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Effects of hand dominance on lateralized tactile processing

El baskınlığının lateralize dokunsal işlemleme üzerindeki etkileri

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Developments and Experiments in Health and Medicine
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Issue:3
RESEARCH ARTICLE
Pages:356- 365

ABSTRACT
BACKGROUND
This study aimed to investigate the impact of manipulating static interstimulus intervals (ISIs) on cortical somatosensory responses to non-painful tactile stimuli applied to both the dominant and non-dominant hands.
METHODS
Nineteen healthy right-handed volunteers participated in the electroencephalography study. During separate sessions, non-painful tactile stimuli were administered to the fingertips of both the right and left hands. The study utilized two ISIs, one with a short 2-s interval (ISI_S) and one with a longer 8-s interval (ISI_L). The primary measurement was the peak-to-peak maximum (PPmax) value, defined as the amplitude difference between the negative N2 component appearing at approximately 160-220 ms and the late somatosensory vertex P300 component observed at approximately 320-380 ms. PPmax amplitudes were analyzed using three-way repeated-measures analysis of variance with ISI, electrode location, and hand as within-subject factors.
RESULTS
A significant main effect of ISI on PPmax amplitudes was found [$F(1,18) = 20.87$, $p < 0.001$, $\eta p^2 = 0.54$], with PPmax amplitudes being significantly higher during ISI_L (8s) sessions compared to ISI_S (2s) sessions ($p < 0.001$). No significant main effects or interactions involving electrode location or hand dominance were observed.
CONCLUSION
The findings suggest that static interstimulus interval significantly influences PPmax amplitudes, with higher response amplitudes associated with longer ISIs. The absence of significant differences in responses between the right and left hands among participants indicates that, under static ISI conditions, PPmax amplitudes are comparable regardless of hand dominance.
KEYWORDS
Electroencephalography, hand dominance, interstimulus interval, non-painful tactile stimulation
ÖZ
AMAÇ
Bu çalışma, statik uyaranlar arası süre manipülasyonunun, baskın ve baskın olmayan ellere uygulanan ağrısız dokunsal uyaranlara yönelik kortikal somatosensoriyel yanıtları nasıl etkilediğini incelemeyi amaçlamıştır.
GEREÇ YÖNTEM
On dokuz sağ el baskın, sağlıklı gönüllü EEG çalışmasına katılmıştır. Ağrısız dokunsal uyaranlar sağ ve sol el parmak uçlarına ayrı oturumlarda uygulanmıştır. Uyaranlar arası süre, ayrı oturumlarda kısa 2 saniyelik aralık (ISI_S) ve uzun 8 saniyelik aralık (ISI_L) olarak belirlenmiştir. Birincil ölçüm, yaklaşık 160-220 ms'de ortaya çıkan negatif N2 bileşeni ile yaklaşık 320-380 ms'de gözlenen geç somatosensoriyel verteks P300 bileşeni arasındaki genlik farkı olarak tanımlanan Tepe-Tepe Maksimum (PPmax) değeriydi. PPmax genlikleri, ISI, elektrot ve el faktörlerinin denek içi faktörler olarak ele alındığı üç yönlü tekrarlı ölçümler varyans analizi (ANOVA) kullanılarak değerlendirilmiştir.
BULGULAR
Uyaranlar arası sürenin PPmax genlikleri üzerinde anlamlı bir ana etkisi olduğu bulunmuştur ($F(1,18) = 20{,}87$, $p < {,}001$, $\eta p^2 = {,}54$); uzun ISI (8s) koşulunda elde edilen PPmax genlikleri, kısa ISI (2s) koşuluna kıyasla anlamlı derecede daha yüksektir ($p < {,}001$). Elektrot veya el dominansını içeren ana etkiler ya da etkileşimler açısından anlamlı bir bulguya rastlanmamıştır.
SONUÇ
Sonuçlar, statik uyaranlar arası sürenin PPmax genliklerini modüle ettiğini ve ISI arttıkça yanıt genliklerinin arttığını göstermektedir. Aynı katılımcı içinde sağ ve sol elden elde edilen yanıtlar arasında anlamlı bir farkın bulunmaması, statik ISI koşulları altında PPmax genliklerinin el dominansından bağımsız olarak benzer şekilde ortaya çıktığını göstermektedir.
ANAHTAR KELİMELER
Ağrısız dokunsal uyaran, elektroensefalografi, el baskınlığı, uyaranlar arası süre

Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

The temporal dynamics of sensory processing are fundamental to understanding how the human brain encodes, processes, and integrates repetitive stimulation (1–3). For understanding how the brain processes repeated inputs, the interstimulus interval (ISI) is a key temporal parameter. The ISI, defined as the time between consecutive stimuli, plays a critical role in shaping cortical responsiveness (4,5). It is often used to investigate neural mechanisms such as habituation, sensory gating (S2/S1 suppression), and attentional or predictive modulation, all of which are strongly influenced by the temporal spacing of stimuli (4,6). While short ISIs are typically applied in the millisecond range (0–500 ms or shorter), ISIs of 1000 ms or longer are generally considered long (7,8).

In the literature, ISI selection varies depending on the methodological design, the measurement technique, and the specific aim of the study (4,9,10). In studies employing both short and long ISIs, an overall increase in cortical response amplitude has been observed with longer ISIs, though the underlying mechanisms appear to differ depending on the temporal ISI range (8,11,12). Short ISIs are often associated with attentional modulation, refractory period effects, and sensory gating mechanisms, whereas longer intervals are more closely linked to habituation processes (13–16).

In the present study, ISIs of 2000 (ISI_S) ms and 8000 (ISI_L) ms were selected to represent short and long conditions, respectively. Previous research has shown that the use of ISIs in the second range leads to a gradual reduction in response amplitudes, a pattern commonly interpreted as reflecting habituation mechanisms (4,11,12). Habituation entails a progressive decrease in amplitudes of responses to a repeated stimulus, independent of sensory adaptation or motor fatigue (16). Conversely, previous studies using ISI manipulation to investigate somatosensory processing have often employed electrical (7,9,10,17–19), vibration or vibrotactile (20–22), mechanical (23), or nociceptive (painful) (24,25) stimuli applied to different body parts including the wrist, palm, elbow, or fingers. In this study, we applied non-painful tactile stimuli to the fingertips to mimic natural touch perception. Given the established contralateral organization of the somatosensory system (26), stimuli were presented to both dominant and non-dominant hands to investigate possible hemispheric variations. While magnetic resonance imaging (MRI) and functional MRI studies have greatly advanced our understanding of the spatial organization of somatosensory processing (27,28), much less is known about its temporal characteristics. The temporal dynamics of stimulus presentation strongly influence cortical responsiveness (29); however, the ways in which these dynamics, particularly under static ISI conditions, differ between dominant and non-dominant hands remain poorly explored. In this context, we aimed to examine the effects of short and long static ISIs on brain responses to non-painful tactile stimuli applied to dominant and non-dominant hands.

Materials and Methods

This study included 19 healthy participants (10 women, 9 men) with a mean age of 22.95 ± 3.64 years. None of the participants reported having any neurological, psychological, or chronic illnesses, nor did they have any sleep disorders based on self-report. According to the Turkish adaptation of the Edinburgh Handedness Inventory (30), all participants were right-handed. They were requested not to take any medication that could affect electroencephalography (EEG) recordings or consume caffeine prior to the experimental sessions. Before taking part in the study, all participants were thoroughly informed about the experimental procedures and gave their written consent. The study was approved by the local ethics committee of the relevant university (Decision No: 2023/04-29, Date: 15/02/2023).

