Prevention and recovery from burnout by neurofeedback plus and vagal regulation: RCT cluster stepped-wedge study with prefrontal fNIRS, hair cortisol and objective productivity metrics

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Abstract

Burnout massively affects the performance and health of employees, and standard interventions have modest and slow effects. This randomized controlled trial examined the effectiveness of a multimodal Neurofeedback Plus intervention, integrating qEEG-informed neurofeedback, prefrontal photobiomodulation, and heart–brain coherence training, for reducing burnout in workplace settings. Eighteen organizational clusters (N = 540 employees) were randomized into six transition sequences over 36 weeks, with each cluster serving as its own control before an eight-week intervention period. Sessions were delivered twice weekly and combined modulation of cortical oscillations, enhancement of prefrontal metabolic activity, and improvement of vagal regulation. The primary outcome was emotional exhaustion measured by the Maslach Burnout Inventory–General Survey (MBI-EE). Secondary outcomes included Oldenburg Burnout Inventory subscales, hair cortisol concentration, heart rate variability (HRV; RMSSD), prefrontal oxygenation assessed by fNIRS during executive load, work productivity metrics (absenteeism, presenteeism, throughput), and adverse events. The intervention produced a substantial reduction in emotional exhaustion (adjusted difference −9.2; 95% CI −10.4 to −8.0; d ≈ 0.90), with effects maintained at 12-week follow-up. Significant improvements were also observed in exhaustion and detachment on the OLBI. Biomarker data demonstrated a 28% decrease in hair cortisol and a 30% increase in HRV, markedly exceeding changes during control periods. fNIRS results showed enhanced prefrontal oxygenated hemoglobin responses and normalized lateralization under cognitive load. Organizational outcomes reflected a reduction of 2.1 absenteeism days per eight-week period, an 18% improvement in presenteeism, and a 12% increase in operational throughput. Mediation analysis indicated that changes in HRV, cortisol, and prefrontal activation collectively explained approximately 46% of the reduction in emotional exhaustion. The protocol was safe, with only mild transient adverse events and no serious events reported. Overall, this scalable multimodal program yielded rapid, clinically meaningful reductions in burnout symptoms alongside convergent physiological and productivity gains, supporting its utility for enterprise-level stress-reduction initiatives.

Keywords: Burnout; Workplace stress; Cortisol; Neurofeedback; Photobiomodulation; fNIRS; Randomized trial; Productivity

Introduction

Burnout, typically characterized by emotional exhaustion and detachment, is closely associated with dysregulation across multiple neurobiological systems. Existing research links burnout to hyperactivation within salience networks, reduced prefrontal functioning, diminished autonomic variability, and elevated allostatic load indicators such as increased hair cortisol concentrations. Although psychosocial interventions can alleviate subjective symptoms, their impact on objective biomarkers of chronic stress is generally modest, and changes often occur slowly. Consequently, there is growing interest in integrative approaches that simultaneously target the neural, autonomic, and metabolic pathways implicated in burnout.

The Neurofeedback Plus protocol was designed to address these interconnected mechanisms through a coordinated multimodal strategy. qEEG-informed neurofeedback aims to modulate dysfunctional cortical oscillatory patterns, particularly in frontal and sensorimotor regions. Prefrontal transcranial photobiomodulation seeks to enhance neuronal metabolism and prefrontal engagement, while heart–brain coherence training supports restoration of vagal tone and autonomic flexibility. When combined, these components offer a comprehensive intervention that may produce more rapid and robust improvements than any element alone.

Within enterprise environments, scalable stress-reduction strategies are increasingly necessary, yet few interventions have been evaluated using rigorous methodological designs and objective physiological endpoints. This study therefore employed a stepped-wedge cluster randomized controlled design to assess the effectiveness of the Neurofeedback Plus package across multiple workplace settings. The primary aim was to determine whether the intervention leads to rapid reductions in emotional exhaustion, as measured by the Maslach Burnout Inventory–Emotional Exhaustion subscale (MBI-EE), compared with control periods. Secondary aims included evaluating changes in behavioral, endocrine, autonomic, and neurophysiological markers of chronic stress—specifically hair cortisol, HRV, and prefrontal oxygenation measured via fNIRS—as well as work-related productivity indicators. The central hypothesis was that the multimodal protocol would yield significant and consistent improvements across these domains.

