STIMEL-03 WHITE PAPER SERIES

White Paper 5

Intention-Driven Neurorehabilitation

Translating Neural Signals into Functional Movement with Stimel-03

Abstract

Neurological rehabilitation is most effective when voluntary motor intent can be linked to successful movement and sensory confirmation. After stroke and other neurological injuries, patients frequently generate weak descending motor signals that represent genuine attempts to move but remain insufficient to produce visible contraction. Conventional stimulation approaches may activate muscles, but they do not consistently reinforce the neural pathways responsible for voluntary control. Intention-driven rehabilitation addresses this limitation by detecting voluntary neuromuscular activity and synchronizing stimulation with the patient's attempted movement. The Stimel-03 platform applies this model through sensitive surface EMG detection, BioRhythmIQ signal processing, adaptive activation thresholds, and stimulation-assisted movement. By converting weak neural intent into assisted contraction and proprioceptive feedback, the platform restores the learning loop that links intention, movement, and sensory return, which is central to motor relearning and neuroplastic recovery [1,2]. This paper explains the principles of intention-driven neurorehabilitation and describes how Stimel-03 translates neural signals into functional therapeutic movement.

Introduction

Effective neurorehabilitation depends on the brain's ability to reconnect intention with successful movement. After stroke or neurological injury, patients often attempt to move but cannot generate sufficient muscle contraction to produce visible motion. When this occurs, the nervous system receives little or no proprioceptive confirmation that the intended action occurred. The absence of this feedback interrupts the learning loop that normally links voluntary intent, motor execution, and sensory return, limiting reinforcement of emerging motor pathways [1].

During early recovery, weak descending neural signals may still generate measurable surface electromyographic activity even when no visible movement is present. These signals represent genuine voluntary motor intent and provide an important opportunity for therapeutic intervention. Rehabilitation systems capable of detecting this intent and converting it into assisted movement can restore the connection between the patient's attempted action and the resulting sensory feedback [3].

Stimel-03 is designed around this principle. By combining sensitive EMG detection, BioRhythmIQ signal processing, adaptive activation thresholds, and stimulation-assisted movement, the platform enables therapy that is driven directly by the patient's voluntary neural activity. This approach allows rehabilitation to begin even when voluntary contraction is insufficient to produce functional movement.

The Concept of Intention-Driven Rehabilitation

Traditional neuromuscular stimulation systems typically deliver stimulation according to predefined programs that are independent of the patient's voluntary effort. While these approaches can maintain muscle activation, they do not necessarily reinforce the neural circuits responsible for voluntary control.

Intention-driven rehabilitation takes a different approach. Instead of delivering stimulation passively, therapy is triggered by the patient's own neural signals. When the patient attempts a movement and produces detectable EMG activity, stimulation assists the contraction and completes the movement. The brain therefore receives confirmation that the intended action occurred.

This alignment between intention and outcome is critical for motor relearning. When voluntary effort leads to successful movement, sensorimotor circuits are reinforced and the nervous system strengthens the neural pathways responsible for the action through repeated sensorimotor coupling [2,4].

Detecting Voluntary Motor Intent

Even in severely impaired patients, descending motor commands often generate low amplitude EMG activity that reflects attempted movement. These signals may be extremely weak and easily obscured by electrical noise, motion artifacts, or electrode instability.

Stimel-03 uses surface EMG electrodes to detect this activity and identify patterns consistent with voluntary motor intent. Rather than relying on fixed trigger levels, the system continuously evaluates the statistical properties of the incoming EMG signal. This enables the platform to distinguish meaningful motor unit activity from background noise.

Detecting these early signals allows rehabilitation to begin at a stage when conventional stimulation systems may remain inactive. The patient's voluntary attempt therefore becomes the driver of therapy from the earliest phases of recovery [3,5].

BioRhythmIQ Signal Processing

Accurate detection of voluntary EMG requires robust signal conditioning. The BioRhythmIQ architecture applies multiple processing stages designed to isolate physiologically meaningful motor unit activity.