In the experimental setup, non-painful tactile stimuli were delivered to the tips of the participants' right and left index fingers in separate sessions via a pneumatic stimulator (Somatosensory Stimulus Generator, 4-D NeuroImaging, San Diego, CA, USA). This device uses pressurized air to inflate a rubber membrane. Thus, the pressure creates a basic non-painful touch sensation on the fingertip. The ISI was set at two durations including a 2-s interval and an 8-s interval. In this study, the 2-s interval was considered a short ISI (ISI_S), whereas the 8-s interval was categorized as a long ISI (ISI_L). The short and long ISI conditions were presented in separate sessions, with a total of four sessions: two sessions for right-hand and two for left-hand stimulation. The order of sessions was counterbalanced across participants to minimize possible sequence effects. Forty stimuli, each with a duration of 200 ms,

Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

were presented sequentially per session. Stimulus presentation and experimental timing were controlled using MATLAB 7.0 (MathWorks, Inc., Natick, MA, USA). The Embedded Interactive Stimulation Unit (EMISU) was used to mark the accurate timing of the stimulus on continuous EEG recordings (31). To eliminate potential auditory confounders, white noise was continuously presented to participants through headphones during the experiment, thereby masking any sound cues related to the somatosensory stimulation and background environmental noise (Figure 1). To visually represent the experimental design, Figure 1 was created using Gemini (Google, USA) based on the authors' specific instructions and design.

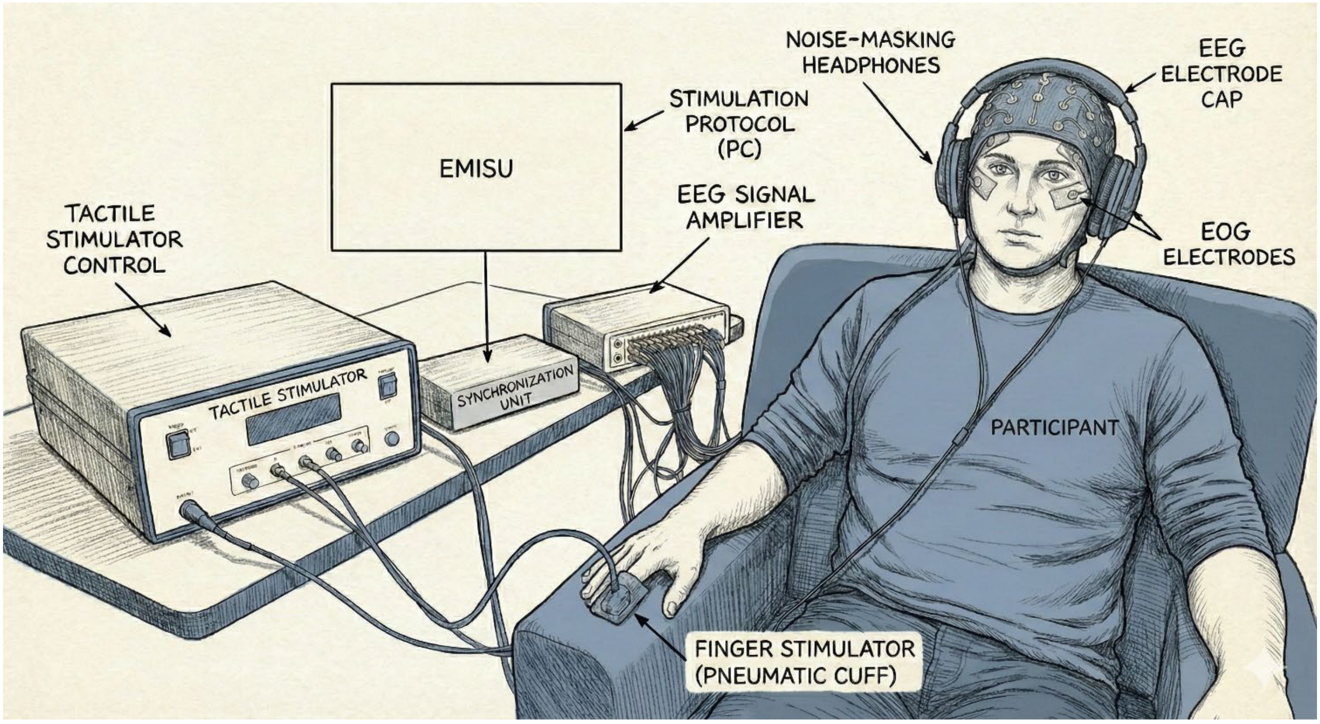


Figure 1. Experimental setup for tactile stimulation and EEG recording.

