Highlights

- Response inhibition was assessed in a balance recovery task
- Compensatory steps were occasionally blocked to force a fixed support reaction
- TMS was used to assess corticospinal excitability in a task-irrelevant hand muscle
- Suppressing a prepotent step coincided with inhibition of an intrinsic hand muscle
- Results indicate the presence of global suppression in a postural context

Staying Upright by Shutting Down?

Evidence for Global Suppression of the Motor System when Recovering Balance

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Abstract

Background: When automatic, yet unwanted action is quickly inhibited, short-lived suppression throughout the motor system ensues. This effect is referred to as *global suppression*. Although response inhibition is essential for behavioral flexibility, widespread motor suppression may delay action reprogramming. In reactive balance control, even fleeting suppression of the motor system could interfere with our ability to adapt compensatory reactions quickly enough to avoid a fall.

Research Question: Is muscle activity in the hand suppressed when a prepotent compensatory step becomes suddenly blocked in a balance recovery task?

Methods: Nineteen young adults were tested using a lean and release apparatus. Participants were occasionally released from a support cable resulting in forward body displacement. At the start of each trial, vision was occluded and a leg block was either placed in front of the legs or removed to allow a forward step. After goggles opened, the cable was released to cause a postural perturbation and participants had to either quickly step forward (STEP) or use a feet-in-place reaction to regain stability (NO-STEP). Step trials were much more frequent to promote stepping. Transcranial magnetic stimulation (TMS) was delivered shortly after receving vision (but before postural perturbation) to assess corticospinal excitability in an intrinsic hand muscle that was irrelevant to the balance recovery task.

Results: Repeated measures ANOVA compared motor-evoked potentials across two step conditions (STEP, NO-STEP) and two TMS latencies (100ms, 200ms). The resultant interaction provided evidence of motor suppression in the hand when a forward step was blocked.

Significance: Inhibition of a hand muscle uninvolved in a compensatory leg response provided evidence of global suppression in a whole-body, reactive balance context. Such widespread suppression of the motor system has implications for maintaining postural equilibrium, where even a momentary shutdown across body regions could interfere with the ability to adapt corrective balance reactions.

Keywords: Response Inhibition; Posture; Transcranial Magnetic Stimulation; Lean-and-Release; go/no-go task.

1. Introduction

Stepping to establish a new support base is often necessary to avoid a fall. Indeed, generating a single, well-placed step with sufficient speed is one hallmark of an effective balance recovery response [1]. But what about those instances where a step would lead to further instability? In the milliseconds following loss of balance, *response inhibition* may paradoxically be called upon. Suppressing a compensatory step could avoid a greater threat to posture (e.g., a stairwell), protect an object on a collision course (e.g., a toddler), and/or expedite a more effective alternative (e.g., grabbing a handrail).

Response inhibition is the ability to stop a highly automatic, yet unwanted action and allows for behavioral flexibility in complex situations that require us to adapt behavior beyond what is instinctual [2]. Given the importance of this capacity as a foundation for higher level cognitive skill, a great deal of investigation has gone into this topic in cognitive psychology. Several behavioral tasks have been used to investigate response inhibition (for review see [3]), but the standard approach is to employ some version of a go/no-go task where participants are instructed to react as fast as possible to an imperative go signal but abstain from reacting when a no-go signal is presented. An important aspect of this test is the higher frequency of go cues versus no-go (or stop) cues in an effort to make the go response very quick and automatic. Notably, the ability to stop a highly automatic action becomes more difficult as the time pressure to respond increases.

An interesting side effect of inhibiting a prepotent movement is a tendancy for other parts of the body, even those uninvolved in the task, to be concurrently suppressed. This phenomenon referred to as *global suppression* is rooted in a ‘quick and dirty’ neural mechanism that transiently suppresses motor output all together [4,5]. As an example, global suppression has been demonstrated via suppressed corticospinal excitability in a task-irrelevant leg muscle when seated participants are required to quickly suppress a prepotent hand response [6]. One consequence of this wholesale motor shutdown is that behavioral flexibility may be compromised in the time frame immediately following the sudden need to suppress action in one part of the body.