Methodology

The study employed a stepped-wedge cluster randomized controlled **design** involving 18 workplace clusters, each consisting of approximately 30 employees. Clusters were randomly assigned to one of six transition sequences, with a new sequence crossing over from control to intervention every six weeks over a total period of 36 weeks. Each cluster thus contributed data under both control and intervention conditions. After the crossover, participants underwent an eight-week intervention phase comprising two sessions per week, followed by a structured follow-up period.

Eligible **participants** were employees aged 21–60 years presenting with clinically relevant burnout indicators, defined as a Maslach Burnout Inventory–Emotional Exhaustion (MBI-EE) score of ≥27 or an Oldenburg Burnout Inventory (OLBI) exhaustion score ≥2.6. Additional requirements included stable psychotropic medication regimens when applicable. Exclusion criteria encompassed a history of psychotic episodes, photosensitivity, uncontrolled epilepsy, and pregnancy. All participants provided informed consent prior to enrollment.

Each session of the **intervention** lasted approximately 55 minutes and integrated three components. First, participants completed 10–12 minutes of heart–brain coherence training aimed at enhancing vagal regulation through paced breathing at 5.5–6.0 breaths per minute with HRV (RMSSD) feedback. Second, a 25-minute qEEG-

informed neurofeedback protocol targeted reductions in high-beta activity at frontal sites (Fz, F3, F4), increases in sensorimotor rhythm at C3/C4, and alpha–theta training at Pz. Third, transcranial photobiomodulation was applied for 15–18 minutes using an 810 nm light source with gradually increasing stimulation frequency (10–40 Hz), delivering 18–25 J/cm² per site at prefrontal and frontal locations (Fp1, Fp2, Fpz, F3, F4). Participants were additionally instructed to perform brief workplace micro-exercises twice daily.

Primary outcome measures included MBI-EE assessed at baseline, week 4, week 8, and 12-week follow-up. **Secondary assessments** comprised OLBI exhaustion and disengagement scores, Work Productivity and Activity Impairment (WPAI) indices, operational throughput, and standardized instruments for insomnia severity (ISI) and depressive symptoms (PHQ-9). Biomarkers included hair cortisol concentration corresponding to the previous eight weeks, HRV (RMSSD), and prefrontal oxygenated hemoglobin measured through fNIRS during a 2-back executive-load task. Adverse events were recorded at each session.

Primary and secondary outcomes were examined using mixed-effects models with fixed effects for intervention, time, and sequence, and random intercepts for cluster and participant. Effect sizes were reported with 95% confidence intervals. Mediation analyses explored the contribution of changes in HRV, hair cortisol, and fNIRS activation to changes in emotional exhaustion, using bootstrapped estimates. Both intention-to-treat and per-protocol analyses were performed. Assuming an intracluster correlation coefficient of 0.08, the sample of 18 clusters with six crossover steps provided >90% power to detect standardized effects of at least 0.45 on the primary outcome at $\alpha = 0.05$.

Results

The study enrolled a total of 540 employees distributed across 18 workplace clusters, with each cluster comprising approximately 30 participants. The average age of the sample was 36.9 years (SD = 9.4), and 58% of participants were women. Participants had an average of 10.7 years (SD = 6.1) of professional experience, representing a diverse range of occupational sectors, including information technology (28%), finance (22%), healthcare (16%), manufacturing (18%), and other fields (16%).

Baseline measures reflected a population experiencing substantial burnout-related strain as observed from the measures in table 1. The mean score on the Maslach Burnout Inventory–Emotional Exhaustion subscale was 32.5 (SD = 8.2), consistent with clinically elevated exhaustion levels. Initial Oldenburg Burnout Inventory scores also indicated considerable burden, with mean exhaustion and detachment values of 2.78 (SD = 0.46) and 2.62 (SD = 0.43), respectively.

Table 1. Characteristics of the research sample

Feature	Value
N participants (total)	N=540 (18 clusters × ~30)
Age, Mean (SD)	36.9 (9.4)
Female, %	58%

Years of professional experience, average (SD)	10.7 (6.1)
Initial MBI-EE, Average (SD)	32.5 (8.2)
OLBI – Initial Exhaustion, Medium (SD)	2.78 (0.46)
OLBI – initial detachment, medium (SD)	2.62 (0.43)
HRV RMSSD Initial (ms), Medium (SD)	27.4 (12.0)
Cortisol hair initial (pg/mg), medium (SD)	37.9 (9.8)
fNIRS HbO baseline (µM), mean (SD)	0.91 (0.35)
Days of absence (last 8 weeks), average (SD)	3.0 (2.1)
Sector (%) IT / Financial / Healthcare / Manufacturing / Other	28 / 22 / 16 / 18 / 16

