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Review

Tactile stimulation interventions: Influence of stimulation parameters on sensorimotor behavior and neurophysiological correlates in healthy and clinical samples

Franca H. Parianen Lesemann[a,b], Eva-Maria Reuter[b,d], Ben Godde[b,c,*]

[a] Department of Social Neuroscience, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[b] Jacobs Center on Lifelong Learning and Institutional Development, Jacobs University Bremen, Bremen, Germany
[c] AGEACT Research Center, Jacobs University Bremen, Bremen, Germany
[d] Institute of Sport science, University of Rostock, Rostock, Germany

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ABSTRACT

The pure exposure to extensive tactile stimulation, without the requirement of attention or active training, has been revealed to enhance sensorimotor functioning presumably due to an induction of plasticity in the somatosensory cortex. The induced effects, including increased tactile acuity and manual dexterity have repeatedly been observed in basic as well as clinical research. However, results vary greatly in respect to the strength and direction of the effects on the behavioral and on the brain level. Multiple evidences show that differences in the stimulation protocols (e.g., two vs. multiple stimulation sites) and parameters (e.g., duration, frequency, and amplitude) might contribute to this variability of effects. Nevertheless, stimulation protocols have not been comprehensively compared yet. Identifying favorable parameters for tactile stimulation interventions is especially important because of its possible application as a treatment option for patients suffering from sensory loss, maladaptive plasticity, or certain forms of motor impairment. This review aims to compare the effects of different tactile stimulation protocols and to assess possible implications for tactile interventions. Our goal is to identify ways of optimizing stimulation protocols to improve sensorimotor performance. To this end, we reviewed research on tactile stimulation in the healthy population, with a focus on the effectiveness of the applied parameters regarding psychophysiological measures. We discuss the association of stimulation-induced changes on the behavioral level with alterations in neural representations and response characteristics.

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* Corresponding author at: Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany. Tel.: +49 4212004760.
E-mail address: b.godde@jacobs-university.de (B. Godde).

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1. What is repetitive tactile stimulation and where is it applied?

Since the seminal work of Merzenich and co-workers in the 1980ies (e.g., Merzenich et al., 1984) the remarkable plasticity of the adult somatosensory cortex has been revealed in numerous studies by active manipulation of tactile stimulation conditions in monkeys (Allard et al., 1991; Armstrong-James et al., 1994; Clark et al., 1988; Jenkins et al., 1990). Also in humans whose regular tactile input differs from that of the general population, e.g., blind Braille readers (Sterr et al., 1998), the differences in sensory input are accompanied by altered organization of somatosensory cortical representations. Hebbian type synaptic mechanisms seem to play a major role in this kind of reorganization (e.g., Beste and Dinse, 2013; Dinse and Boehmer, 2002). In order to systematically study somatosensory cortical plasticity on the neural and behavioral level, Godde et al. (1996, 2000) introduced a paradigm of peripheral associative tactile stimulation. This paradigm was characterized by several hours of simultaneous repetitive tactile stimulation (rTS) of separated receptive fields on the skin and was driven by two basic assumptions. Firstly, extensive stimulation of separated locations on the skin should result in hebbian-like synchronous coactivation of respective neural afferents and cortical neurons. Secondly, this enduring coactivation should induce brain plasticity in terms of neural response characteristics and cortical topography. The authors revealed that induced cortical changes were associated with changes in tactile perceptual abilities comparable to those occurring after application of active perceptual learning paradigms. Since then, many studies that used different variants of tactile stimulation interventions revealed supportive evidence that the spatiotemporal pattern and frequency of tactile stimulation protocols were decisive for somatosensory cortical plasticity in terms of neural excitability, cortical topography, as well as tactile performance (Beste and Dinse, 2013; Dinse et al., 1996; Kalisch et al., 2007). Moreover, similarities of rTS induced plasticity to synaptic plasticity in terms of long term potentiation (LTP) or long term depression (LTD) have been revealed by cellular and pharmacological studies (Dinse et al., 2003a,b; Kalisch et al., 2007). rTS has the advantage of being non-invasive and relatively easy and convenient to apply. This allows for self-administered and home based application as well as for clinical applications (e.g., Dewald et al., 1996; Flor et al., 2001; Levin and Hui-Chan, 1992; Pascual-Leone et al., 2005).

Importantly, the results of rTS based effects vary between studies. Part of this variability might rely on stimulation parameters, including the duration and amount of administration (Kalisch et al., 2010). Thus, it is of particular importance to determine which stimulation protocols are most effective. This review aims to compare different rTS paradigms in humans and their effects on the neural and behavioral level. At last, we will propose some general guidelines for effective rTS protocols.

2. Different stimulation protocols

An overview of the most frequent stimulation protocols and the applied parameters, respectively stimulation devices is given in Table 1. Table 2 provides detailed information about studies using rTS to induce somatosensory changes on the behavioral and/or neurophysiological level. The applied parameter and observed effects of these rTS studies are also listed in Table 2.

In the first experiments reported by Godde et al. (1996, 2000) stimulation with single-pulses for several hours was applied at a mean frequency of 1–1.7 Hz and variable interstimulus intervals. This type of stimulation will be referred to as single-pulse stimulation in the following. More recently, stimulation paradigms with frequencies of about 20 Hz and inter-burst intervals of about 5 s (in the following termed burst stimulation) allowed reduction of stimulation duration to less than half an hour (Freyer et al., 2012, 2013; Kalisch et al., 2007; Tossi et al., 2013). Even higher stimulation frequencies of 50 Hz, for 30 min have been applied in some studies, including burst like and continuous stimulation protocols (Christova et al., 2011; Golaszewski et al., 2010; Kaelin-Lang et al., 2002).

Most studies used rTS on the fingers by stimulating either the tip of one finger, (Godde et al., 1996, 2003; Hodzic et al., 2004; Pleger et al., 2001, 2003) two- or more adjacent fingers (e.g., Dinse et al., 2006; Höffken et al., 2007; Kalisch et al., 2007, 2008; Pilz et al., 2004), or rather the whole hand simultaneously with a specific glove to maximize the effect of coactivation (Golaszewski et al., 1999, 2004). Few studies also stimulated other body parts, such as the palm or foot (Christova et al., 2012; Peurala et al., 2002). If multiple fingers or body parts were stimulated, some studies applied stimulation simultaneously to all body parts, whereas others stimulated them asynchronously (Höffken et al., 2007; Huse et al., 2001; Kalisch et al., 2007; Kowalewski et al., 2012). Irrespectively of the stimulation site, the area of stimulation needs to be sufficiently large. Stimulating only a single “point-like” location of the skin has been found to be insufficient to induce plastic changes (Pleger et al., 2003; Ragert et al., 2008). Besides tactile stimulation, direct transcutaneous electrical stimulation (TENS) of the median, peroneal, radial and/or the ulnar nerve, respectively, was applied to activate a broad population of the sensory afferents and to induce somatosensory plasticity (e.g., Adak and Göksoy, 1998; Ng and Hui-Chan, 2009; Tinazzi et al., 2005). Although this is not tactile stimulation in the proper sense, rationales behind these protocols as well as the induced effects are similar. Most TENS studies used stimulation durations of 2 h applied at 10 Hz. All stimulation methods have in common that they are supposed to affect tactile perception and somatosensory cortical processing. Irrespectively of the stimulation protocol, the effects are highly specific for the stimulated body part and hardly spread to other parts of the body. However, some forms of rTS cause opposite effects on the neurophysiological as well as the behavioral level (see Table 2).