



The effect of movie-watching on electroencephalographic responses to tactile stimulation

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ABSTRACT

Movie-watching is becoming a popular acquisition method to increase compliance and enable neuroimaging data collection in challenging populations such as children, with potential to facilitate studying the somatosensory system. However, relatively little is known about the possible crossmodal (audiovisual) influence of movies on cortical somatosensory processing. In this study, we examined the impact of dynamic audiovisual movies on concurrent cortical somatosensory processing using electroencephalography (EEG). Forty healthy young adults (18–25 years) received passive tactile fingertip stimulation while watching an “entertaining” movie and a novel “low-demand” movie called ‘Inscapes’ compared to eyes-open rest. Watching a movie did not modulate properties of early or late somatosensory-evoked potentials (SEPs). Similarly, no crossmodal influence on somatosensory adaptation, denoted by a reduction in SEP amplitude with repetitive tactile stimulation, was found. The prominent oscillatory responses in the alpha and beta frequency bands following tactile stimulation differed as a function of viewing condition, with stronger alpha/beta event-related desynchronization (ERD) during movie-watching compared to rest. These findings highlight that movie-watching is a valid acquisition method during which SEPs can be measured in basic research and clinical studies, but that the attentional demands of movies need to be taken into account when performing oscillatory analyses.

1. Introduction

Evoked somatosensory responses, including somatosensory-evoked potentials (SEPs) and multispectral oscillatory neural responses, measured using electroencephalography (EEG) can provide useful information about the nature, organization and timing of neural responses that subserve the processing of touch. Different SEP components can be discerned, with early components thought to reflect unconscious and conscious processing of stimulus features and later components reflecting the perceptual and cognitive processing of stimuli (Allison et al., 1992, 1989; Desmedt et al., 1983; Kitazawa, 2002; Libet et al., 1967; Schubert et al., 2006). Similarly, somatosensory stimulation evokes frequency-specific decreases and increases in oscillatory brain activity that have been tied to the processing of this information (Bardouille

et al., 2010; Cheyne et al., 2003; Gaetz and Cheyne, 2006; Haegens et al., 2012; Salenius et al., 1997; van Ede et al., 2014).

Prolonged exposure to invariant stimulation typically leads to a reduction of neural response strength (Angel et al., 1985; Hsiao et al., 2013; McLaughlin and Kelly, 1993; Wiesman et al., 2017). This well-studied neurophysiological process, commonly referred to as “adaptation” or “sensory gating”, is thought to reflect ‘filtering’ of redundant sensory information in order to prevent excessive environmental stimulation from overloading shared neural resources (Wang et al., 2010; Wark et al., 2008). Adaptation or sensory gating plays an important role in daily life, and has been shown to be disrupted in a wide range of disorders such as autism and schizophrenia (Andrade et al., 2016; Lawson et al., 2015; Matsuzaki et al., 2014; Puts et al., 2014; Thoma et al., 2007; Tommerdahl et al., 2007). Importantly, SEPs, their

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adaptation and oscillatory neural changes can provide insight into neural processing of somatosensory information without the need for active participation of the individual, thus making them an invaluable tool for the study of somatosensory function in pediatric populations and in disorders involving altered somatosensory processing (i.e. autism, multiple sclerosis) (Cascio et al., 2015; Cruccu et al., 2008; Doria-Lamba et al., 2009; Fagan et al., 1987).

However, compliance during an EEG recording can be challenging for these populations. In particular, young children and children with neurodevelopmental disorders (NDDs) may show poor cooperation, often necessitating sedation for clinical assessment which can produce marked changes in event-related neural activity (for review see (Banoub et al., 2003; Fagan et al., 1987)). To increase compliance and avoid the need for sedation, movies have become a popular acquisition method to distract and entertain participants during neuroimaging research data collection (Gabrielsen et al., 2018; Vanderwal et al., 2019). Movies elicit genuine sensory, social and emotional percepts (Hasson et al., 2008) and their power of engagement is pivotal to their success and popularity. However, despite their growing use in pediatric and clinical neuroimaging research, to the best of our knowledge, no studies have assessed the potential effect of movie-watching without systematic touch-related content on various stages of cortical somatosensory processing.

Although the somatosensory cortex primarily processes tactile, proprioceptive and nociceptive information, it also receives input from brain regions that are known to respond to visual and auditory stimuli (for review see (Keysers et al., 2010)). In line with this anatomical consideration, studies of brain activity while participants observe other people being touched (Blakemore et al., 2005; Ebisch et al., 2008; Keysers et al., 2004; Schaefer et al., 2009), performing an action (Dinstein et al., 2007; Filimon et al., 2007; Gazzola and Keysers, 2009; Voisin et al., 2010) or experiencing somatic pain (Botvinick and Cohen, 1998; Bufalari et al., 2007; Voisin et al., 2011) and hearing action sounds (Gazzola et al., 2006; Ricciardi et al., 2009) consistently show vicarious activation in the somatosensory cortex, suggesting that non-primary sensory modalities can modulate somatosensory processing.

These crossmodal effects are likely linked to increased attention to the corresponding stimulated location. Attentional modulation of somatosensory activity has been demonstrated in animal and human imaging studies (for review see (Burton and Sinclair, 2000; Johansen-berg and Lloyd, 2000)), with attention directed towards somatosensory stimulation typically resulting in enhanced evoked neural activity. Accordingly, movies are likely to direct attention away from concurrent somatosensory stimulation and might thus, reduce evoked neural responses. In light of these findings, it seems likely that cortical somatosensory processing would be affected by movie-watching and revealing the direction of such effects (i.e. enhancing/suppressing) is essential to avoid misinterpretation of results in basic and clinical studies.

Here, we investigated the effect of movie-watching, as an acquisition method, on the processing of somatosensory signals. This is of particular importance as movie-watching may facilitate data collection in challenging populations such as individuals with NDDs, who may not otherwise tolerate a research EEG procedure. For this purpose, SEPs elicited by passive tactile stimulation were examined when participants watched movies with and without auditory and social content relative to 'movie-free' rest.

2. Methods

2.1. Participants

Forty healthy young adults (aged 18–25 years) took part in this study. Six participants were excluded due to technical issues and artifact contamination during EEG recording. All included participants ($N = 34$, mean age 21 ± 1 years, 13 females) had normal or corrected-to-normal vision and fulfilled the following inclusion criteria: no history of neurological, psychiatric or neurodevelopmental disease, no history of major

head trauma or loss of consciousness of >5 min, and no use of psychotropic medications. All participants were righthanded as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The study was approved by the University of Calgary Conjoint Health Research Ethics Board (REB16-0576). All participants gave written informed consent in accordance with the Declaration of Helsinki.

2.2. Procedure

Participants received passive tactile stimulation of the fingers while they completed three viewing conditions: 1) watching a cartoon movie of their choice ('Finding Nemo', Disney and Pixar, 2003; $N = 13$; 'Happy Feet', Warner Bros. Pictures, 2006; $N = 5$; 'Over the Hedge', DreamWorks Animation, 2006; $N = 2$; 'Ice Age', 20th Century Fox, 2002; $N = 9$; 'Spirit', DreamWorks Animation, 2002; $N = 3$), 2) watching an abstract movie called 'Inscapes', and 3) 'movie-free' rest (Fig. 1A).

All viewing conditions were presented on a 15-inch HD monitor (Dell Inspiron 15 3000 Series, display dimensions 1366×768 mm, resolution 1366×768 pixels, refresh rate 60 Hz). Inscapes is a novel 7-min movie paradigm featuring a series of non-verbal, non-social, slowly evolving abstract shapes without scene-cuts or sudden pans and zooms (www.headspacestudios.org; a detailed description can be found in (Vanderwal et al., 2015)). For the duration of the passive tactile stimulation (typically lasting ~ 15 min), the cartoon movie was played continuously with auditory content and the volume adjusted to each participant's personal preference level, while the 7-min Inscapes movie was played on repeat (typically two repetitions) and without sound. We chose Inscapes without sound as it eliminates some important features of typical movies such as social, semantic and auditory content and thus, in theory provides an intermediate level of crossmodal sensory integration between movie and rest. During the rest condition, a black fixation cross centered on a dark grey background was presented. For all viewing conditions, participants were instructed to focus on the visual content of the movies or fixation cross provided. The order of viewing conditions was counter-balanced across participants to account for order effects.

2.3. Tactile stimuli

During each viewing condition, participants received passive tactile stimuli to the right digit 2 (RD2; index finger) and digit 3 (RD3; middle finger) simultaneously (Fig. 1C). The rationale for stimulating two fingers simultaneously in this study was that this approach activates a larger cortical somatosensory area and thus, results in a higher signal-to-noise ratio. Somatosensory mechanical stimuli were generated using a customized Brain Gauge two-digit vibrotactile stimulator (Cortical Metrics, North Carolina, USA). Stimulus delivery was controlled by a computer running Presentation software (Neurobehavioral Systems, Berkeley, CA, USA). All stimuli were suprathreshold (frequency 25 Hz, amplitude 300 μm , duration 40 ms) and delivered to the glabrous skin using a cylindrical probe (5 mm in diameter) (Fig. 1B). Tactile stimulation consisted of two successive blocks with fifty repetitions of a 6-stimulus train in each block (300 stimuli in total in each block). Each train of 6 stimuli was separated from the next by an interval of 5 ± 0.5 s (measured from the last stimulus in a train to the first stimulus of the preceding train). Within each block, the inter-stimulus interval (ISI) within the trains of tactile stimulation was constant and set to either 1050 ms or 150 ms (Fig. 1C). The order of the long (1050 ms) and short (150 ms) ISI blocks was counterbalanced. Shorter ISIs, in which stimuli are presented close together in time, typically lead to a reduction in the cortical response amplitude, hereafter referred to as adaptation (Angel et al., 1985). Thus, while the 1050 ms ISI was used to assess the cross-modal influence of movies on somatosensory processing of individual stimuli, the 150 ms ISI allowed us to assess modulatory effects on somatosensory adaptation.

