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Research report

Somatosensory input to non-primary motor areas is enhanced during preparation of cued contraterlateral finger sequence movements

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HIGHLIGHTS

- Frontal N30s enhanced during late stages of movement preparation.
- Enhancement depends on complexity of prepared movement.
- Enhancement occurs with contralateral movement.

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ABSTRACT

Frontal N30 somatosensory evoked potentials (SEPs) represent early somatosensory input into non-primary motor areas. Importantly, modulations of frontal N30 SEPs can provide insight into the mechanisms involved in sensory processing for movement control. Enhancements of frontal N30 SEPs have been revealed during repetitive but not during the preparation of movements that are contralateral to median nerve (MN) stimulation (i.e. contralateral movements). Importantly, these enhancements during contralateral movements may be dependent on increased activity in several neural areas such as the primary motor cortex (M1), supplementary motor area (SMA) and basal ganglia (BG). Furthermore, research has also shown that patients with prefrontal lesions have enhanced early frontal SEPs (i.e. N28) at rest supporting a role of the prefrontal cortex in inhibitory modulation of early somatosensory input. The current study evaluated whether differential modulations of frontal N30 SEPs occurred during different time periods when individuals prepared and executed contralateral (right) finger sequences to attended vibrotactile (VibT) stimuli at the left index finger. SEPs were measured to median nerve (MN) stimuli elicited at the left wrist and MN stimuli were time-locked in four different periods relative to VibT onset (during pre-stimulus, early response preparation, late movement preparation and movement execution). Results revealed that frontal N30 SEPs were significantly enhanced when MN stimulation occurred in the late preparatory and/or early movement execution period (~750 ms) after the attended VibT stimuli. This result supports that increases in frontal N30 amplitudes during contralateral movements are dependent on the complexity of preparing and executing finger sequences, which is associated with increased activity in several neural areas such as the non-primary motor areas, prefrontal cortex and BG. Furthermore, enhanced N30 SEPs during contralateral movement preparation and execution may be a necessary mechanism to decrease sensory gating to facilitate somatosensory processing in non-primary motor areas when there is a 'noisy' environment.

1. Introduction

Sensorimotor integration involves selective extraction of relevant sensory input and suppression of irrelevant or distracting information (i.e. sensory gating) to effectively plan and execute movements. Importantly, abnormal sensory gating has been associated to atypical movement control in various disorders including delayed response deficits in prefrontal lesion patients [1] and slow, bradykinetic movements in basal ganglia disorders such as Parkinson's diseases [2]. Thus, it is important to understand the mechanisms contributing to modulations of sensory input for movement control.

Frontal N30 somatosensory evoked potentials (SEPs) have frequently been recorded by surface electrodes over non-primary motor areas after transcutaneous electrical stimulation of the median nerve (MN) [3–13]. It is well-established that the frontal

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N30 is gated during preparation, execution or imagination of movements to the same limb as MN stimulation (i.e. ipsilateral movements) [3–14]. In contrast, previous research has also shown that N30 peaks are enhanced during the execution of contralateral repetitive finger-to-thumb opposition movements [15] and during self-paced gripping [8]. Furthermore, it was revealed that the facilitation of the N30 peaks occur predominantly during contralateral non-dominant rather than dominant limb self-paced gripping [7]. It was hypothesized that these facilitatory effects on N30 peaks during non-dominant hand movements resulted from increased activity in supplementary motor area (SMA), primary motor cortex (M1) and basal ganglia (BG) [7]. However, it is currently unclear if this mechanism (i.e. increased activity in SMA, M1 and/or BG) is responsible for facilitating N30 peaks.

One way to investigate this hypothesis is through the evaluation of SEP modulation during the preparation and execution of movements that are known to recruit and increase activity in these neural areas. Previous imaging research has identified increased blood flow in several neural areas including the rostral supplementary motor area (pre-SMA), ipsilateral primary motor cortex (M1) and basal ganglia when preparing and executing movement sequences with increased complexity [16]. Thus, it appears that the frontal N30 peaks could be modulated by the preparation and execution of sequential finger movements compared to repetitive contralateral movements. In addition to motor areas, imaging research has also identified increased activity in the prefrontal cortex (Brodmann's areas 9, 10 and 46) during movements that require greater executive control such as timing the initiation of movements or more difficult sequential movements [17,18]. Furthermore, the prefrontal cortex has also been linked to both the extraction of relevant and inhibition of distracting sensory stimuli [1]. Interestingly, previous research demonstrated that amplitude of frontal SEPs around 30 ms (frontal N28) increased in unilateral prefrontal lesion patients (involving Brodmann's areas 9 and 46) at rest compared to control participants [19]. These findings suggest that the prefrontal cortex may be involved in inhibitory modulation of early somatosensory processing in non-primary motor areas [19]. However, previous manipulations of selective spatial attention have not revealed amplitude modulations of frontal N30 SEPs [20,21]. Thus, it is currently unclear what role the prefrontal cortex has in modulating frontal N30 peaks in healthy adults.

