecified for N3 and REM; other outcomes used two-tailed tests.



REM	N3	TOTAL SLEEP
+16.9 min	+15.1 min	+60.5 min
49.75 vs 32.81	84.94 vs 69.84	363.1 vs 302.6
$t(15)=2.25$, $p=.020$	$t(15)=1.78$, $p=.048$	$t(15)=2.43$, $p=.028$

SLEEP ARCHITECTURE



REM increased as a proportion of TST: 11.1% vs 7.6% • $t(15)=2.35$, $p=.017$

- N3 minutes increased, but N3 percentage of TST did not (19.7% vs 18.8%, $p=.513$).
- No significant differences in N1, N2, or WASO duration.

EMBEDDED IMPEDANCE MONITORING

Distributed scalp sensors acquired low-frequency impedance measurements at 15-minute intervals during overnight sleep.

AUTOMATED STAGING IS THE SHARED TEMPORAL BACKBONE

SLEEP WISP OVERNIGHT RECORDING

CONTINUOUS EEG		IMPEDANCE EVERY 15 MIN
↓		↓
AUTOMATED STAGING Online state + timestamped labels	STAGE LABELS →	TIME-STAMPED IMPEDANCE SAMPLES
↓		↓
TARGET STAGE DETECTED TES on treatment night; EEG continues		COMBINE STAGE LABELS with impedance timestamps
↓		↓
CONTROL vs TREATMENT Compare sleep architecture		STAGE-ALIGNED ANALYSIS Characterize impedance dynamics
↓		↓
↑ N3 • ↑ REM • ↑ total sleep		Sleep-dependent impedance change

The same staging stream times the intervention and supplies the physiological labels used in both outcome analyses.

INITIAL FINDING

Cross-head impedance decreased consistently during consolidated sleep.

INTERPRETATION & NEXT STEP

The direction of change is consistent with reports from multi-frequency impedance spectroscopy showing sleep-associated reductions in brain parenchymal resistance. These wearable measurements suggest sensitivity to sleep-dependent changes in cranial conductivity, but do not uniquely identify the underlying mechanism.

NEXT • Continuous monitoring will enable higher-resolution, sleep-stage–resolved characterization of impedance dynamics.

OPERATIONAL RELEVANCE

One participant-operated platform can combine intervention, automated sleep-state monitoring, and a candidate recovery signal outside the sleep laboratory.

READINESS RELEVANCE • Portable intervention + sleep-state monitoring + physiological recovery sensing

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