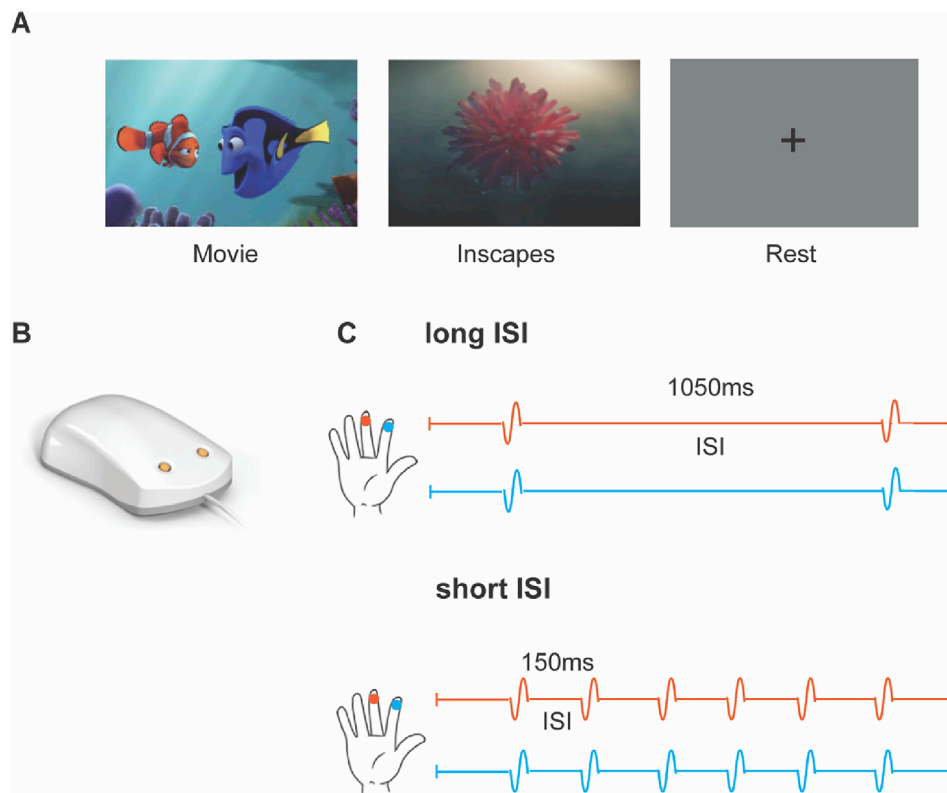


Fig. 1. Experimental design and tactile stimuli. A, Participants completed three viewing conditions during passive tactile stimulation (depicted from left to right): watching a cartoon movie with sound, a movie featuring abstract shapes called ‘Inscapes’, and eyes-open rest with a static fixation cross. B, A Brain Gauge two-digit vibrotactile stimulator was used for stimulus generation. C, Schematic of the passive tactile stimulation. Trains of 6 tactile stimuli were delivered simultaneously to the right-hand digit 2 and digit 3. In the long ISI condition stimuli were delivered further apart in time (ISI of 1050 ms), while in the short ISI condition stimuli were presented closer together (ISI of 150 ms) which typically leads to a reduction in the neural response. Each stimulus train was separated from the next by 5 ± 0.5 s. Inscapes image reproduced from (Vanderwal et al., 2015).

2.4. EEG recording

Scalp EEG was recorded at 1000 Hz using a 64-electrode geodesic sensor net (Electrical Geodesic Inc., Oregon, USA) soaked in an electrolyte solution. The impedance level was kept below 50 k Ω and the EEG signal was referenced to Cz during recording. The timing of the first tactile stimulus in a train was marked in the simultaneous EEG recording, with separate markers for each ISI condition (long, short).

2.5. Eye blink analysis

Eye blinks are an inevitable artifact source during scalp EEG recording. Especially for event-related potential (ERP) experiments, eye blinks and eye movements disturb the evoked potential and may lead to detrimental loss of trials (Croft and Barry, 2000; Gratton, 1998). To determine whether EEG data quality varied across viewing conditions (Movie, Inscapes, Rest), we semi-automatically detected and quantified participant’s eye blink and eye movement rate using the four eye electrodes of the geodesic sensor net.

For this, the raw EEG signal was filtered from 1 Hz to 30 Hz, downsampled to 250 Hz, and re-referenced to the average signal of all electrodes. To detect eye blinks, we employed the moving window peak-to-peak threshold method as implemented in the ERPLAB ‘artifact detection’ function (Lopez-Calderon and Luck, 2014). Since the amplitude of eye blinks varies between participants, the threshold was individually adjusted. Results were visually inspected and, when necessary, manually adjusted. To assess the effect of crossmodal influences (visual and auditory information) on EEG data quality, we compared the rate of eye blinks per minute between viewing conditions (3 levels: Movie, Inscapes, Rest) using a repeated-measures ANOVA.

2.6. EEG data analysis

2.6.1. Preprocessing

EEG data pre-processing and analysis were performed using EEGLAB

(version 14) (Delorme and Makeig, 2004), ERPLAB Toolbox (version 7) (Lopez-Calderon and Luck, 2014) and additional scripts written in Matlab (version R2017b). The raw EEG signal was filtered using a high-pass filter at 0.1 Hz and a low-pass filter at 45 Hz, downsampled to 250 Hz, and re-referenced to the average signal of all electrodes. Excessively noisy EEG electrodes (mean 1 ± 2 electrodes, range 0–6 electrodes) were removed and interpolated prior to re-referencing so as to not include excessive noise in the common average. Artifact correction was based on independent component analysis (ICA) using the infomax algorithm as implemented in EEGLAB (excluding the interpolated electrodes). Artifact independent components (ICs) were visually identified using SASICA (Chaumon et al., 2015) as a guideline. An average of 2.7 ± 1 ICs (range 2–5 ICs) relating to physiological artifacts (i.e. eye blinks and eye movements) were removed, and the number of ICs did not differ between viewing conditions [$F_{(2,64)} = 1.78, p = 0.178$].

The data were epoched from -50 ms to 500 ms relative to stimulus onset (0 ms), with a 50 ms pre-stimulus baseline. EEG trials were visually inspected and trials containing residual artifacts were removed. For information about data retention, please refer to section 3.1 EEG data quality.

2.6.2. SEP analysis

The artifact-free EEG data were averaged over trials and participants, and the topography examined to determine a region of interest (ROI) over the somatosensory cortex contralateral to the stimulated fingers based on electrodes that showed a major positive peak ~ 50 ms after the stimulus. Electrodes were selected from SEP data grand-averaged over all participants and viewing conditions, using the long ISI (1050 ms), for which the SEP had the strongest signal. This approach of using a collapsed localizer is an unbiased and common approach for selecting electrodes and time windows for analysis (Keil et al., 2014; Kilner, 2013; Luck and Gaspelin, 2017). The topographic plot in Fig. 3A shows the selected electrodes over the somatosensory cortex.

Visual inspection of the grand-average showed two major, well-known components associated with early somatosensory cortical

processing (P50) (Allison et al., 1989; Desmedt et al., 1983) and with more cognitive functioning such as attention and stimulus evaluation (P300 also called P3 or late positive component) (Polich, 2007). Studying these early and late components allows us to understand which stages of somatosensory processing might be affected by the visual and auditory information of movies. Time windows appropriate for each SEP component were identified from the grand-averaged SEP data as the time point at which the voltage reached ~50% of the peak amplitude (this is the optimal method for computing onset latency in many cases – see (Luck et al., 2006; Luck and Kappenman, 2009)). This resulted in a time window of 35–65 ms for the P50 and 270–340 ms (relative to stimulation, respectively) for the P300. Selected electrodes and time windows applied to all participants, viewing conditions and ISIs, and were not adjusted individually.

Subsequently, for each individual participant, the peak latency and mean amplitude for each SEP component and viewing condition was derived from the respective time windows and averaged over the ROI. The mean amplitude difference between the long (1050 ms) and short (150 ms) ISI generated the amount of adaptation in the response amplitude of the SEP component. Please note that a quantitative assessment of adaptation was only possible for the early SEP component (P50) as the time window for the later SEP component overlapped with the SEP to the subsequent stimulus in the short ISI.

2.6.3. Time-frequency analysis

A time-frequency analysis was conducted to explore whether any aspect of the oscillatory neural signal was differentially modulated by the viewing conditions. Only the long ISI (1050 ms) somatosensory stimulation trials were considered in this analysis. Artifact-free EEG data from each single trial were decomposed into their time-frequency representations (TFR) in the 1–45 Hz range using a sliding window fast Fourier transform (FFT), in which the time-series is multiplied by an Hanning window (Makeig, 1993). Power was normalized by the average spectral power in the pre-stimulus baseline period (–50–0 ms prior to stimulus) for each frequency band and shown in units of decibels ($\text{dB} = 10 \log_{10}$). For each participant, spectral power time-series were averaged over trials in the ROI selected previously in the SEP analysis, overlying the somatosensory cortex. Changes in spectral power over time were referred to as event-related desynchronization/synchronization (ERD/ERS) (Pfurtscheller and Aranibar, 1977; Pfurtscheller and Lopes Da Silva, 1999), denoting relative power decreases and increases, respectively.

To select time-frequency windows of interest that were orthogonal to potential differences in viewing conditions, we examined activity in the a priori chosen somatosensory alpha (8–13 Hz; also referred to as mu rhythm) and beta (13–30 Hz) frequency bands, grand-averaged over viewing conditions and subjects. We then chose specific time-frequency windows based on peak changes in alpha and beta activity in the averaged TFR, which revealed clear stimulation-related suppression (ERD) of alpha and beta-band activity (Fig. 5A). This information was used to optimize the alignment of time windows to capture maximum alpha (200–400 ms relative to stimulation) and beta (100–300 ms relative to stimulation) ERD. Selected time-frequency windows (dashed areas in Fig. 5A, B, and C) applied to all participants and viewing conditions, and were not adjusted individually. Subsequently, for each individual participant and viewing condition, average power change in alpha and beta activity were extracted from the respective time-frequency windows.

In addition, power was averaged across the alpha frequency range and the entire trial, and converted to absolute power ($\mu\text{V}^2/\text{Hz}$). Given that alpha power has been put forward as a generic mechanism of attentional engagement (with lower ongoing alpha power indicating greater engagement) (Cooper et al., 2003; Foxe and Snyder, 2011; Klimesch et al., 1998), comparing (ongoing) alpha power allowed us to assess whether the three viewing conditions evoked different levels of attentional engagement.