Signals acquired from surface electrodes pass through band pass filtering that captures the frequency range associated with motor unit action potentials. In surface EMG recordings, most motor unit activity typically lies within an approximate 20–500 Hz band, which guides the filtering strategy used in the BioRhythmIQ signal pipeline. The signal chain is designed to detect very low-amplitude motor unit activity, enabling reliable identification of micro-volitional EMG signals that may fall near the lower limits of surface detection during early recovery. Additional filtering suppresses environmental electrical interference such as 50 or 60 Hz noise. Artifact reduction algorithms further reduce disturbances caused by electrode movement or muscle cross talk.

Following signal conditioning, the system evaluates EMG amplitude relative to patient specific baseline activity. This allows the platform to identify genuine voluntary activation events while maintaining stability across therapy sessions. Reliable signal detection at this stage is essential because downstream therapy decisions depend on accurately distinguishing true voluntary intent from noise. Once voluntary activity can be measured with confidence, the next challenge is determining when that activity should trigger therapeutic stimulation.

Adaptive Activation Thresholds

A key limitation of many EMG triggered stimulation systems is the use of fixed activation thresholds. When thresholds remain static, small fluctuations in EMG amplitude can prevent stimulation from triggering even when the patient is making a genuine effort to move.

Stimel-03 addresses this limitation through adaptive activation thresholds that continuously adjust to the patient’s current neuromuscular capability. The threshold is calculated using recent signal statistics and is updated as the patient’s EMG characteristics evolve during therapy.

This adaptive approach allows stimulation to respond to voluntary effort even when signal amplitude changes due to fatigue, recovery progression, or electrode conditions [5]. Session-to-session variability caused by muscle fatigue, electrode impedance changes, or fluctuating voluntary activation can therefore be accommodated without requiring constant manual recalibration by the therapist. Adaptive thresholds therefore act as the decision layer of the system, translating detected neural activity into a trigger condition for therapeutic action.

Converting Intent into Assisted Movement

When EMG activity exceeds the adaptive activation threshold, Stimel-03 delivers electrical stimulation that assists the intended contraction. This stimulation activates motor nerves and produces muscle contraction aligned with the patient’s voluntary effort.

Because stimulation occurs during the attempted movement, the resulting contraction provides proprioceptive feedback that confirms successful execution of the action. The brain therefore receives a coherent sensory signal linking voluntary intent to movement outcome. Repeated pairing of intention, movement, and feedback promotes cortical reorganization and motor recovery [2,6]. To deliver this reinforcement consistently, the underlying rehabilitation platform must coordinate sensing, signal interpretation, and stimulation delivery in a tightly integrated architecture.

The Stimel-03 Intention-Driven Therapy Architecture

The Stimel-03 platform is built to translate voluntary neural intent into meaningful therapeutic movement. Rather than applying stimulation passively, the system organizes rehabilitation around the patient’s own motor signals, allowing neural intent to directly drive therapy. This architecture integrates EMG sensing, BioRhythmIQ signal processing, adaptive thresholding, and stimulation timing into a single coordinated rehabilitation loop.

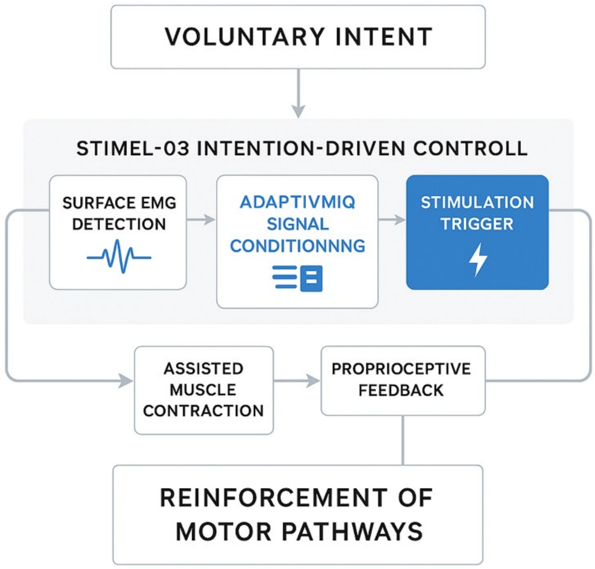

Figure 1. Stimel-03 Intention Driven Therapy Architecture (Schematic) *A closed-loop rehabilitation architecture in which voluntary neural intent is detected via surface EMG, processed through the BioRhythmIQ signal pipeline, evaluated by adaptive threshold logic, and translated into stimulation-assisted contraction that produces proprioceptive confirmation and reinforces motor learning.*

At the sensing level, surface EMG electrodes capture electrical activity generated by attempted voluntary contraction. Even when the patient cannot produce visible movement, weak motor unit activity may still reflect genuine descending neural drive, as surface EMG can detect neuromotor activity not visible during clinical observation in early neurological recovery.