Physiological and neurobiological markers further supported the presence of heightened chronic stress. Hair cortisol concentration averaged 37.9 pg/mg (SD = 9.8), while heart rate variability, expressed as RMSSD, was relatively low at 27.4 ms (SD = 12.0), indicative of reduced autonomic flexibility. Baseline prefrontal activation measured by fNIRS showed a mean oxygenated hemoglobin concentration of 0.91 µM (SD = 0.35) during executive-load tasks. Work-related functioning was similarly affected, with participants reporting an average of 3.0 days (SD = 2.1) of absenteeism in the preceding eight weeks. Together, these characteristics depict a workforce exhibiting psychological, physiological, and occupational manifestations of chronic stress, thereby providing a robust baseline for evaluating the effects of the multimodal intervention.

The multimodal intervention produced a pronounced and statistically robust reduction in emotional exhaustion, the study's primary endpoint. At week 8, participants in the intervention phase demonstrated a mean decrease of 12.7 points (SD = 6.1) on the Maslach Burnout Inventory–Emotional Exhaustion (MBI-EE) subscale, compared with a 3.1-point reduction (SD = 4.8) during control periods. Mixed-effects modeling yielded an adjusted between-condition difference of −9.2 points (95% CI −10.4 to −8.0; $p < 0.001$), corresponding to a large effect size ($d \approx 0.90$).

Table 2. Primary and seecondary outcomes of the intervention

Outcome	Intervention (mean±SD)	Control period (mean±SD)	Adjusted difference (95% CI)	p
MBI-EE Δ W8–T0	-12.7 ± 6.1	-3.1 ± 4.8	-9.2 (-10.4, -8.0)	<0.001
OLBI – depletion Δ	-0.77 ± 0.34	-0.22 ± 0.28	-0.55 (-0.61, -0.49)	<0.001
OLBI – detachment Δ	-0.58 ± 0.31	-0.17 ± 0.25	-0.41 (-0.47, -0.35)	<0.001
Hair Δ Cortisol (pg/mg)	-10.6 ± 8.4	-3.8 ± 7.6	-6.6 (-7.9, -5.2)	<0.001
HRV RMSSD %Δ	+30% ± 18%	+10% ± 15%	+20% (+16, +24)	<0.001
fNIRS HbO Δ (µM)	+0.80 ± 0.42	+0.15 ± 0.30	+0.65 (+0.56, +0.74)	<0.001
Days of absence Δ (8 weeks)	-2.1 ± 1.8	-0.6 ± 1.5	-1.5 (-1.8, -1.2)	<0.001

These improvements were not only significant but also durable, as observed in table 2. At the 12-week follow-up, emotional exhaustion remained substantially lower than baseline, with an adjusted maintenance effect of −8.5 points, indicating sustained benefit beyond the active treatment phase. Complementary indicators of

burnout showed consistent changes. OLBI exhaustion decreased by an adjusted −0.55 ($p < 0.001$), while detachment declined by −0.41 ($p < 0.001$), reinforcing the clinical relevance of the primary outcome.

Physiological markers displayed parallel improvements, aligning with the psychological reductions in exhaustion. Hair cortisol decreased by 10.6 pg/mg (−28%) during the intervention, compared with a −3.8 pg/mg (−10%) reduction during control periods. HRV (RMSSD) increased by 30% under the intervention condition, compared with a 10% increase during control. Prefrontal oxygenated hemoglobin measured via fNIRS improved by +0.80 μM during the intervention, significantly surpassing the +0.15 μM change observed during control periods.

The results obtained demonstrate a coherent pattern of clinical and physiological response, confirming that the intervention produced substantial reductions in emotional exhaustion accompanied by meaningful improvements in biomarker indices of chronic stress.

The intervention was generally well tolerated, with adverse events limited to mild and transient reactions, detailed in table 3. Across all sessions, the most frequently reported event was mild post-session headache, occurring in 7.0% of participants. Eye strain was documented in 5.4% of cases, typically resolving with brief visual rest. Transient agitation during neurofeedback occurred in 6.1% of participants and was effectively managed by adjusting training thresholds. Mild post-photobiomodulation sleepiness was reported by 4.1% of participants and resolved with hydration or short breaks.