2.7. Statistical analysis

Statistical analyses were performed using SPSS (IBM SPSS Statistics, Armonk, NY, USA) and custom-written Matlab routines. One participant whose standardized SEP amplitude was more than 2.5 standard deviations from the mean was excluded from the statistical analysis. To assess the crossmodal influence of movies on properties of SEPs, separate repeated-measures ANOVAs with factor ‘viewing condition’ (3 levels: Movie, Inscapes, Rest) were used. To replicate previous neurophysiological data showing a reduction in SEP amplitude with repetitive stimulation (adaptation) (Angel et al., 1985; Hsiao et al., 2013; McLaughlin and Kelly, 1993), the mean amplitude of the early SEP component (P50) was compared in a repeated-measures ANOVA with factors ‘viewing condition’ and ISI (2 levels: long ISI, short ISI). The contrast between long versus short ISIs was included to provide a measure of somatosensory adaptation with the rationale that the early SEP component should show a decrease in amplitude during stimulation with shorter ISIs compared to longer ISIs. A significant interaction between viewing condition and ISI would therefore suggest differences in adaptation between viewing conditions. To complement our initial frequentist approach, Bayesian analysis was performed in JASP (JASP Team, 2019), using a zero-centered Cauchy distribution with a default scale of 0.707. Bayes factor (B_{01}) was considered “anecdotal” (1–3), “moderate” (3–10), “strong” (10–30), “very strong” (30–100) or “extreme” (>100) evidence for the null hypothesis (Jeffreys, 1961; Lee and Wagenmakers, 2014).

To assess the crossmodal influence of movies on the oscillatory changes induced by passive tactile stimulation, mass univariate ANOVAs were applied at the level of time/frequency points across the three viewing conditions. This was done using permutation-based statistics

(i.e. randomizing data across viewing conditions and re-running the statistical test 1000 times) as implemented in EEGLAB to obtain a surrogate distribution. The actual differences in the time-frequency data were tested against this distribution. The resulting *p*-values were corrected for multiple comparisons using the false discover rate (FDR) approach (Benjamini and Hochberg, 1995), which has a number of advantages for exploratory data analysis (for discussion see (Nichols and Hayasaka, 2003)). In addition, we performed spectral band specific analyses, using separate repeated measures ANOVAs to evaluate the effect of viewing condition on the most prominent oscillatory responses in the somatosensory cortex (i.e. alpha and beta ERD). Lastly, we verified that the three viewing conditions evoked different levels of attentional engagement by comparing absolute alpha power.

A Greenhouse-Geiger correction was applied whenever Mauchly’s test indicated a lack of sphericity. Effect sizes (η^2 ranging between 0 and 1) and their 95% confidence intervals (CI) are given (Quertemont, 2011; Sullivan and Feinn, 2012). *Post hoc* *t*-tests were performed whenever main effects and interaction effects were detected in the ANOVAs. Results were considered significant if *p*-values were less than 0.05. All data presented in the text and figures are represented as mean \pm SD unless stated otherwise.

3. Results

3.1. EEG data quality

Fig. 2 shows the eye blink rate for the three viewing conditions. Although the eye blink rate was on average slightly smaller for both movie conditions (Movie: 17.94 ± 10.24 ; Inscapes: 17.61 ± 8.89) compared to rest (19.04 ± 11.69), no significant effect of viewing condition was found [$F_{(2,64)} = 0.51, p = 0.603$, effect size $\eta^2 = 0.016$, 95% CI of effect size [0.00, 0.11]].

Further, for each viewing condition an average of 241 ± 27 artifact-free EEG trials remained for analysis, and the number of trials did not differ between viewing conditions (Movie: 240 ± 28 ; Inscapes: 240 ± 28 ; Rest: 245 ± 26 ; $p > 0.5$, repeated-measures ANOVA) nor ISI (long ISI: 239 ± 28 ; short ISI: 243 ± 26 ; $p > 0.08$, repeated-measures ANOVA), suggesting comparable EEG data quality whether participants watch a movie or not.

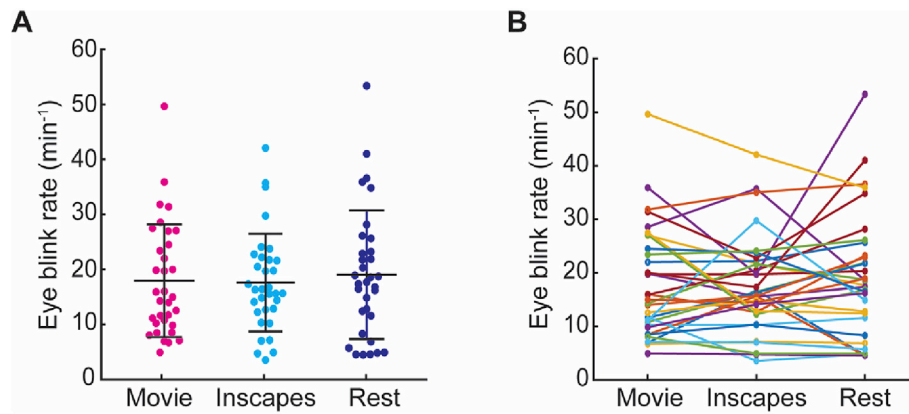


Fig. 2. Eye blink rate during each viewing condition. **A**, Dots represent individual participants' eye blink rates for Movie (pink), Inscapes (light blue) and Rest (dark blue) conditions. Black bars represent mean \pm SD across participants. **B**, Individual participants are represented by different colours, indicating no consistent trend.

3.2. Somatosensory potentials and adaptation

Average SEP traces in response to passive tactile finger stimulation from contralateral somatosensory cortex are shown in Fig. 3A for the two movie conditions (Movie, Inscapes) and 'movie-free' rest, using the 1050 ms ISI (SEP traces for example participants in Supplementary Figure 2). Similar to previous studies using mechanical stimulation (e.g. (Hämäläinen et al., 1990; Taylor-Clarke et al., 2002)), the first somatosensory response peaked around 50 ms after stimulus onset, with the topographical distribution in line with a source in the primary somatosensory cortex (Allison et al., 1989). Another prominent but later, longer-lasting positive peak occurred at \sim 300 ms. While multiple regions contribute to the somatosensory P300 (Bruyant et al., 1993; Tarkka et al., 1996), the topographical maps align with a predominantly contralateral origin from temporal-parietal activity (Valeriani et al., 2001). The gross

morphology and time course of the SEPs are highly similar between viewing conditions. Topographical distributions (Fig. 3D) of the P50 and P300 further show strong similarity between viewing conditions.

Estimates of mean amplitude and peak latency of the early SEP component, P50, recorded from contralateral somatosensory cortex were both unaffected by 'viewing condition' [mean amplitude: $F_{(2,64)} = 0.42$, $p = 0.608$, Greenhouse-Geisser corrected, effect size $\eta^2 = 0.013$, 95% CI of effect size [0.00, 0.09]; peak latency: $F_{(2,64)} = 0.83$, $p = 0.442$, effect size $\eta^2 = 0.025$, 95% CI of effect size [0.00, 0.15]] (Fig. 3B). *Post-hoc* Bayesian analysis of these effects gave strong evidence for the null hypothesis, suggesting that properties of the P50 component are indeed viewing condition invariant [mean amplitude: $BF_{01} = 12.993$, error % = 2.108; peak latency: $BF_{01} = 9.273$, error % = 0.677].

Similarly, analysis of the mean amplitude and peak latency of the P300 provided no evidence for crossmodal (audiovisual) influences at

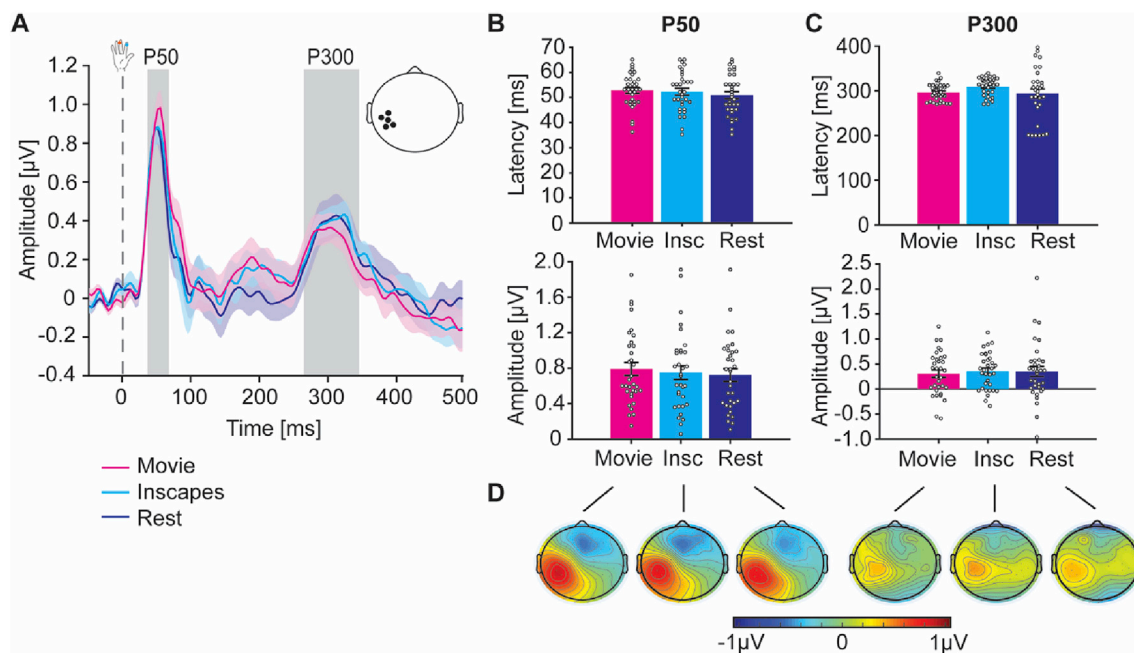


Fig. 3. SEPs to passive tactile stimulation. **A**, Average SEP traces in response to passive tactile stimulation from a ROI over the contralateral somatosensory cortex (black circles in topographical plot) while watching a movie (pink), Inscapes (light blue) and during rest (dark blue) for the 1050 ms ISI. Two major positive peaks are clearly distinguishable indicated by grey rectangles: P50 (35–65 ms) and P300 (270–340 ms). **B**, Peak latency and **C**, mean SEP amplitude for P50 and P300 across all participants is shown for the three different viewing conditions. Dots represent individual participants. **D**, Topographical plots (bottom panel) representing neural activity averaged over the respective time windows for each SEP component show a predominantly contralateral activation pattern for early and late SEP components. Shaded area (**A**) and error bars (**B**, **C**) indicate between-participant SEM. Insc: Inscapes.