The participant was seated in a comfortable chair during the experiment. The EEG signals were recorded via an EEG cap. EEG signals were amplified using an EEG signal amplifier and recorded continuously throughout the experiment. Non-painful tactile stimulation was applied to the participant's index finger using the tactile stimulator. The stimuli were simultaneously marked on the EEG recording via the EMISU. Headphones were used to eliminate auditory cues.

Raw EEG data were processed using Neuroscan 4.5 software (Compumedics Neuroscan Inc.). Ocular artifacts and eye blinks were extracted employing a method based on independent component analysis. Continuous data were subsequently segmented into epochs, which were time-locked to the onset of the tactile stimuli, spanning from 1000 ms before the stimulus to 2000 ms after the stimulus. Epochs containing artifacts exceeding 50 μV were manually reviewed and excluded. The remaining epochs underwent filtering with a bandpass filter (0.5–48 Hz) characterized by a 12-dB/octave slope and zero-phase shift. Baseline correction was applied using the prestimulus interval. Finally, individual average waveforms were generated for each experimental condition.

Amplitude and latency values of the brain responses were manually measured by identifying negative peak and positive peak. Positive peak was defined as the late positive component of the somatosensory vertex complex (P300), occurring within an approximate latency range of 250–350 ms

Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

(12,32). Although this component temporally overlapped with the conventional P300 time window, it was not interpreted as a classical P300, as the experimental paradigm did not include attentional manipulation, task-related demands, or target–nontarget discrimination. The peak-to-peak maximum (PPmax) amplitude was calculated as the difference between the maximum positive peak and the preceding minimum negative peak (PPmax = $Amp_{P300} - Amp_{N200}$).