We present a novel approach for imposing the infrequent need to suppress a highly automated step in a balance recovery task. This allowed us to study response inhibition—a topic richly explored in cognitive psychology—but now within a standing postural context. Traditional response inhibition studies have used simplistic hand actions such as pressing buttons on a keyboard while participants are seated. Reactive stepping on the other hand, involves an intensified motor challenge to establish a new support base with one leg, while simultaneously stabilizing the body with the other leg. It is unclear if past research on response inhibition generalizes to a reactive stepping context. Our approach used TMS to estimate suppression throughout the motor system (i.e. global suppression) when a balance recovery step needed to be inhibited and a feet-in-place reaction was used in its place. The concept of global suppression is particularly relevant to reactive balance control where whole-body movements must be coordinated at great speed. Even short-lived suppression throughout the motor system could potentially impair the ability to quickly adapt our reactions to avoid a fall.

2. Methods

2.1. Participants

A convenience sample of 20 young adults aged 19–25 years ($M = 21.7 \pm 1.5$) were recruited and provided written informed consent for experimental protocols as approved by the

Utah State University Institutional Review Board. Participants were free of contraindications for TMS [7].

2.2. Electromyography

EMG was recorded using Delsys DE-2.1 differential surface electrodes, and EMG signals from the right first dorsal interosseus (FDI) were amplified (gain = 1000) using a Delsys Bagnoli-4 amplifier (Delsys Inc., Boston, MA, USA). EMG data was sampled at 5000Hz and bandpass filtered (10–500 Hz) using Signal Software and a Cambridge Electronic device (Power 1401, Cambridge Electronic Design, Cambridge, UK).

2.3. Testing Apparatus

2.3.1. Lean and release system: A custom-made *lean-and-release* cable system was used to impose temporally unpredictable forward perturbations [8–10]. All testing was conducted with participants standing in a forward lean position maintained by means of a body harness attached to a cable, which was secured to a wall behind the participant. The experimenter had the ability to suddenly release the cable tension thereby perturbing the participant forward. The direction and amplitude of perturbation was fixed, however onset of the perturbation was unpredictable. As a failsafe, participants were secured via support cables to girders in the ceiling to prevent falling to the ground.

2.3.2. Control of vision: Visual access was manipulated in this study by use of liquid crystal goggles (Translucent Technologies Inc. Toronto, ON, Canada) and limited to a time window immediately before postural perturbation. These goggles can be programed to open at precise time points, allowing a means for controlling the onset of visual stimuli in the environment. While closed, these goggles allowed an illuminated view without access to the visual scene. Therefore, participants were unaware of the upcoming response setting. During visual occlusion, the configuration of obstacles and handholds were changed forcing participants to quickly perceive and adapt their movements to a novel environment once the goggles opened.

2.4. TMS protocol

Single-pulse TMS was delivered over the left primary motor cortex to target the right FDI [11]. Magnetic stimuli were delivered by a Magstim 200 stimulator using a figure of eight D70² Coil (Magstim Company Ltd., Whitland, UK). The stimulating coil was oriented at approximately 45 degrees to the sagittal plane, thus inducing posterior to anterior current flow across the motor strip [12,13]. To allow hotspot localisation and consistent coil placement, markings were made directly on the scalp. Once the hotspot was located, a test stimulus intensity was determined as the stimulator intensity that produced a 1.0–1.5mV (peak-to-peak) motor-evoked potential (MEP). The purpose was to investigate the influence on motor preparation immediately upon receiving visual access to the environment, therefore TMS was delivered soon after visual access, but prior to any movement. The TMS coil remained fixed on the hotspot for all trials and the coil position was reset following any head motion associated with a corrective balance response. Note that test stimulus intensity was determined while subjects were in a standing, forward-lean position (with no postural perturbations) to control for the influence of postural state on CSE.

2.5. Procedures

2.5.1. Lean and Release Task: Figure 1 summarizes our methods, where a *lean-and-release* system was used to instigate forward falls from a forward lean position. The experimenter instructed participants to lean as far forward as the cable allowed while keeping both feet in contact with the floor, and to remain relaxed. This position required anterior rotation about the ankle, as the rest of the body remained aligned. Pre-release lean angle was individually titrated to a maximum whereby a feet-in-place response could recover balance (~6°). However, at this threshold, participants defaulted to a forward step when the footway was unobstructed.

Trials began with participants in a forward lean, with vision blocked. During this time, the scene in front of participants changed as computer-driven motors randomly moved a leg block to either block a forward step (NO-STEP) or allow a step (STEP). The handle cover and leg block were moved into position via computer-triggered, servo motors at the start of each trial regardless of condition. The consistent sound of the motors across trials, in addition to ear plugs and occluded vision, were intended to avoid advanced cueing of the upcoming condition. In this way, participants were unaware of the setting until visual access was provided.