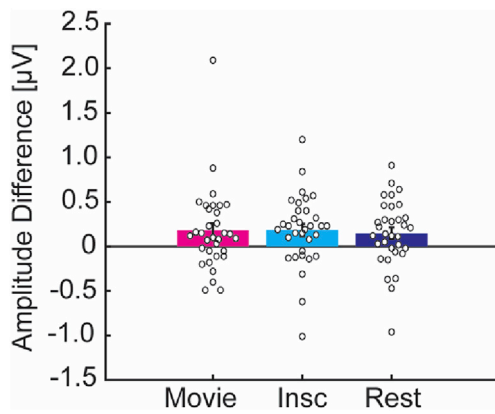


Fig. 4. Somatosensory adaptation to repeated passive tactile stimulation. Mean amplitude difference between long and short ISI across all participants is shown for each viewing condition. Dots represent individual participants. Error bars indicate between-participant SEM. Insc: Inscapes.

this later stage of somatosensory processing [mean amplitude: $F_{(2,64)} = 0.16$, $p = 0.849$, effect size $\eta^2 = 0.005$, 95% CI of effect size [0.00, 0.08]; latency: $F_{(2,64)} = 1.35$, $p = 0.266$, effect size $\eta^2 = 0.041$, 95% CI of effect

size [0.00, 0.16]] (Fig. 3C). Post-hoc Bayesian analysis of these effects also provided strong and moderate evidence for the null hypothesis, respectively, suggesting that properties of the P300 component are indeed unaffected by viewing condition [mean amplitude: $BF_{01} = 16.009$, error % = 2.281; peak latency: $BF_{01} = 4.181$, error % = 0.678].

Next, we compared SEP amplitudes elicited with long (1050 ms) and short (150 ms) ISIs to characterise somatosensory adaptation in response to repetitive stimulation. We were able to identify an adaptation effect, thereby successfully replicating previous findings (Angel et al., 1985; McLaughlin and Kelly, 1993). Over the somatosensory cortex contralateral to the stimulated fingers, there was a significant effect of ISI for the early SEP component, P50 [$F_{(1,32)} = 9.39$, $p = 0.004$, effect size $\eta^2 = 0.227$, 95% CI [0.03, 0.48]]. For each viewing condition, the mean amplitude was significantly reduced for the short ISI compared to the long ISI [Movie: $t_{(32)} = 2.23$, $p = 0.033$, effect size $d = 0.388$; Inscapes: $t_{(32)} = 2.64$, $p = 0.013$, effect size $d = 0.459$; Rest: $t_{(32)} = 2.28$, $p = 0.030$, effect size $d = 0.396$] (see Supplementary Figure 1), demonstrating significant somatosensory adaptation across conditions.

Turning to the effect of movies on somatosensory adaptation, there was no significant effect of viewing condition [$F_{(2,64)} = 0.36$, $p = 0.649$, Greenhouse-Geisser corrected, effect size $\eta^2 = 0.011$, 95% CI of effect size [0.00, 0.09]] nor an interaction between viewing condition and ISI [$F_{(2,64)} = 0.12$, $p = 0.885$, effect size $\eta^2 = 0.004$, 95% CI of effect size

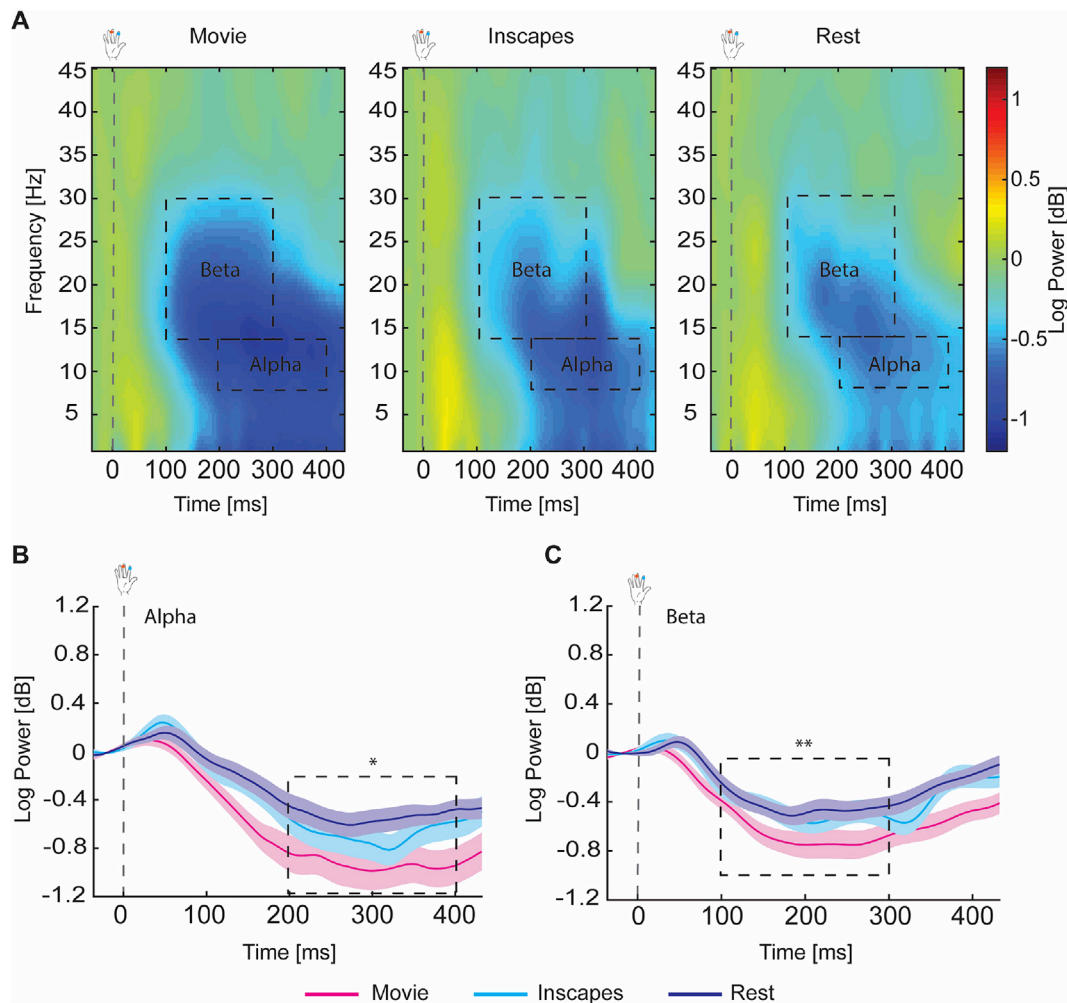


Fig. 5. Time-frequency representation for each viewing condition from somatosensory cortex. A, Averaged stimulus-related changes in spectral power (dB) as a function of time (x-axis) and frequency (y-axis) is shown for the three different viewing conditions (Movie, Inscapes, Rest). The colour represents decreases (ERD) (blue colours) or increases (ERS) (red colours) relative to pre-stimulus baseline period (-50–0 ms). The dashed areas indicate time-frequency windows of peak changes in the alpha (8–13 Hz) and beta (13–30 Hz) frequency bands. B, C, Averaged alpha and beta power time courses from somatosensory cortex for each viewing condition. The dashed areas indicate the time window that was tested for significant differences between viewing conditions. Shaded area indicates between-participant SEM. Statistical difference between viewing conditions: * $p < 0.05$, ** $p < 0.01$ using ANOVA.

[0.00, 0.05]], suggesting that somatosensory adaptation of the early SEP component was not modulated by the dynamic crossmodal (audiovisual) input of movies (Fig. 4). *Post-hoc* Bayesian analysis on the effect of viewing condition on the amount of somatosensory adaptation further provided strong evidence for the null hypothesis [BF₀₁ = 17.435, error % = 1.122].

3.3. Spectral power

Having demonstrated no significant modulation of SEP components and their adaptation with viewing condition, we next tested whether the oscillatory neural response induced by the passive tactile stimulation was modulated by the dynamic crossmodal input of movies relative to rest. Average spectral changes over the somatosensory cortex in response to tactile stimulation are shown in Fig. 5A for each viewing condition. Similar to previous tactile stimulation studies (Cheyne et al., 2003; Gaetz and Cheyne, 2006; Salenius et al., 1997), a decrease in both alpha (8–13 Hz) and beta (13–30 Hz) band power (ERD) beginning within 100–200 ms following tactile stimulation, was observed over somatosensory cortex. Although the beta ERD can be expected to be followed by a transient increase in beta power (ERS), the trial length of our study design did not allow us to assess this spectral dynamic.

Although, the overall morphology of patterns of spectral changes was similar between viewing conditions and mass univariate analysis showed no effect of movie-watching (all time/frequency points, FDR-corrected *p*-values >0.05), spectral band specific analyses revealed differences in mean power change (ERD) in the alpha [$F_{(2,64)} = 4.11, p = 0.021$, effect size $\eta^2 = 0.114$, 95% CI of effect size [0.00, 0.25]] (Fig. 5B) and beta [$F_{(2,64)} = 5.35, p = 0.007$, effect size $\eta^2 = 0.143$, 95% CI of effect size [0.01, 0.29]] (Fig. 5C) frequency band as a function of viewing condition. *Post-hoc* analyses showed that alpha and beta ERD were significantly enhanced (greater desynchronization) while watching a movie relative to ‘movie-free’ rest [alpha ERD: $t_{(32)} = -2.88, p = 0.021$, effect size $d = 0.49$; beta ERD: $t_{(32)} = -3.31, p = 0.007$, effect size $d = 0.59$]. There were no differences in alpha or beta suppression between Inscapes and ‘movie-free’ rest [alpha ERD: $t_{(32)} = -1.09, p = 0.841$, effect size $d = 0.18$; beta ERD: $t_{(32)} = -0.43, p = 1.00$, effect size $d = 0.09$] nor Inscapes and Movies [alpha: $t_{(32)} = -1.69, p = 0.305$, effect size $d = 0.29$; beta: $t_{(32)} = -2.36, p = 0.074$, effect size $d = 0.40$].

