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Test–retest reliability of concurrently recorded steady-state and somatosensory evoked potentials in somatosensory sustained spatial attention

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ABSTRACT

We investigated the test–retest reliability of sustained spatial attention modulation of steady-state somatosensory evoked potentials (SSSEPs) and the N140 component of the somatosensory evoked potentials (SEPs). Participants attended to one or both hands to perform a target detection task while concurrent mechanical vibrations were presented for 4500 ms to both hands in two recording sessions. Results revealed that the amplitude and the attentional modulation of SSSEPs had high test–retest reliability, while the test–retest reliability for the N140 component was low. SSSEPs for stimuli with focused and divided attention had about the same amplitude. For the N140 component only the stimuli with focused attention were significantly enhanced. We found greater habituation effects for the N140 compared to SSSEP amplitudes but attentional modulation was unaffected in both signals. Given the great test–retest reliability of SSSEP amplitude modulation with attention, SSSEPs serve as an excellent tool for studying sustained spatial attention in somatosensation.

1. Introduction

The steady-state somatosensory evoked potential (SSSEP) enables us to study neural mechanisms of sustained spatial attention in the sense of touch under concurrent mechanical vibratory stimulation to multiple body parts (Adler, Giabbiconi, & Müller, 2009; Breitwieser, Pokorny, Neuper, & Müller-Putz, 2011; Giabbiconi, Dancer, Zopf, Gruber, & Müller, 2004; Giabbiconi, Trujillo-Barreto, Gruber, & Müller, 2007), and also it is a powerful tool for driving Brain Computer Interfaces (BCIs; cf. Breitwieser, Kaiser, Neuper, & Müller-Putz, 2012). The SSSEP is a sinusoidal electrophysiological brain response which is elicited by mechanical vibrotactile stimulation delivered to the glabrous skin, and it has the same temporal frequency as the driving stimulus, probably include higher harmonics (Adler et al., 2009; Giabbiconi et al., 2004, 2007; Ishibashi et al., 2000; Kelly & Folger, 1999; Kelly, Trulsson, & Folger, 1997; Snyder, 1992; Tobimatsu, Zhang, & Kato, 1999). The amplitudes of the SSSEP maximize in the 20 Hz range (Snyder, 1992; Tobimatsu et al., 1999), which is the so-called flutter range. Previous studies showed that SSSEP amplitudes at the driving frequencies of the vibratory stimulation increased significantly when participants attended to the stimulated location compared to when the location was ignored (Adler et al., 2009; Giabbiconi et al., 2004, 2007).

Embedding transient events into the ongoing vibrotactile stimulus stream allows one to concurrently analyze somatosensory evoked potentials (SEPs) elicited by such events (Adler et al., 2009). SEPs provide a detailed time course of individual post-stimulus processing at different stages in the somatosensory pathway (Eimer & Forster, 2003a, 2003b; Forster & Eimer, 2004, 2005; Kida, Nishihira, Wasaka, Nakata, & Sakamoto, 2004a; Zopf, Giabbiconi, Gruber, & Müller, 2004). Previous research investigating spatial attention in touch revealed that the processing of stimuli presented at the attended location was facilitated compared to their counterparts presented at the ignored location. This facilitation was reflected in behavioral aspects, such as faster reaction times and higher accuracy to stimuli presented to the attended location (Forster & Eimer, 2005; Forster & Gillmeister, 2011; Johansen-Berg & Lloyd, 2000; Spence & McGlone, 2001), as well as in electrophysiological aspects, such as enhanced components in the SEP (P100, N140 and late positive component, LPC) to attended stimuli (Eimer & Forster, 2003a, 2003b; Forster & Eimer, 2004, 2005; Kida et al., 2004a; Kida, Nishihira, Wasaka, Nakata, & Sakamoto, 2004b; Zopf et al., 2004) and SSSEPs (Adler et al., 2009; Giabbiconi et al.,

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2004, 2007). While SSSEPs were considered as reflecting low-level, early stimulus processing (Giabbiconi et al., 2007), SEPs, such as the aforementioned P100 and N140 components, were seen as a signature of in-depth subsequent stimulus processing in somatosensory processing stages (Eimer & Forster, 2003a). Obviously, concurrent analysis of SSSEPs and SEPs provides complementary information on neural mechanisms of spatial attention allowing one to receive a more conclusive picture of these neural dynamics in different processing stages compared to an isolated analysis of just one of these brain responses.