Captured EMG signals are processed through the BioRhythmIQ signal architecture, which isolates physiologically meaningful motor unit activity while suppressing environmental electrical interference, motion artifacts, and cross talk from adjacent muscles, which is essential when stimulation artifacts contaminate EMG recordings during FES therapy.

Once voluntary activity is confirmed, the adaptive threshold engine evaluates the signal relative to patient specific baseline characteristics. Instead of relying on fixed activation levels, the system continuously adjusts detection thresholds based on the patient’s real time neuromuscular performance. Adaptive EMG onset detection approaches have been shown to outperform static thresholds for identifying voluntary motor activation in real time control systems.

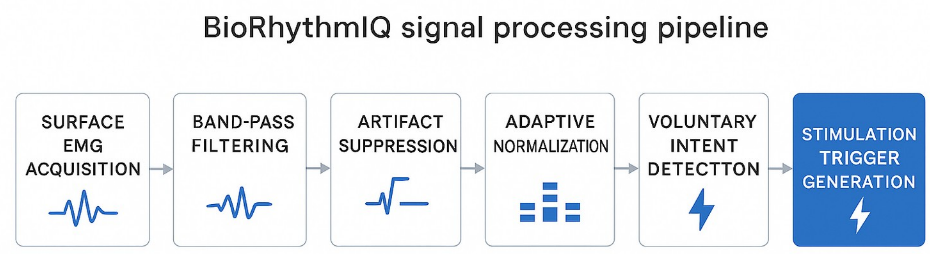

Figure 2. BioRhythmIQ Signal Processing Pipeline (Schematic) *Signal acquisition from surface EMG electrodes is followed by band-pass filtering, artifact suppression, signal normalization, adaptive threshold computation, and voluntary intent detection. When the processed signal exceeds the adaptive trigger condition, stimulation is generated to assist the intended movement.*

When EMG activity crosses the adaptive activation threshold, the system delivers electrical stimulation synchronized with the patient's attempted contraction. The processing and trigger architecture are designed to preserve low system latency so that stimulation occurs within the natural temporal window linking voluntary intent and sensory feedback, which is critical for associative motor learning. This stimulation assists the intended movement, activating the appropriate motor nerves and generating muscle contraction aligned with the patient's voluntary effort.

Conventional EMG triggered stimulation systems often treat EMG as a simple threshold event and rely on static trigger levels that can miss weak voluntary signals. Stimel-03 instead interprets EMG as a dynamic representation of motor intent, allowing rehabilitation to begin earlier and remain synchronized with the patient's evolving neuromuscular capability. Because thresholds adapt continuously and stimulation is temporally aligned with the patient's own neural command, the platform maintains the biological timing window required for effective sensorimotor learning. In practice, this means patients can begin intention-driven therapy earlier in recovery and perform a larger number of meaningful repetitions linked to genuine voluntary effort.

Closed Loop Reinforcement of Motor Learning

Stimel-03 therapy operates as a closed loop reinforcement system. Each cycle of therapy includes several steps:

- Patient attempts a target movement
- Voluntary neural signals generate EMG activity

- Stimel-03 detects the EMG signal
- Electrical stimulation assists the contraction
- Proprioceptive feedback confirms the movement
- Neural circuits associated with the movement are reinforced
- Repeated cycles strengthen the relationship between motor intent and sensory feedback, promoting functional motor recovery [2,6,7].