Lastly, we found that absolute alpha power was differentially modulated by viewing condition [$F_{(2,64)} = 6.63, p = 0.002$, effect size η^2

= 0.172, 95% CI of effect size [0.04 0.29]]. While movie-watching yielded lowest alpha activity, followed by watching Inscapes and ‘movie-free’ rest (Fig. 6), *post-hoc* t-tests revealed a significant reduction in (ongoing) alpha activity only for watching a movie relative to ‘movie-free’ rest [$t_{(32)} = -3.80, p = 0.002$, effect size $d = 0.40$]. There was no difference between Inscapes and ‘movie-free’ rest [$t_{(32)} = -1.40, p = 0.516$, effect size $d = 0.14$] nor Inscapes and Movies [$t_{(32)} = -2.16, p = 0.116$, effect size $d = 0.27$]. The same pattern of alpha activity (Movies < Inscapes < Rest) was found in the occipital cortex (Supplementary Figure 3).

4. Discussion

The present study investigated the potential crossmodal influence of movies on cortical somatosensory processing in a group of healthy young adults. Our results demonstrate that properties of early and late SEP components are unaffected by the information from other sensory modalities while watching an “entertaining” movie and a “low-demand” non-narrative movie compared to rest. Similarly, no modulation of the adaptation of the early SEP component, denoted by a reduction in response strength, was found when participants viewed movies compared to rest, ignoring concurrent stimulation. Using *post-hoc* Bayesian analysis, our study provides the first evidence for the null hypothesis of no effect of movies on evoked somatosensory responses and their adaptation. In addition, our assessments indicate that the prominent stimulation-related power suppression (ERD) in the alpha and beta bands can be measured during movie-watching, but that it is differentially modulated with viewing condition. Overall, our findings suggest that movie-watching is a valid acquisition method during which somatosensory processing can be assessed, in particular in challenging populations, who may not otherwise tolerate a research EEG procedure.

Abundant evidence exists for crossmodal audiovisual and attentional modulation of SEPs at various temporal stages, and possibly as early as 50 ms post-stimulus (Bufalari et al., 2007; Cardini et al., 2012; Desmedt and Robertson, 1977; Desmedt and Tomberg, 1989; Dionne et al., 2013; Eimer and Driver, 2000; Eimer and Forster, 2003; Kok, 2001; Michie et al., 1987; Polich, 2007; Popovich and Staines, 2014; Schubert et al., 2008; Taylor-Clarke et al., 2002; Zopf et al., 2004). However, no studies have assessed the potential effect of movie-watching on cortical somatosensory processing, even though movies have become a popular acquisition method to improve neuroimaging research data collection, especially in challenging populations (Gabrielsen et al., 2018; Vanderwal et al., 2019). Here, we provide the first evidence that movie-watching does not systematically modulate early or late SEPs. While our findings appear to be somewhat in contrast with previous studies, this discrepancy is most likely linked to important methodological differences in the procedures used.

In previous studies, crossmodal sensory stimuli were typically informative of tactile events and participants needed to respond to either the primary and/or secondary modality stimuli. As a consequence, these stimuli could not be completely ignored. In contrast, the dynamic audiovisual content of movies was irrelevant for the processing of tactile stimuli in our study (e.g. no temporal or spatial concordance between sensory modalities) and none of the tactile stimuli required any response, that is, somatosensory stimulation could be entirely ignored. It has been proposed that somatosensory processing, indexed by SEPs, may be decoupled from other sensory modalities (vision and audition) when tactile stimuli can be completely ignored, but not when they remain potentially relevant for responding (Dionne et al., 2013; Eimer and Driver, 2001, 2000). Our findings align with this notion as SEPs evoked by passive tactile stimulation were unaffected by the crossmodal content of movies.

In line with previous studies (Angel et al., 1985; McLaughlin and Kelly, 1993), we observed robust adaptation of the early somatosensory response with repetitive tactile stimulation. Importantly, our study provides the first evidence that the magnitude of somatosensory adaptation

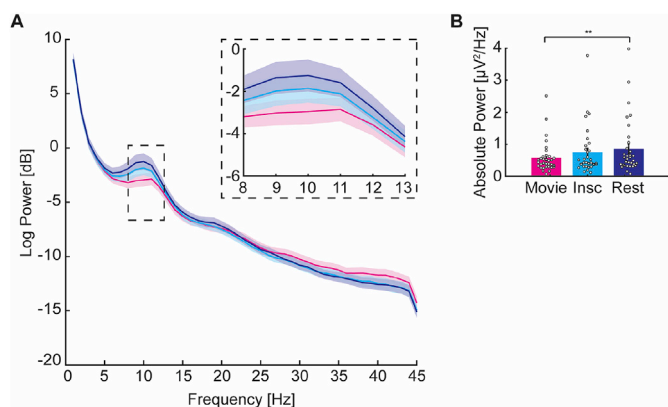


Fig. 6. Absolute alpha power from somatosensory cortex. **A**, Power spectrum across all participants from the ROI over the contralateral somatosensory cortex is shown for each viewing condition. The power spectrum shows a clear peak around 10 Hz, with the dashed area indicating the frequency boundaries used in subsequent analysis. Inset shows enlarged view of the spectrum for the alpha frequency range (8–13 Hz). **B**, Absolute power averaged for the alpha frequency range shows reduced alpha activity while watching a movie (pink) relative to rest (dark blue). Dots represent individual participants. Shaded area (A) and error bars (B) indicate between-participant SEM. Insc: Inscapes.

is practically unaffected by the dynamic crossmodal content of movies. While the neural mechanisms underlying adaptation are still debated (Grill-Spector et al., 2006), adaptation is of interest as it plays a role in moment-to-moment dynamic sensory processing and appears to be disrupted in disorders such as autism (Lawson et al., 2015; Puts et al., 2014; Tannan et al., 2008; Tommerdahl et al., 2007) and schizophrenia (Andrade et al., 2016; Huang et al., 2010; Matsuzaki et al., 2014; Thoma et al., 2007). Adaptation tends to be specific to the temporal proximity and similarity of the adapting and test stimuli (Angel et al., 1985; McLaughlin and Kelly, 1993; Solomon and Kohn, 2014). Hence, we might speculate that a degree of congruency across sensory modalities is necessary for crossmodal influences to modulate somatosensory adaptation. However, the current study was not designed to study the specific role of sensory stimulus parameters and response relevance for cross-modal effects on somatosensory processing, and thus, these interpretations are purely speculative.

SEPs provide an assay with which to measure modulations in somatosensory processing, but analysis is limited to the time domain. To investigate frequency-specific modulations in somatosensory processing that may be differentially affected by viewing condition, exploratory time-frequency analyses measuring oscillatory activity over somatosensory cortex were conducted. While mass univariate analyses did not reveal a significant difference in time-frequency representations, spectral band specific analyses revealed that the prominent alpha and beta power suppression (ERD) following tactile stimulation differed as a function of viewing condition. Specifically, a stronger alpha and beta ERD (greater desynchronization) was observed during movie-watching compared to 'movie-free' rest. In line with previous studies demonstrating attentional modulation (selective and spatial attention) of somatosensory rhythms (Anderson and Ding, 2011; Bardouille et al., 2010; Bauer et al., 2006; Dockstader et al., 2010; Haegens et al., 2012; Jones et al., 2010; Piitulainen et al., 2015; Van Ede et al., 2011), the modulation of alpha/beta ERD in our study likely reflects allocation of attentional resources, which is greatest during movie-watching. The notion that the audiovisual information of movies is relatively more engaging than rest was corroborated by different levels of (ongoing) alpha activity, which was lowest for the 'Movie' condition, followed by Inscapes and 'movie-free' rest (Fig. 6). The overall pattern of modulation (Movie < Inscapes < Rest) further suggests that the novel, 'low-demand' movie Inscapes provides an intermediate level of attentional engagement between movies and rest. Interestingly, the attentional modulation of alpha/beta ERD without a concurrent modulation of SEPs imply that these measures capture, at least to a certain degree, different neurophysiological processes (Bas-tiaansen and Brunia, 2001).

The idea of using movies to increase compliance and make EEG recordings more tolerable is not new. Passive auditory ERP studies commonly employ movies with or without an audible soundtrack (Bellis et al., 2000; Gilley et al., 2005; Kraus et al., 1993; McArthur and Bishop, 2002). While movie soundtracks may impact passive auditory ERP components (e.g. mismatch negativity) (Mahajan and McArthur, 2011; McArthur et al., 2003), possibly due to within-modality interference from two competing auditory inputs, our study is the first to show that movies with or without auditory content do not systematically modulate SEP components during passive tactile stimulation. Our findings can therefore support researchers making decisions about whether or not to include sound as part of passive stimulation paradigms. Although one must be cautious in generalizing these findings to all types of somatosensory stimulation, we argue that mechanical stimulation, which is known to activate sensory pathways in a more natural and pain-free way compared to electrical stimulation (Forss et al., 1994; Hashimoto et al., 1990; Pratt et al., 1980), and the undemanding nature of passive stimulation (i.e. no response required) makes this approach an ideal tool for assessing somatosensory function and dysfunction in clinical research and pediatric populations.

A few limitations are worth discussing in more detail. While we purposefully gave participants a choice among different cartoon movies

to increase each participant's engagement with the movie and to increase generalizability of findings, we cannot rule out that the variance across different movies and the 'cinematic uniqueness' of cartoons might have influenced effect sizes. However, we argue that the strength of this approach lies in its clinical appropriateness as children will comply more with cartoon movies that they find highly engaging. In addition, even though participants were instructed to focus on the movies or fixation cross, they were not explicitly asked whether they were engaged in the movie content or occasionally shifted their attention to the somatosensory domain. Hence, it is not possible to estimate the impact of these moment-to-moment shifts in attention on our results. Further, while movies have been shown to exhibit considerable influence over widespread brain networks (Bartels and Zeki, 2004; Cohen and Parra, 2016; Hasson and Malach, 2008; Lankinen et al., 2016, 2014), the current study focused on evoked neural responses from somatosensory cortex only. This decision was based on the critical role of the somatosensory cortex in processing afferent tactile information and was not meant to imply that there would not be possible effects of movie-watching on other types of evoked potentials. Lastly, here we assessed the effect of movies' dynamic audiovisual content on cortical somatosensory processing in a sample of healthy young adults. While we expect these results to generalize, other populations, specifically children and clinical populations who are likely to benefit the most from watching an entertaining movie to increase compliance, may not show the same result. Thus, future studies should determine the effect of movies on properties of SEPs and multispectral oscillatory neural responses across the lifespan and in the context of pathology.