On trials where a postural perturbation occurred, the cable was released 600ms post-vision. Trials with no perturbation were randomly interspersed to discourage pre-release movement allowing us to focus on preparatory corticospinal activity. Critically, the STEP condition was more frequent (75%) to promote prepotent motor activity, a prerequisite for obligating response inhibition [14]. There were 6 blocks of 18 trials ([3 STEP + 1 NO-STEP] × 2 vision–TMS latencies × [1 release + 1 no-release] + 2 reference); however, probabilities exclude the no-vision/no-perturbation reference trials. TMS was delivered 100ms or 200ms post-vision on separate trials to provide temporal resolution of inhibitory processes. On a select number of trials, goggles did not open, and these trials served as a reference to normalize MEPs in subsequent analysis.

2.6. Data Analysis

Using preestablished criteria, trials were discarded if background EMG prior to TMS onset was $> 10\mu V$ RMS amplitude, if MEPs were small (i.e. $< 100\mu V$ peak-to-peak), or if outliers were present (i.e. values falling outside the threshold defined by 1.5 times the interquartile range). A 2 × 2 repeated measures ANOVA was used to test for interactions between factors Step Condition (OBS, BAL) and Latency (100ms, 200ms) for the MEP amplitude in the FDI muscle. To test our specific hypothesis that MEPs from a hand muscle (FDI) would be suppressed when participants were forced to stop an automated forward step, directional paired t-tests were used to compare MEP amplitude at the 200ms delay versus the 100ms (baseline) delay for the STEP and NO-STEP conditions ($\alpha < 0.05$).

3. Results

One dataset was discarded for insufficient trials conserved due to technical difficulties during collection combined with our standard screening process (i.e. less than five trials for less frequent conditions). For the remaining 19 participants, there were 34 trials on average used in the final analysis for each of the frequent STEP conditions, 11 trials on average for the NO-STEP conditions, and 11 trials on average for the reference condition. From the repeated measures ANOVA, the Step Condition × Latency interaction, $F_{1,18} = 4.47$, $p = .049$, was significant. Visual inspection of the line graph in Figure 2 reveals decreasing MEP amplitude over time for the NO-STEP condition only and this was confirmed with follow-up comparisons. Specifically, these comparisons revealed a significant decrease at 200ms compared with 100ms $t_{18} = 2.595$, $p = 0.009$ for the NO-STEP condition. By contrast a similar comparison between 200ms and 100ms for the STEP condition reveals no difference $t_{18} = 0.346$, $p = 0.367$.

4. Discussion

Suppressing a prepotent balance recovery step coincided with inhibition of a task-irrelevant hand muscle. From observed FDI inhibition, we infer evidence for global suppression, which began shortly after viewing a stepping obstacle. This is consistent with past results where task-irrelevant leg muscles were inhibited when subjects refrained from executing an automatic hand response [6]. This suggests that global suppression—previously shown in seated subjects performing focal hand tasks in response to arbitrary stimuli presented on a computer screen—generalizes to a standing balance context.

As a qualifier, we recognize that motor cortical suppression may not truly be ‘global’ as our TMS probe was limited to a finger abductor muscle. It is possible, indeed likely, that other muscles more relevant to the fixed-support response may be selectively spared from inhibition (e.g. shoulder or trunk muscles); however, this awaits further investigation. The question here was if the need to suppress a rapid leg response resulted in concomitant inhibition of a task-irrelevant hand muscle. Notably, our procedure yielded a general expectation of perturbation, including magnitude and direction, while discouraging anticipatory movement. Face validity is presented by the metro rider who awaits the sensory volley of a stop before taking corrective action. However, our findings may not inform perturbations that are wholly unexpected or when information about the immediate surroundings is incomplete.

5. Conclusion

Rapid disruption of hand muscle activity has potential implications where a compensatory reach-to-grasp reaction may be a last resort to reestablish a base of support when a step is unexpectedly blocked. Wide-ranging suppression can be particularly salient in the domain of reactive balance control where rapid whole-body, coordinated actions are typically needed to achieve stability [15,16]. It is unclear in what contexts, and when during balance recovery global suppression is adaptive (if at all). If ongoing activity is contraindicated, global suppression may be a critical reset before generating an appropriate response. Conversely, widespread inhibition throughout the motor system, even if short-lived, may delay the emergence of a more suitable response. Further testing is required to determine if postural performance is affected by global suppression and if overt recovery behaviour actually relates to cortical motor set as presently measured.