Task Specific Rehabilitation Applications

Intention driven stimulation can be applied to a wide range of rehabilitation tasks. For example, in an early-stage stroke patient attempting wrist extension, only weak EMG activity may be present without visible movement. Stimel-03 can detect this micro-volitional signal and deliver stimulation that assists the contraction, allowing the patient to see and feel the intended movement and reinforcing the emerging motor pathway. In upper limb therapy, the system can assist wrist extension, hand opening, and reaching movements. In lower limb rehabilitation it can support ankle dorsiflexion and stepping mechanics during gait training.

Because stimulation is triggered by voluntary effort, the patient remains actively engaged throughout the therapy session. Increased engagement and repetition are key factors supporting neuroplastic recovery following stroke and neurological injury [4,7].

Clinical Workflow

Stimel-03 integrates into standard rehabilitation workflows used by physical and occupational therapists. Electrodes are placed over the target muscle groups, and the system is calibrated to detect voluntary EMG signals generated during attempted movements.

During therapy sessions, patients observe and attempt specific functional movements while the system monitors EMG activity. When voluntary intent is detected, stimulation assists the movement and provides proprioceptive confirmation.

Therapists can adjust stimulation parameters and exercise tasks according to the patient’s rehabilitation goals, allowing therapy to progress from basic activation exercises to more complex functional tasks.

Clinical Impact

By aligning stimulation with voluntary neural activity, Stimel-03 transforms neuromuscular stimulation from a passive modality into an intention driven rehabilitation tool. Patients experience a direct relationship between their effort and the resulting movement, reinforcing motivation and engagement.

This relationship increases the number of meaningful movement repetitions performed during therapy sessions. High repetition of successful movements is a key driver of neuroplastic change and functional recovery in neurological rehabilitation [2,7].

Key Takeaways for Clinicians

- Weak voluntary EMG signals often represent genuine motor intent even when visible movement is absent.
- Intention driven stimulation allows therapy to begin earlier by converting weak neural effort into assisted movement.
- Adaptive activation thresholds improve detection reliability when EMG amplitude changes with fatigue, recovery progression, or electrode conditions.
- BioRhythmIQ signal processing helps isolate physiologically meaningful EMG activity from noise and motion artifacts.
- Synchronizing voluntary intent, assisted contraction, and proprioceptive feedback strengthens the sensorimotor pathways required for functional recovery.

Conclusion

Effective neurorehabilitation requires restoring the connection between motor intent and successful movement. Stimel-03 achieves this by detecting voluntary EMG signals, converting those signals into stimulation assisted contractions, and delivering proprioceptive feedback that confirms the intended action.

Through this intention driven approach, the platform reinforces sensorimotor learning during each therapy cycle and supports the gradual recovery of functional motor control.

References

1. Daly JJ, Wolpaw JR. Brain computer interfaces in neurological rehabilitation. Lancet Neurology. 2008;7(11):1032–1043.
2. Kleim JA, Jones TA. Principles of experience dependent neural plasticity: implications for rehabilitation after brain damage. Journal of Speech Language and Hearing Research. 2008;51:S225–S239.
3. Biasiucci A, Leeb R, Iturrate I, et al. Brain actuated functional electrical stimulation elicits lasting arm motor recovery after stroke. Nature Communications. 2018;9:2421.
4. Khan MA, Fares H, Ghayvat H, et al. A systematic review Functional electrical stimulation based rehabilitation systems for upper limb post stroke recovery. Frontiers in Neurology. 2023;14:1272992.
5. Marquez Chin C, Popovic MR. Functional electrical stimulation therapy for restoration of motor function after spinal cord injury and stroke: a review. BioMedical Engineering OnLine. 2020;19:34.
6. Eraifej J, Clark W, France B, Desando S, Moore D. Effectiveness of upper limb functional electrical stimulation after stroke: systematic review and meta analysis of randomized controlled trials. Clinical Rehabilitation. 2017;31(4):429–438.
7. Howlett OA, Lannin NA, Ada L, McKinstry C. Functional electrical stimulation improves activity after stroke: a systematic review with meta analysis. Archives of Physical Medicine and Rehabilitation. 2015;96(5):934–943.
8. Ambrosini E, Ferrante S, Pedrocchi A, Ferrigno G, Molteni F. Cycling induced by electrical stimulation improves motor recovery in post acute stroke patients: randomized controlled trial. Neurorehabilitation and Neural Repair. 2011;25(7):676–684.