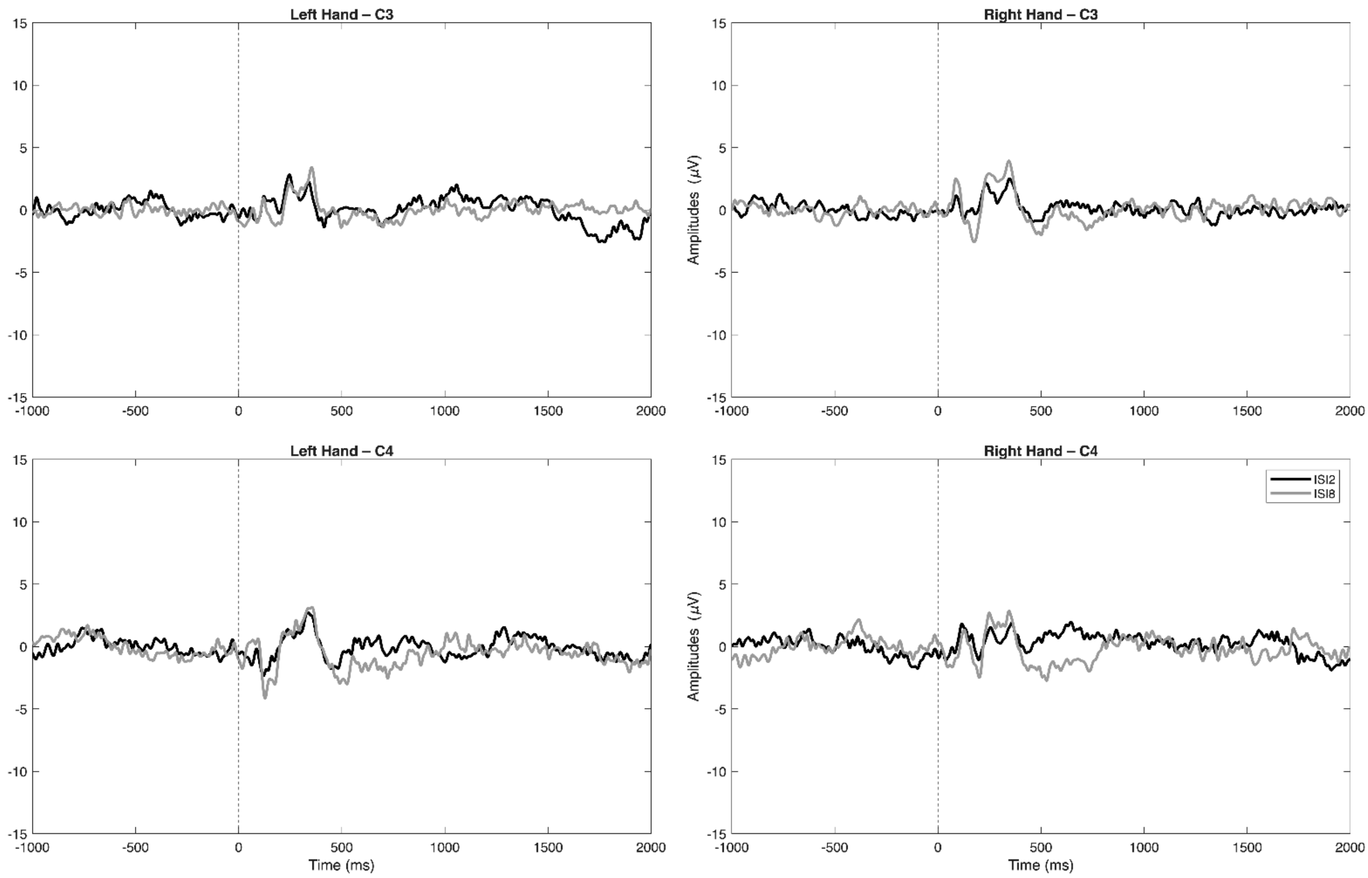
Statistical analysis

To establish the minimum sample size needed for repeated-measures analysis of variance (ANOVA) with a within-subjects design, a priori power analysis was performed using G*Power software version 3.1.9.7 (33). The analysis was based on a medium effect size (f = 0.25), α error probability of 0.05, and desired statistical power ($1 - \beta$) of 0.95. The findings suggested that at least 14 participants were necessary to reach the desired power level. To ensure strong statistical reliability, the study included 19 participants.

Statistical analyses were conducted using IBM SPSS Statistics 24 (IBM Corp., Armonk, NY, USA). To investigate the effects of ISI (short vs. long), electrode location (C3 vs. C4), and hand dominance (right vs. left) on PPmax amplitudes, three-way (2 × 2 × 2) repeated-measures ANOVA was employed. All factors were treated as within-subject variables. In cases where the assumption of sphericity was violated, Greenhouse–Geisser correction was utilized. Effect sizes were reported as partial eta-squared ($\eta 2$) values and a significance threshold of $p < 0.05$ was established for all analyses.

Results

The ANOVA results indicated a significant main effect of ISI on PPmax amplitudes [$F(1, 18) = 20.87$, $p < 0.001$, $\eta p2 = 0.54$]. This suggests a substantial difference in PPmax amplitudes between the ISI conditions ISI_S and ISI_L (Figure 2). Pairwise comparisons revealed that PPmax amplitudes were significantly higher in the ISI_L condition compared to the ISI_S condition (MD= 4.038, SE = 0.884, $p < 0.001$).



Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

Figure 2. Somatosensory evoked potentials were averaged and recorded from electrodes positioned on the contralateral (C3) and ipsilateral (C4) sides in response to non-painful touch stimuli applied to the index fingers of both hands. The horizontal axis represents time in milliseconds, while the vertical axis displays amplitude in microvolts. Tactile stimuli were administered at 0 ms, as indicated by the dashed vertical line in all graphs. The black line depicts responses during the 2-s interval (ISI_S), whereas the gray line depicts responses during the 8-s interval (ISI_L).

These results support the modulatory effect of the ISI on PPmax responses.

In contrast, the main effect of electrode location did not reach statistical significance [$F(1, 18) = 0.73$, $p = 0.405$, $\eta p^2 = 0.04$], nor did the main effect of hand dominance [$F(1, 18) = 1.30$, $p = 0.269$, $\eta p^2 = 0.07$] (Figure 3). Additionally, no significant two-way interactions were observed between ISI and electrode location [$F(1, 18) = 2.22$, $p = 0.154$, $\eta p^2 = 0.11$], ISI and hand dominance [$F(1, 18) = 0.42$, $p = 0.527$, $\eta p^2 = 0.02$], or electrode location and hand dominance [$F(1, 18) = 0.57$, $p = 0.459$, $\eta p^2 = 0.03$]. Furthermore, the three-way interaction among ISI, electrode location, and hand dominance was not statistically significant [$F(1, 18) = 1.36$, $p = 0.259$, $\eta p^2 = 0.07$].