5. Conclusion

In conclusion, this study is the first to evaluate the crossmodal influence of movies' audiovisual content on cortical somatosensory processing. The present study highlights that SEPs are practically unaffected by viewing an "entertaining" or "low-demand" movie compared to rest. This finding has important implications for basic and clinical research as it suggests that SEPs can be assessed during movie-watching which, in the context of pediatric imaging, may enable data collection and assessment of neurodevelopmental disorders with altered tactile functioning, including autism (Casio et al., 2015; Puts et al., 2014; Tannan et al., 2008), Tourette's syndrome (Puts et al., 2015), and attention deficit hyperactivity disorder (Puts et al., 2017). In addition, our work characterizes differences in stimulation-related oscillatory dynamics (ERD) associated with movie-watching, which likely reflects attentional states and needs to be taken into account when performing and interpreting future studies employing oscillatory analyses. Overall, these findings suggest that movie-watching is a valid acquisition method during which somatosensory processing can be measured in basic research and clinical studies.

Declaration of competing interest

There is no conflict of interest.

CRediT authorship contribution statement

Svenja Espenhahn: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Supervision, Writing - review & editing. **Tingting Yan:** Formal analysis, Investigation. **Winnica Beltrano:** Formal analysis, Investigation. **Sakshi Kaur:** Formal analysis, Investigation. **Kate Godfrey:** Investigation. **Filomeno Cortese:** Methodology, Writing - review & editing. **Signe Bray:** Conceptualization, Resources, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Ashley D. Harris:** Conceptualization, Resources, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

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Appendix A. Supplementary data

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References

- Allison, T., McCarthy, G., Wood, C., Williamson, P.D., Spencer, D.D., 1989. Human cortical potentials evoked by stimulation of the median nerve. II. Cytoarchitectonic areas generating long-latency activity. *J. Neurophysiol.* <https://doi.org/10.1152/jn.1989.62.3.711>.
- Allison, T., McCarthy, G., Wood, C.C., 1992. The relationship between human long-latency somatosensory evoked potentials recorded from the cortical surface and from the scalp. *Electroencephalogr. Clin. Neurophysiol. Evoked Potentials.* [https://doi.org/10.1016/0168-5597\(92\)90082-M](https://doi.org/10.1016/0168-5597(92)90082-M).
- Anderson, K.L., Ding, M., 2011. Attentional modulation of the somatosensory mu rhythm. *Neuroscience.* <https://doi.org/10.1016/j.neuroscience.2011.02.004>.
- Andrade, G.N., Butler, J.S., Peters, G.A., Molholm, S., Foxe, J.J., 2016. Atypical visual and somatosensory adaptation in schizophrenia-spectrum disorders. *Transl. Psychiatry* 6, e804. <https://doi.org/10.1038/tp.2016.63>.
- Angel, R.W., Quick, W.M., Boylls, C.C., Weinrich, M., Rodnitzky, R.Y., 1985. Decrement of somatosensory evoked potentials during repetitive stimulation. *Electroencephalogr. Clin. Neurophysiol.* 60, 335–342.
- Banoub, M., Tetzlaff, J.E., Schubert, A., 2003. Pharmacologic and physiologic influences affecting sensory evoked potentials. *Anesthesiology* 99, 716–737. <https://doi.org/10.1097/0000542-200309000-00029>.
- Bardouille, T., Picton, T.W., Ross, B., 2010. Attention modulates beta oscillations during prolonged tactile stimulation. *Eur. J. Neurosci.* <https://doi.org/10.1111/j.1460-9568.2010.07094.x>.
- Bartels, A., Zeki, S., 2004. Functional brain mapping during free viewing of natural scenes. *Hum. Brain Mapp.* 21, 75–85. <https://doi.org/10.1002/hbm.10153>.
- Bastiaansen, M.C.M., Brunia, C.H.M., 2001. Anticipatory attention: an event-related desynchronization approach. *Int. J. Psychophysiol.* 43, 91–107. [https://doi.org/10.1016/S0167-8760\(01\)00181-7](https://doi.org/10.1016/S0167-8760(01)00181-7).
- Bauer, M., Oostenveld, R., Peeters, M., Fries, P., 2006. Tactile spatial attention enhances gamma-band activity in somatosensory cortex and reduces low-frequency activity in parieto-occipital areas. *J. Neurosci.* <https://doi.org/10.1523/JNEUROSCI.5228-04.2006>.
- Bellis, T.J., Nicol, T., Kraus, N., 2000. Aging affects hemispheric asymmetry in the neural representation of speech sounds. *J. Neurosci.* 20, 791–797.
- Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Stat. Soc. Ser. B.* <https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>.
- Blakemore, S., Bristow, D., Bird, G., Frith, C., Ward, J., 2005. Somatosensory activations during the observation of touch and a case of vision – touch synaesthesia. *Brain* 128, 1571–1583. <https://doi.org/10.1093/brain/awh500>.
- Botvinick, M., Cohen, J., 1998. Rubber hands “feel” touch that eyes see [8]. *Nature.* <https://doi.org/10.1038/35784>.
- Bruyant, P., García-Larrea, L., Mauguère, F., 1993. Target side and scalp topography of the somatosensory P300. *Electroencephalogr. Clin. Neurophysiol. Evoked Potentials.* [https://doi.org/10.1016/0168-5597\(93\)90036-O](https://doi.org/10.1016/0168-5597(93)90036-O).
- Bufoalari, I., Aprile, T., Avenanti, A., Russo, D., Aglioti, S.M., Psicologia, D., 2007. Empathy for pain and touch in the human somatosensory cortex. *Cerebr. Cortex* 17, 2553–2561. <https://doi.org/10.1093/cercor/bhl161>.
- Burton, H., Sinclair, R.J., 2000. Attending to and remembering tactile stimuli: a review of brain imaging data and single-neuron responses. *J. Clin. Neurophysiol.* <https://doi.org/10.1097/00004691-200011000-00004>.
- Cardini, F., Longo, M.R., Driver, J., Haggard, P., 2012. Rapid enhancement of touch from non-informative vision of the hand. *Neuropsychologia* 50, 1954–1960. <https://doi.org/10.1016/j.neuropsychologia.2012.04.020>.
- Cascio, C.J., Gu, C., Schauder, K.B., Key, A.P., Yoder, P., 2015. Somatosensory event-related potentials and association with tactile behavioral responsiveness patterns in children with ASD. *Brain Topogr.* 28, 895–903. <https://doi.org/10.1016/j.physbeh.2017.03.040>.
- Chaumon, M., Bishop, D.V.M., Busch, N.A., 2015. A practical guide to the selection of independent components of the electroencephalogram for artifact correction. *J. Neurosci. Methods* 250, 47–63. <https://doi.org/10.1016/j.jneumeth.2015.02.025>.
- Cheyne, D., Gaetz, W., Garnero, L., Lachaux, J.P., Ducorps, A., Schwartz, D., Varela, F.J., 2003. Neuroimaging of cortical oscillations accompanying tactile stimulation. *Cognit. Brain Res.* 17, 599–611. [https://doi.org/10.1016/S0926-6410\(03\)00173-3](https://doi.org/10.1016/S0926-6410(03)00173-3).
- Cohen, S.S., Parra, L.C., 2016. Memorable audiovisual narratives synchronize sensory and supramodal neural responses. *eNeuro* 3, 1–11. <https://doi.org/10.1523/eneuro.0203-16.2016>.
- Cooper, N.R., Croft, R.J., Dominey, S.J.J., Burgess, A.P., Gruzeli, J.H., 2003. Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *Int. J. Psychophysiol.* [https://doi.org/10.1016/S0167-8760\(02\)00107-1](https://doi.org/10.1016/S0167-8760(02)00107-1).
- Croft, R.J., Barry, R.J., 2000. Removal of ocular artifact from the EEG: a review. *Neurophysiol. Clin.* [https://doi.org/10.1016/S0987-7053\(00\)00055-1](https://doi.org/10.1016/S0987-7053(00)00055-1).
- Crucci, G., Aminoff, M.J., Curio, G., Guerit, J.M., Kakigi, R., Mauguère, F., Rossini, P.M., Treede, R.D., García-Larrea, L., 2008. Recommendations for the clinical use of somatosensory-evoked potentials. *Clin. Neurophysiol.* 119, 1705–1719. <https://doi.org/10.1016/j.clinph.2008.03.016>.
- Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J. Neurosci. Methods.* <https://doi.org/10.1016/j.jneumeth.2003.10.009>.
- Desmedt, J.E., Tran Huy, Nguyen, Bourguet, M., 1983. The cognitive P40, N60 and P100 components of somatosensory evoked potentials and the earliest electrical signs of sensory processing in man. *Electroencephalogr. Clin. Neurophysiol.* 56, 272–282. [https://doi.org/10.1016/0013-4694\(83\)90252-3](https://doi.org/10.1016/0013-4694(83)90252-3).
- Desmedt, J.E., Robertson, D., 1977. Differential enhancement of early and late components of the cerebral somatosensory evoked potentials during forced-paced cognitive tasks in man. *J. Physiol.* <https://doi.org/10.1113/jphysiol.1977.sp012025>.
- Desmedt, J.E., Tomberg, C., 1989. Mapping early somatosensory evoked potentials in selective attention: critical evaluation of control conditions used for titrating by difference the cognitive P30, P40, P100 and N140. *Electroencephalogr. Clin. Neurophysiol. Evoked Potentials.* [https://doi.org/10.1016/0168-5597\(89\)90001-4](https://doi.org/10.1016/0168-5597(89)90001-4).
- Dinstein, I., Hasson, U., Rubin, N., Heger, D.J., 2007. Brain areas selective for both observed and executed movements. *J. Neurophysiol.* 98, 1415–1427. <https://doi.org/10.1152/jn.00238.2007.Brain>.
- Dionne, J.K., Legon, W., Staines, W.R., 2013. Crossmodal influences on early somatosensory processing: interaction of vision, touch, and task-relevance. *Exp. Brain Res.* 226, 503–512. <https://doi.org/10.1007/s00221-013-3462-z>.
- Dockstader, C., Cheyne, D., Tannock, R., 2010. Cortical dynamics of selective attention to somatosensory events. *Neuroimage.* <https://doi.org/10.1016/j.neuroimage.2009.09.035>.
- Doria-Lamba, L., Montaldi, L., Grosso, P., Veneselli, E., Giribaldi, G., 2009. Short latency evoked somatosensory potentials after stimulation of the median nerve in children: normative data. *J. Clin. Neurophysiol.* 26, 176–182. <https://doi.org/10.1097/WNP.0b013e3181a76a56>.
- Ebisch, S.J.H., Perrucci, M.G., Ferretti, A., Del Gratta, C., Romani, G.L., Gallese, V., 2008. The Sense of touch: embodied simulation in a visuotactile mirroring mechanism for observed animate or inanimate touch. *J. Cognit. Neurosci.* <https://doi.org/10.1162/jocn.2008.20111>.
- Eimer, M., Driver, J., 2001. Crossmodal links in endogenous and exogenous spatial attention: evidence from event-related brain potential studies. *Neurosci. Biobehav. Rev.* 25, 497–511.
- Eimer, M., Driver, J., 2000. An event-related brain potential study of cross-modal links in spatial attention between vision and touch. *Psychophysiology* 37, 697–705. <https://doi.org/10.1017/S0048577200990899>.
- Eimer, M., Forster, B., 2003. Modulations of early somatosensory ERP components by transient and sustained spatial attention. *Exp. Brain Res.* 151, 24–31. <https://doi.org/10.1007/s00221-003-1437-1>.
- Fagan, E.R., Taylor, M.J., Logan, W.J., 1987. Somatosensory evoked potentials: Part I. A review of neural generators and special considerations in pediatrics. *Pediatr. Neurol.* 3, 189–196. [https://doi.org/10.1016/0887-8994\(87\)90015-4](https://doi.org/10.1016/0887-8994(87)90015-4).
- Filimon, F., Nelson, J.D., Hagler, D.J., Sereno, M.I., 2007. Human cortical representations for reaching: mirror neurons for execution, observation, and imagery. *Neuroimage* 37, 1315–1328.
- Forss, N., Salmelin, R., Hari, R., 1994. Comparison of somatosensory evoked fields to airpuff and electric stimuli. *Electroencephalogr. Clin. Neurophysiol. Evoked Potentials* 92, 510–517. [https://doi.org/10.1016/0168-5597\(94\)90135-X](https://doi.org/10.1016/0168-5597(94)90135-X).
- Foxe, J.J., Snyder, A.C., 2011. The role of alpha-band brain oscillations as a sensory suppression mechanism during selective attention. *Front. Psychol.* <https://doi.org/10.3389/fpsyg.2011.00154>.
- Gabrielsen, T.P., Anderson, J.S., Stephenson, K.G., Beck, J., King, J.B., Kellems, R., Top, D.N., Russell, N.C.C., Anderberg, E., Lundwall, R.A., Hansen, B., South, M., 2018. Functional MRI connectivity of children with autism and low verbal and cognitive performance. *Mol. Autism.* 9, 1–14. <https://doi.org/10.1186/s13229-018-0248-y>.
- Gaetz, W., Cheyne, D., 2006. Localization of sensorimotor cortical rhythms induced by tactile stimulation using spatially filtered MEG. *Neuroimage* 30, 899–908. <https://doi.org/10.1016/j.neuroimage.2005.10.009>.
- Gazzola, V., Aziz-zadeh, L., Keysers, C., 2006. Empathy and the somatotopic auditory mirror system in humans. *Curr. Biol.* 16, 1824–1829. <https://doi.org/10.1016/j.cub.2006.07.072>.
- Gazzola, V., Keysers, C., 2009. The observation and execution of actions share motor and somatosensory voxels in all tested subjects: single-subject analyses of unsmoothed fMRI data. <https://doi.org/10.1093/cercor/bbn181>.
- Gilley, P.M., Sharma, A., Dorman, M., Martin, K., 2005. Developmental changes in refractoriness of the cortical auditory evoked potential. *Clin. Neurophysiol.* 116, 648–657. <https://doi.org/10.1016/j.clinph.2004.09.009>.