Given the power of that approach to uncover basic neural principles of spatial attention in somatosensation, along with its potential for application such as in BCIs, it is surprising that there are a very limited number of studies investigated the reliability of attentional modulations of these measures. So far only one study assessed the stability of SSSEPs elicited by vibrotactile stimulation (Breitwieser, Kaiser, Neuper, & Müller-Putz, 2012). In this study, all five fingers on the right hand were separately stimulated in a random order 10 times for 2 s in each trial when subjects were performing a visual task in two recording sessions. The stimulation was a vibration with a 200 Hz carrier frequency modulated by a rectangular signal with frequencies ranging from 17 to 35 Hz in 2 Hz steps. Results of this study revealed that the relative band power of SSSEPs was stable between sessions. Animal studies using the method of optical intrinsic signal imaging revealed that the increase in absorbance evoked by 25 Hz flutter remained relatively constant within a continuous stimulation period of 3–30 s (Tommerdahl, Delemos, Whitsel, Favorov, & Metz, 1999). However, the reliabilities of the SSSEP amplitude within a longer duration of continuous stimulation and the attentional modulation of SSSEP amplitudes are still unknown. Given the use of SSSEPs as a measure of sustained spatial attention in various types of studies (including applications in BCIs), it is important to know to what extent SSSEP amplitudes and amplitude modulations exhibit sufficient test–retest reliability. The same is true when one looks at the N1 component of the SEP, which is the most commonly reported component when the experimental task involved attention selection between two hands while mechanical transient stimuli were presented (cf. Adler et al., 2009; Eimer & Forster, 2003a; Forster & Eimer, 2004, 2005; Forster & Gillmeister, 2011; Zopf et al., 2004). Blom and colleagues (Blom, Wiering, & van der Lubbe, 2012) found that the N1 component evoked by electrocutaneous stimuli exhibited habituation effects with reduced amplitudes between sessions completed within a day, but the habituation was unaffected by attention. Habituation of the SEP amplitudes during repeated mechanical stimulation was also found in the latency overlapping the P1 window (Angel, Quick, Boylis, Weinrich, & Rodnitzky, 1985). Given the wealth of studies that used the N1 component of the SEP as a marker for basic neural attentional mechanisms, the test–retest reliabilities of amplitudes of the N1 component and attentional modulation are of particular interest. Thus, the present study aimed at investigating the test–retest reliability of sustained spatial attention modulation in SSSEPs for concurrent mechanical vibrotactile stimulation to two hands within a trial or between two recording sessions, along with the test–retest reliability of the N1 component of the SEP. To this end, participants went through two recording sessions, in which they performed a detection task for rare events embedded in the to-be-attended vibratory stream(s) when concurrent vibrations were presented for 4.5 s to the index finger on both hands.

A common way to investigate mechanisms of spatial attention is to employ a typical Posner design (Posner & Cohen, 1984). Historically, the Posner design was applied first in the visual domain by presenting participants spatial attention direction cues for example in form of arrows that pointed either to the direction where a stimulus occurred (valid cues), or the stimulus occurred in the opposite visual hemifield (invalid cues). By comparing reaction times of validly and invalidly cued trials with neutral cues (arrows point in both directions), one can calculate costs and benefits of covert shifts of attention to the cued location. On the neuronal level, Luck and co-workers (Luck, Hillyard, Mouloua, Woldorff, & Hawkins, 1994) showed for the visual modality that temporal early stages of visual stimulus processing exhibited a mixed response of facilitation of the to-be-attended and suppression of the to-be-ignored location. The Posner design was also employed in the somatosensory modality. Forster and Eimer (2005) investigated the facilitation and attenuation effects of tactile spatial attention contributed to attention modulations in early components of SEPs. As in the classical Posner design, they presented visual arrow cues that were valid in 80% of the trials. Subjects were instructed to respond to short vibrotactile target stimuli and not to respond to non-targets that were presented either to the left or the right index finger. Subsequent analysis was based on SEPs elicited by non-targets to avoid the influence of motor responses to targets. Validly cued trials were compared to invalidly cued trials for the overall effects of tactile-spatial attention. Validly cued trials were compared to neutrally cued trials to reveal benefits (enhancement) in processing, whereas invalidly cued trials were compared to neutrally cued trials to illustrate costs (suppression) in processing. They found that the contribution of costs and benefits to the attention modulation in the N140 component were the same, while at longer latencies they found mainly an effect of costs. In a follow-up study, visual cues were replaced by vibratory somatosensory cues delivered to the nape of the neck (Forster & Gillmeister, 2011). Furthermore, the authors instructed their subjects to attend to both hands in neutrally cued trials what ensured that subjects were attending to both locations, rather than attending to one location (perhaps the cued location of the preceding trial) and then shifting (or keeping) attention to (at) the location where the stimulus occurred. With these changes, the attention modulation in the N140 component was primarily dependent on benefits, whereas the longer latency modulations, in line with the previous study, were mainly dependent on costs. The authors discussed that different findings in the N140 component might be related to the modality of attention cues, which was visually presented in the first study and tactilely presented in the latter one. Given these somewhat inconclusive findings with regard to underlying neural mechanisms of the modulation in the N1 component, we adopted a similar design of the aforementioned studies conducted by Forster and colleagues (Forster & Eimer, 2005; Forster & Gillmeister, 2011), in which participants were instructed either to focus attention to one hand and to react to events presented at the to-be-attended hand while ignoring events presented to the other hand, or to attend and respond to events presented to both hands. On the other hand, the differences in the interpretation of the "neutral" condition between Forster and colleagues' studies and the present one should be noted. Forster and Gillmeister (2011) considered trials when subjects were cued by non-directional cues and instructed to attending both hands simultaneously as a "neutral" condition and revealed benefits and costs of spatial attention by comparing validly and invalidly cued trials with the neutral condition. However, we considered that when participants were attending to both hands, they had divided attention to two locations simultaneously. Thus, the difference between conditions when one hand and both hands were attended was conceptualized as the facilitation of focused attention over divided attention, while the difference between attended conditions (both focused and divided attention) and the ignored condition was considered as the enhancement of processing of sustained spatial attention.

To summarize, the present study aims to investigate the test–retest reliabilities of the sustained spatial attention modulation of SSSEPs and the N1 component under concurrent vibratory stimulation in the 20 Hz range and the facilitation of sustained