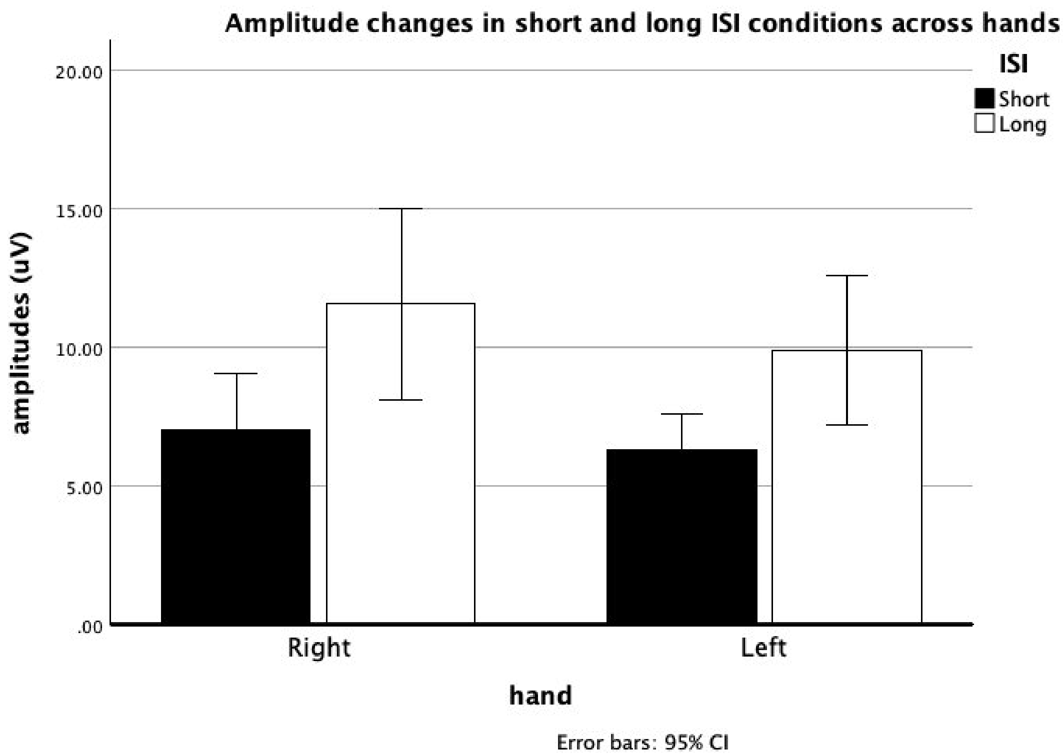


Figure 3. Bars represent mean PPmax amplitudes (µV) for right- and left-hand stimulation under short (2-s interval) and long (8-s interval) ISI conditions. Error bars indicate 95% confidence intervals. Black bars denote the short ISI and white bars denote the long ISI.

Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

Discussion

This study aimed to examine how static ISI manipulation influences cortical somatosensory responses to non-painful tactile stimulation applied to dominant and non-dominant hands. Our results revealed that the ISI significantly modulated PPmax amplitudes, whereas hand dominance did not have a significant effect on PPmax responses. Under both conditions, where non-painful tactile stimuli were applied to fingertips of both hands, the PPmax amplitudes obtained for the long ISI (ISI_L) condition were found to be higher compared to the short ISI (ISI_S) condition. Despite methodological differences including distinct stimulus types (vibrotactile vs. tactile), different recording modalities (MEG vs. EEG), and a focus on earlier components (P50 vs. our PPmax component), previous studies have similarly reported increased amplitudes for longer ISIs (11,17,22,34). These results emphasize the importance of ISI parameters in shaping somatosensory responses, as demonstrated in studies of somatosensory gating where varying ISIs systematically influenced response suppression (4,6).