- Gratton, G., 1998. Dealing with artifacts: the EOG contamination of the event-related brain potential. *Behav. Res. Methods Instrum. Comput.* 30, 44–53. <https://doi.org/10.3758/BF03209415>.
- Grill-Spector, K., Henson, R., Martin, A., 2006. Repetition and the brain: neural models of stimulus-specific effects. *Trends Cognit. Sci.* 10, 14–23. <https://doi.org/10.1016/j.tics.2005.11.006>.
- Haegens, S., Luther, L., Jensen, O., 2012. Somatosensory anticipatory alpha activity increases to suppress distracting input. *J. Cognit. Neurosci.* https://doi.org/10.1162/jocn_a.00164.
- Hämäläinen, H., Kekoni, J., Sams, M., Reinikainen, K., Näätänen, R., 1990. Human somatosensory evoked potentials to mechanical pulses and vibration: contributions of SI and SII somatosensory cortices to P50 and P100 components. *Electroencephalogr. Clin. Neurophysiol.* [https://doi.org/10.1016/0013-4694\(90\)90148-D](https://doi.org/10.1016/0013-4694(90)90148-D).
- Hashimoto, I., Yoshikawa, K., Sasaki, M., 1990. Latencies of peripheral nerve and cerebral evoked responses to air-puff and electrical stimuli. *Muscle Nerve* 13, 1099–1104. <https://doi.org/10.1002/mus.880131203>.
- Hasson, U., Malach, R., 2008. Human brain activation during viewing of dynamic natural scenes. In: *Percept, Decision, Action: Bridging the Gaps.* <https://doi.org/10.1002/9780470034989.ch16>.
- Hasson, U., Yang, E., Vallines, I., Heeger, D.J., Rubin, N., 2008. A hierarchy of temporal receptive windows in human cortex. *J. Neurosci.* 28, 2539–2550. <https://doi.org/10.1523/JNEUROSCI.5487-07.2008>.
- Hsiao, F.J., Cheng, C.H., Chen, W.T., Lin, Y.Y., 2013. Neural correlates of somatosensory paired-pulse suppression: a MEG study using distributed source modeling and dynamic spectral power analysis. *Neuroimage.* <https://doi.org/10.1016/j.neuroimage.2013.01.041>.
- Huang, M.X., Lee, R.R., Gaa, K.M., Song, T., Harrington, D.L., Loh, C., Theilmann, R.J., Edgar, J.C., Miller, G.A., Canive, J.M., Granholm, E., 2010. Somatosensory system deficits in schizophrenia revealed by MEG during a median-nerve oddball task. *Brain Topogr.* <https://doi.org/10.1007/s10548-009-0122-5>.
- JASP Team, 2019. JASP ([Computer software]), Version 0.11.1.0.
- Jeffreys, H., 1961. *The Theory of Probability.* Oxford University Press, Oxford.
- Johansen-berg, H., Lloyd, D.M., 2000. The physiology and psychology of selective attention to touch. *Front. Biosci.* 5, D894–D904.
- Jones, S.R., Kerr, C.E., Wan, Q., Pritchett, D.L., Hämäläinen, M., Moore, C.I., 2010. Cued spatial attention drives functionally relevant modulation of the mu rhythm in primary somatosensory cortex. *J. Neurosci.* <https://doi.org/10.1523/JNEUROSCI.2969-10.2010>.
- Keil, A., Debener, S., Gratton, G., Junghöfer, M., Kappenman, E.S., Luck, S.J., Luu, P., Miller, G.A., Yee, C.M., 2014. Committee report: publication guidelines and recommendations for studies using electroencephalography and magnetoencephalography. *Psychophysiology* 51, 1–21. <https://doi.org/10.1111/psyp.12147>.
- Keyers, C., Kaas, J.H., Gazzola, V., 2010. Somatosensation in social perception. *Nat. Rev. Neurosci.* 11, 417–428. <https://doi.org/10.1038/nrn2833>.
- Keyers, C., Wicker, B., Gazzola, V., Anton, J., Fogassi, L., Gallese, V., Physiologiques, L.D.N., 2004. *A Touching Sight: SII/PV Activation during the Observation and Experience of Touch, vol. 42, pp. 335–346.*
- Kilner, J.M., 2013. Bias in a common EEG and MEG statistical analysis and how to avoid it. *Clin. Neurophysiol.* <https://doi.org/10.1016/j.clinph.2013.03.024>.
- Kitazawa, S., 2002. Where Conscious Sensation Takes Place. *Conscious. Cogn.* [https://doi.org/10.1016/S1053-8100\(02\)00031-4](https://doi.org/10.1016/S1053-8100(02)00031-4).
- Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., Schwaiger, J., 1998. Induced alpha band power changes in the human EEG and attention. *Neurosci. Lett.* [https://doi.org/10.1016/S0304-3940\(98\)00122-0](https://doi.org/10.1016/S0304-3940(98)00122-0).
- Kok, A., 2001. On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology.* <https://doi.org/10.1017/S0048577201990559>.
- Kraus, N., McGee, T., Micco, A., Sharma, A., Carrell, T., Nicol, T., 1993. Mismatch negativity in school-age children to speech stimuli that are just perceptibly different. *Electroencephalogr. Clin. Neurophysiol. Evoked Potentials* 88, 123–130. [https://doi.org/10.1016/0168-5597\(93\)90063-U](https://doi.org/10.1016/0168-5597(93)90063-U).
- Lankinen, K., Saari, J., Hari, R., Koskinen, M., 2014. Intersubject consistency of cortical MEG signals during movie viewing. *Neuroimage* 92, 217–224. <https://doi.org/10.1016/j.neuroimage.2014.02.004>.
- Lankinen, K., Smeds, E., Tikka, P., Pihko, E., Hari, R., Koskinen, M., 2016. Haptic contents of a movie dynamically engage the spectator's sensorimotor cortex. *Hum. Brain Mapp.* 37, 4061–4068. <https://doi.org/10.1002/hbm.23295>.
- Lawson, R.P., Aylward, J., White, S., Rees, G., 2015. A striking reduction of simple loudness adaptation in autism. *Sci. Rep.* <https://doi.org/10.1038/srep16157>.
- Lee, M., Wagenmakers, E.-J., 2014. *Bayesian Cognitive Modelling: a Practical Course.* Cambridge University Press.
- Libet, B., Alberts, W.W., Wright, E.W., Feinstein, B., 1967. Responses of human somatosensory cortex to stimuli below threshold for conscious sensation. *Science* 80. <https://doi.org/10.1126/science.158.3808.1597>.
- Lopez-Calderon, J., Luck, S.J., 2014. ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Front. Hum. Neurosci.* 8 <https://doi.org/10.3389/fnhum.2014.00213>.
- Luck, S.J., Fuller, R.L., Braun, E.L., Robinson, B., Summerfelt, A., Gold, J.M., 2006. The speed of visual attention in schizophrenia: electrophysiological and behavioral evidence. *Schizophr. Res.* 85, 174–195. <https://doi.org/10.1016/j.schres.2006.03.040>.
- Luck, S.J., Gaspelin, N., 2017. How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology* 54, 146–157. <https://doi.org/10.1111/psyp.12639>.
- Luck, S.J., Kappenman, E.S., 2009. Impaired response selection in schizophrenia: evidence from the P3 wave and the lateralized readiness potential. *Psychophysiology* 46, 776–786. <https://doi.org/10.1038/jid.2014.371>.
- Mahajan, Y., McArthur, G., 2011. The effect of a movie soundtrack on auditory event-related potentials in children, adolescents, and adults. *Clin. Neurophysiol.* 122, 934–941. <https://doi.org/10.1016/j.clinph.2010.08.014>.
- Makeig, S., 1993. Auditory event-related dynamics of the EEG spectrum and effects of exposure to tones. *Electroencephalogr. Clin. Neurophysiol.* [https://doi.org/10.1016/0013-4694\(93\)90110-H](https://doi.org/10.1016/0013-4694(93)90110-H).
- Matsuzaki, J., Kagitani-Shimono, K., Sugata, H., Hirata, M., Hanaie, R., Nagatani, F., Tachibana, M., Tominaga, K., Mohri, I., Taniike, M., 2014. Progressively increased M50 responses to repeated sounds in autism spectrum disorder with auditory hypersensitivity: a magnetoencephalographic study. *PLoS One.* <https://doi.org/10.1371/journal.pone.0102599>.
- McArthur, G., Bishop, D., 2002. Event-related potentials reflect individual differences in age-invariant auditory skills. *Neuroreport* 13, 1079–1082. <https://doi.org/10.1097/00001756-200206120-00021>.
- McArthur, G.M., Bishop, D.V.M., Proudfoot, M., 2003. Do video sounds interfere with auditory event-related potentials? *Behav. Res. Methods Instrum. Comput.* <https://doi.org/10.3758/BF03202561>.
- McLaughlin, D.F., Kelly, E.F., 1993. Evoked potentials as indices of adaptation in the somatosensory system in humans: a review and prospectus. *Brain Res. Rev.* 18, 151–206. [https://doi.org/10.1016/0165-0173\(93\)90001-G](https://doi.org/10.1016/0165-0173(93)90001-G).
- Michie, P.T., Bearparic, H.M., Crawford, J.M., Glue, L.C.T., 1987. The effects of spatial selective attention on the somatosensory event-related potential. *Psychophysiology.* <https://doi.org/10.1111/j.1469-8986.1987.tb00316.x>.
- Nichols, T., Hayasaka, S., 2003. Controlling the familywise error rate in functional neuroimaging: a comparative review. *Stat. Methods Med. Res.* <https://doi.org/10.1191/0962280203sm341ra>.
- Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia.* [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4).
- Pfurtscheller, G., Aranibar, A., 1977. Event-related cortical desynchronization detected by power measurements of scalp EEG. *Electroencephalogr. Clin. Neurophysiol.* [https://doi.org/10.1016/0013-4694\(77\)90235-8](https://doi.org/10.1016/0013-4694(77)90235-8).
- Pfurtscheller, G., Lopes Da Silva, F.H., 1999. Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clin. Neurophysiol.* [https://doi.org/10.1016/S1388-2457\(99\)00141-8](https://doi.org/10.1016/S1388-2457(99)00141-8).
- Piitulainen, H., Bourguignon, M., Smeds, E., de Tiège, X., Jousmäki, V., Hari, R., 2015. Phasic stabilization of motor output after auditory and visual distractors. *Hum. Brain Mapp.* <https://doi.org/10.1002/hbm.23001>.
- Polich, J., 2007. Updating P300: an integrative theory of P3a and P3b. *Clinic* 118, 2128–2148. <https://doi.org/10.1016/j.clinph.2007.04.019>.
- Popovich, C., Staines, W.R., 2014. The attentional-relevance and temporal dynamics of visual-tactile crossmodal interactions differentially influence early stages of somatosensory processing. *Brain Behav* 4, 247–260. <https://doi.org/10.1002/brb3.210>.
- Pratt, H., Politoske, D., Starr, A., 1980. Mechanically and electrically evoked somatosensory potentials in humans: effects of stimulus presentation rate. *Electroencephalogr. Clin. Neurophysiol.* 49, 240–249. [https://doi.org/10.1016/0013-4694\(80\)90218-7](https://doi.org/10.1016/0013-4694(80)90218-7).
- Puts, N.A.J., Harris, A.D., Crocetti, D., Nettles, C., Singer, H.S., Tommerdahl, M., Edden, R.A.E., Mostofsky, S.H., 2015. Reduced GABAergic inhibition and abnormal sensory symptoms in children with Tourette syndrome. *J. Neurophysiol.* <https://doi.org/10.1152/jn.00060.2015>.
- Puts, N.A.J., Harris, A.D., Mikkelsen, M., Tommerdahl, M., Edden, R.A., Mostofsky, S.H., 2017. Altered tactile sensitivity in children with attention deficit hyperactive disorder. *J. Neurophysiol.* 118, 2568–2578. <https://doi.org/10.1152/jn.00087.2017>.
- Puts, N.A.J., Wodka, E.L., Tommerdahl, M., Mostofsky, S.H., Edden, R.A.E., 2014. Impaired tactile processing in children with autism spectrum disorder. *J. Neurophysiol.* 111, 1803–1811.
- Quertemont, E., 2011. How to statistically show the absence of an effect. *Psychol. Belg.* <https://doi.org/10.5334/pb-51-2-109>.
- Ricciardi, E., Bonino, D., Sani, L., Vecchi, T., Guazzelli, M., Haxby, J.V., Fadiga, L., Pietrini, P., 2009. Do we really need Vision? How blind people “see” the actions of others. *J. Neurosci.* 29, 9719–9724. <https://doi.org/10.1523/JNEUROSCI.0274-09.2009>.
- Salenius, S., Schnitzler, A., Salmelin, R., Jousmäki, V., Hari, R., 1997. Modulation of human cortical rolandic rhythms during natural sensorimotor tasks. *Neuroimage.* <https://doi.org/10.1006/nimg.1997.0261>.
- Schaefer, M., Xu, B., Flor, H., Cohen, L.G., 2009. Effects of different viewing perspectives on somatosensory activations during observation of touch. *Hum. Brain Mapp.* <https://doi.org/10.1002/hbm.20701>.
- Schubert, R., Blankenburg, F., Lemm, S., Villringer, A., Curio, G., 2006. Now you feel it - now you don't: ERP correlates of somatosensory awareness. *Psychophysiology.* <https://doi.org/10.1111/j.1469-8986.2006.00379.x>.
- Schubert, R., Ritter, P., Wüstenberg, T., Preuschhof, C., Curio, G., Sommer, W., Villringer, A., 2008. Spatial attention related SEP amplitude modulations covary with BOLD signal in S1 - a simultaneous EEG - fMRI study. *Cerebr. Cortex* 18, 2686–2700. <https://doi.org/10.1093/cercor/bhn029>.
- Solomon, S.G., Kohn, A., 2014. Moving sensory adaptation beyond suppressive effects in single neurons. *Curr. Biol.* <https://doi.org/10.1016/j.cub.2014.09.001>.
- Sullivan, G.M., Feinn, R., 2012. Using effect size—or why the P value is not enough. *J. Grad. Med. Educ.* <https://doi.org/10.4300/jgme-d-12-00156.1>.
- Tannan, V., Holden, J.K., Zhang, Z., Baranek, G.T., Tommerdahl, M., 2008. Perceptual metrics of individuals with autism provide evidence for disinhibition. *Autism Res.* 1, 223–230. <https://doi.org/10.1002/aur.34>.