Declaration of Interests

None.

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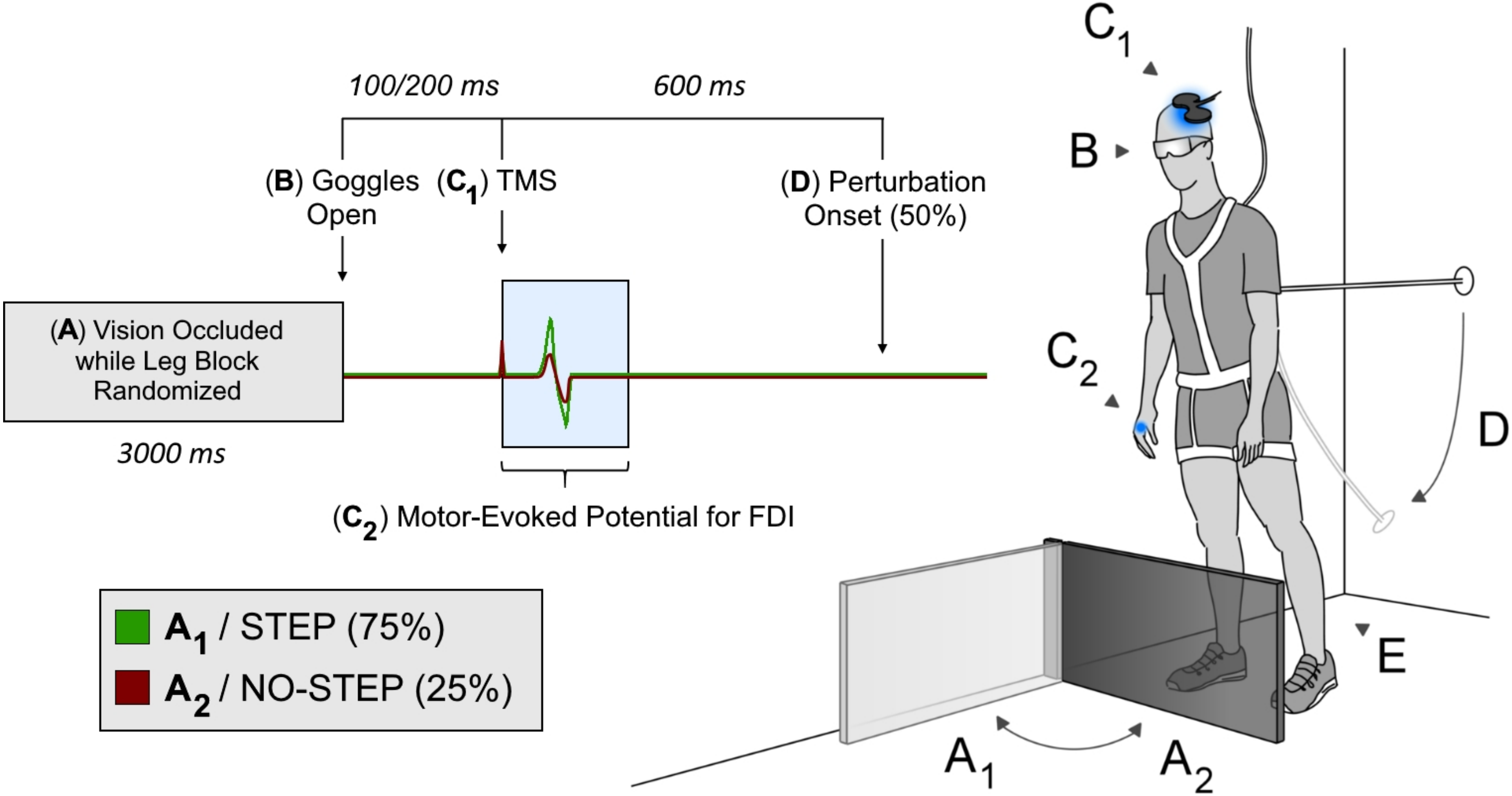
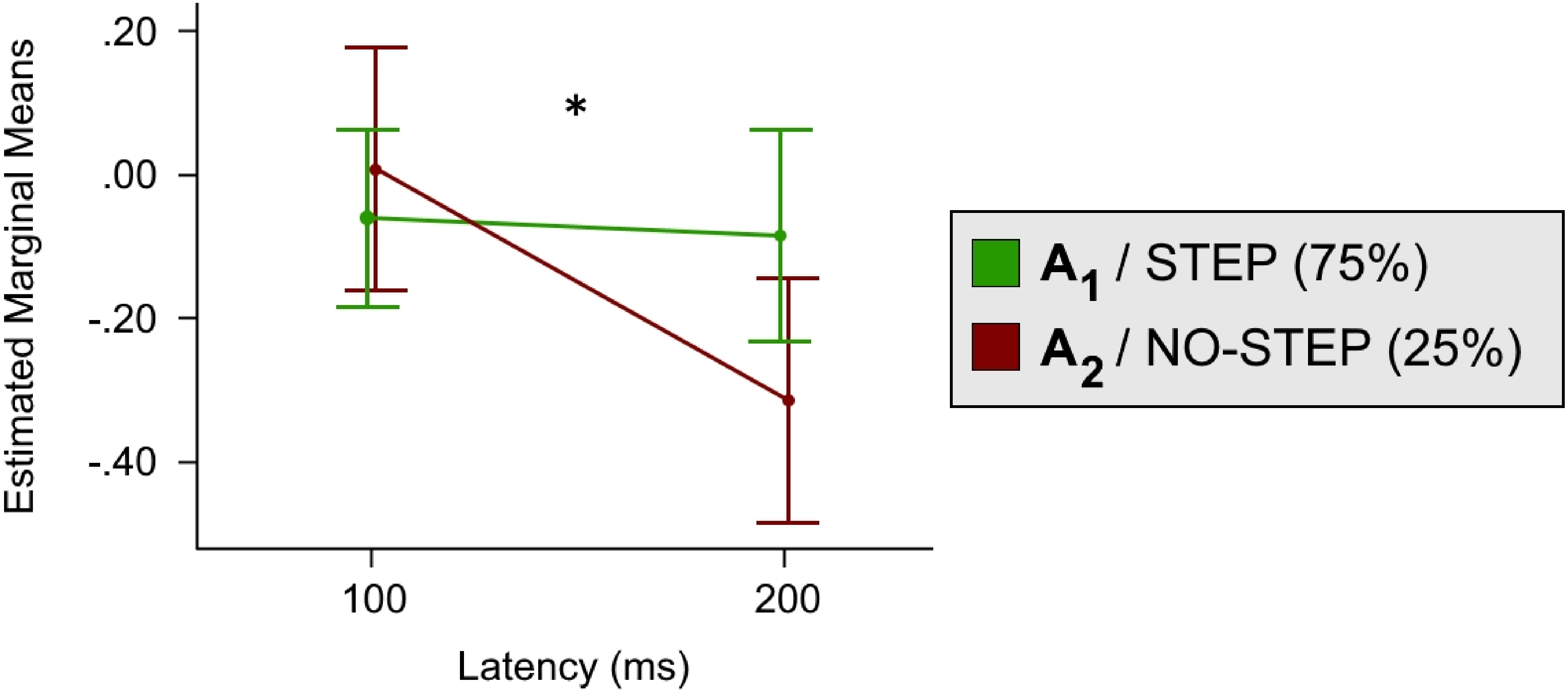
Figure captions

Figure 1. Trial sequence illustrated to represent EMG from first dorsal interosseous muscle (left) along with a schematic of electrophysiological sites and the lean-and-release apparatus (right).

Figure 2. Evidence for global suppression from 2 × 2 repeated-measures ANOVA. Error bars demarcate ± 1 standard error. $*p < .05$


100/200 ms
600 ms
(B) Goggles Open
(C$_1$) TMS
(D) Perturbation Onset (50%)
(A) Vision Occluded while Leg Block Randomized
3000 ms
(C$_2$) Motor-Evoked Potential for FDI
🟩 A$_1$ / STEP (75%)
🟥 A$_2$ / NO-STEP (25%)
C$_1$
B
C$_2$
D
E
A$_1$
A$_2$


Estimated Marginal Means
.20
.00
-.20
-.40
*
100
200
Latency (ms)
🟩 A1 / STEP (75%)
🟥 A2 / NO-STEP (25%)