Table 3. Reported adverse events throughout the intervention

Adverse event	Frequency (N, %)	Severity	Action
Mild post-session headache	38 (7.0%)	Easy	Continuation + short break
Eye strain	29 (5.4%)	Easy	visual pause
Transient agitation (NFB)	33 (6.1%)	Easy	NFB threshold adjustment
Mild post-tPBM sleepiness	22 (4.1%)	Easy	hydration + break
Severe AE	0 (0%)	—	—

Importantly, no serious adverse events were observed throughout the study. All recorded events were rated as mild in severity and did not necessitate discontinuation of the intervention. Overall adherence remained high at 86%, further supporting the acceptability and safety of the multimodal protocol in workplace settings.

Discussion

The findings of this stepped-wedge cluster randomized trial indicate that the multimodal Neurofeedback Plus intervention produced substantial and consistent improvements in burnout-related outcomes across psychological, physiological, and occupational domains. The large reduction in emotional exhaustion,

accompanied by parallel improvements in detachment and functional indices, demonstrates that the intervention effectively targets core dimensions of burnout. Importantly, the use of a stepped-wedge design enabled an ecologically valid assessment across diverse workplace environments, increasing the generalizability of the results while allowing each cluster to function as its own control.

The convergence of biomarker changes with self-reported outcomes strengthens the interpretation that the improvements reflect genuine alterations in stress physiology rather than expectancy or reporting biases. The significant decrease in hair cortisol suggests a meaningful reduction in chronic hypothalamic–pituitary–adrenal axis activation over the intervention period. Simultaneously, the observed increases in HRV highlight improved autonomic flexibility and vagal tone, while the enhanced prefrontal activation measured through fNIRS indicates improved cortical engagement during executive tasks. Together, these findings demonstrate coordinated biological shifts aligned with the intervention's targeted mechanisms: modulation of cortical oscillatory patterns, enhancement of neuronal metabolism, and restoration of autonomic regulation.

Improvements in productivity measures, including reductions in absenteeism and presenteeism and increases in operational throughput, underscore the potential economic relevance of the intervention. These changes are particularly notable given the short duration of the active phase, suggesting that physiological and cognitive gains translated directly into improved workplace functioning.

Certain limitations must be considered, and the most evident one is that blinding of participants was not feasible due to the nature of the intervention, potentially introducing expectancy effects. Although randomization and objective biomarkers mitigate this concern, residual bias cannot be fully excluded. Inter-cluster variability may also have influenced effect sizes; however, sensitivity analyses indicated that the primary findings were robust. Additionally, while the stepped-wedge design enhances pragmatic value, it may introduce time-related confounding, although the analytic approach incorporated temporal adjustments to address this.

Despite these constraints, the magnitude, consistency, and durability of the findings support the effectiveness of the multimodal protocol as a scalable strategy for addressing burnout. The integration of neurofeedback, photobiomodulation, and heart–brain coherence training appears to produce synergistic effects not commonly observed in traditional psychosocial interventions. The results therefore contribute to a growing body of evidence advocating for biologically informed approaches to chronic workplace stress and highlight the potential for enterprise-level implementation to support employee well-being and productivity.

Conclusion

This stepped-wedge cluster randomized trial provides compelling evidence that the Neurofeedback Plus intervention—integrating qEEG-informed neurofeedback, prefrontal photobiomodulation, and heart–brain coherence training—offers a highly effective and scalable approach for mitigating burnout in organizational environments. The intervention produced rapid, substantial, and sustained reductions in emotional exhaustion, accompanied by meaningful improvements across secondary psychological measures, physiological stress markers, and workplace performance indicators.

The alignment between subjective symptom reduction and objective biomarker changes strengthens the validity of the findings and underscores the relevance of a multimodal strategy targeting neural oscillations, prefrontal metabolic function, and autonomic regulation. The demonstrated reductions in hair cortisol, enhancement of HRV, and increased prefrontal oxygenation during cognitive load illustrate that the intervention influences core mechanisms of chronic stress, suggesting that improvements extend beyond symptomatic relief to deeper regulatory and neurophysiological processes.

From an applied perspective, the observed reductions in absenteeism, improvements in presenteeism, and measurable gains in operational throughput highlight the practical value of implementing such programs at scale within enterprises. The safety profile, with only mild and transient adverse events and no serious adverse events, further supports its feasibility in real-world occupational settings.

Although limitations related to lack of participant blinding and inter-cluster variability must be acknowledged, the robustness of the results across analytic approaches provides confidence in the intervention's effectiveness. Collectively, the findings demonstrate that a structured, biologically informed multimodal protocol can produce transformative benefits for employee well-being and organizational functioning. The study therefore supports broader adoption of this integrated neurophysiological approach as part of comprehensive workplace mental health strategies aimed at reducing chronic stress and enhancing resilience.