The current study investigated amplitude modulations of frontal N30 peaks during contralateral (right) finger sequences that were cued by somatosensory input at an attended location. The current experimental paradigm measured SEPs to MN stimulations that were elicited during four different periods (pre-stimulus, early response selection, late movement preparation and movement execution) during the vibrotactile cued response task. This experimental protocol was different compared to previous SEP gating experiments since index finger vibrations were used to direct attention and cue movement rather than the MN stimuli themselves or alternatively, epoching MN stimulation during self-paced movements. The current paradigm provided two major advantages compared to previous protocols of SEP gating: (1) experimental manipulations of attention to index finger vibrations (rather than MN stimuli themselves) allowed investigation of the timing of attentional and movement-related modulatory effects but maintained spatial attention to somatosensory input to the left hand MN representation and (2) the cued-response task allowed for attended somatosensory input to be relevant for movement that would not be possible when epoching MN stimulation during self-paced movement. Thus, the time-locking of MN stimulation during the cued response task allowed the investigation of SEP modulation that would be associated with different neural activity in particular regions during each period: (a) prefrontal mediated activity during pre-stimulus anticipatory period [22,23], (b) increased activity in prefrontal [24] and non-primary motor areas during early response selection and late movement preparation [25,26], and (c) in primary motor cortex during movement execution [27]. It was hypothesized that the amplitude of frontal N30 peaks would be modulated in each period as follows: (a) enhanced during anticipatory period as a result of disinhibitory attentional effects, (b) gated during early response selection and late movement preparation mediated by widespread increased activity in both prefrontal and non-primary motor areas associated with the executive control and planning of movements and (c) enhanced during movement execution as a result of increased activity in the contralateral primary motor areas.

2. Materials and methods

2.1. Participants

Ten right-hand dominant healthy adults (five males, aged 27 ± 3.6 years old; range 21–33 years old) were recruited and provided written informed consent to participate in the experiment. The University of Waterloo Office of Research Ethics Board approved all experimental procedures used in the current study.

2.2. Experimental task

The behavioral task required participants to detect vibrotactile (VibT) stimuli at an attended (i.e. left index finger, D2) or ignore distracting stimuli to an unattended location (i.e. left pinky finger, D5) and determine whether attended VibT stimuli were standard, high or low amplitude. If participants perceived VibT stimuli as low or high amplitude at the attended D2 (i.e. targets), they would execute a pre-matched finger sequence movement with the contralateral (right) hand corresponding to the perceived high or low stimuli. In contrast, if participants perceived standard amplitude VibT or VibT stimuli to the unattended D5 location no response was required. Overall, the VibT stimulation paradigm applied frequent non-targets (65%) (standard amplitude to attended location and stimuli to the unattended D5) and infrequent targets (35%) (high and low amplitude to attended D2) during the experimental conditions. Furthermore, transcutaneous electrical stimulation of the median nerve (MN) at the left wrist occurred throughout the experiment, but was irrelevant for the behavioral aspect of the task.

2.3. Experimental design

Participants were instructed to perform one of two experimental conditions in pseudo-randomized trials while receiving both VibT and MN stimulation. The first experimental condition, *No Task*, had participants visually fixating forward while receiving VibT randomly to left D2 or D5 fingers with time-locked MN stimulations (see below) without any required behavioral response. In the second experimental condition, *Attend Index and Move*, participants were instructed to detect high and low VibT stimuli to left D2 and respond with a pre-matched finger sequence with the right hand (i.e. contralateral hand) under the same fixation and stimulation parameters as the *No Task* condition. The pre-matched finger sequences were produced with digits two through five of the right hand on a custom-made response device. The response device consisted of four separate force-sensing resistors (FSRs) placed and secured on plexiglass in accordance with the position of the participant's digits. The finger sequences included seven sequential finger taps in accordance with digits two through five: D2-D2-D3-D4-D4-D4-D5 or D5-D5-D4-D3-D2-D2-D2. Each finger sequence was pre-matched before experimental testing began and randomized for low and high VibT targets across participants. Each participant