The present study focused on the PPmax amplitude measured between the N2 and P3 peaks, which are commonly associated with the cognitive processing of tactile stimuli. Late somatosensory event-related potential (ERP) components, particularly the vertex complex, have been consistently associated with adaptive modulation in the presence of repeated stimulation in the brain. The strong ISI-dependent modulation of our PPmax component, likely corresponding to the late vertex potentials N2/P2, supports this framework (12). In our previous study, we established that PPmax amplitudes, measured between the N200 and P300 peaks, progressively increased with extended ISIs. That investigation revealed that PPmax amplitudes, determined as the peak-to-peak difference between N2–P3 and P3–N4, exhibited a tendency to increase with longer ISIs (11). Several studies have reported that late somatosensory ERP components exhibit repetition-related attenuation, a phenomenon commonly discussed in relation to neural habituation (6). However, the present study was not designed to directly assess habituation mechanisms and the current findings should be interpreted at a phenomenological level. Future studies employing extended electrode coverage are required to further explore the neural mechanisms underlying these effects.

While many studies have shown that longer ISIs lead to increased somatosensory response amplitudes, this study builds on that research by systematically exploring this effect under constant ISI conditions and directly comparing the stimulation of dominant and non-dominant hands in the same individuals. Our findings indicated no significant difference in PPmax amplitudes between the dominant (right) hand and non-dominant (left) hand within the same participant. A key discovery of this study is that, under static ISI conditions, there was no notable difference in brain responses between the right and left hands. However, some earlier research suggested that ISI manipulations do not consistently alter the amplitude difference between hands, with the dominant hand generally exhibiting higher responses (34–36), even during sleep (37). The results of the present study demonstrate no difference in ipsilateral and contralateral amplitude responses to tactile stimulation with a static ISI in both the dominant and non-dominant hands of the same participant.

The cortical processing of tactile stimuli is typically characterized by contralateral dominance (38). Accordingly, previous studies employing randomized or variable ISIs have reported amplitude differences between contralateral and ipsilateral somatosensory responses, indicating preserved hemispheric lateralization (19). Notably, such lateralized processing has also been observed during non-painful tactile stimulation. In the present study, ipsilateral and contralateral responses were directly compared using C3 and C4 electrodes during stimulation of the right and left hands under static ISI conditions. The analysis revealed no significant differences between contralateral and ipsilateral PPmax amplitudes. Consistent with our previous findings obtained under similar static ISI conditions (39), the present results suggest that temporally regular stimulation may be associated with reduced hemispheric differentiation at the level of PPmax amplitudes, without allowing inferences regarding the underlying neural mechanisms. Taken together, this study indicates that temporal regularity introduced by static ISIs is associated with similar PPmax response amplitudes across hemispheres, in contrast to the lateralized patterns commonly reported under randomized or variable ISI paradigms.

Importantly, this observation should be interpreted at a phenomenological level, as the current experimental design does not allow conclusions regarding habituation mechanisms, attentional control, or higher-order cognitive processes.

Limitations

The most robust responses to tactile stimuli are generated by activity within the primary somatosensory cortex of the contralateral hemisphere, specifically in Brodmann area 3b. Therefore, electrodes C3 and C4 best represent this region. Consequently, analyses were conducted using only those electrodes in the present study. This design was intended to evaluate the main response foci rather than show the complete topographic distribution.

Conclusion

The present findings demonstrate that the ISI systematically modulates PPmax amplitudes, with larger responses observed at longer ISIs. Moreover, the absence of significant differences between right- and left-hand responses within the same participants suggests that, under static ISI conditions, PPmax amplitudes are expressed similarly irrespective of hand dominance.

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Ethical approval
The study was approved by Dokuz Eylül University Non-Interventional Research Ethics Committee ethics committee of the university (Decision No:2023/04-29, Date:15/02/2023).
Data availability statement
Due to legal and ethical considerations, the raw and processed data necessary to replicate the aforementioned findings cannot be disclosed at this time.
Conflicts of interest and source of funding
None declared.

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Developments and Experiments in Health and Medicine
Year: 2026
Volume: 40
Issue:3
RESEARCH ARTICLE
Pages:356- 365

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