- Tarkka, I.M., Micheloyannis, S., Stokić, D.S., 1996. Generators for human P300 elicited by somatosensory stimuli using multiple dipole source analysis. *Neuroscience*. [https://doi.org/10.1016/0306-4522\(96\)00287-4](https://doi.org/10.1016/0306-4522(96)00287-4).
- Taylor-Clarke, M., Kennett, S., Haggard, P., 2002. Vision modulates somatosensory cortical processing. *Curr. Biol.* 12, 233–236. [https://doi.org/10.1016/S0960-9822\(01\)00681-9](https://doi.org/10.1016/S0960-9822(01)00681-9).
- Thoma, R.J., Hanlon, F.M., Huang, M., Miller, G.A., Moses, S.N., Weisend, M.P., Jones, A., Paulson, K.M., Irwin, J., Cañive, J.M., 2007. Impaired secondary somatosensory gating in patients with schizophrenia. *Psychiatr. Res.* <https://doi.org/10.1016/j.psychres.2006.10.011>.
- Tommerdahl, M., Tannan, V., Cascio, C., Baranek, G., Whitsel, B., 2007. Vibrotactile adaptation fails to enhance spatial localization in adults with autism. *Brain Res.* 1154, 116–123. <https://doi.org/10.1002/ana.22528>. Toll-like.
- Valeriani, M., Fraioli, L., Rangi, F., Giaquinto, S., 2001. Dipolar source modeling of the P300 event-related potential after somatosensory stimulation. *Muscle Nerve* 24, 1677–1686. <https://doi.org/10.1002/mus.1203>.
- Van Ede, F., De Lange, F., Jensen, O., Maris, E., 2011. Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha- and beta-band oscillations. *J. Neurosci.* <https://doi.org/10.1523/JNEUROSCI.5630-10.2011>.
- van Ede, F., Szebényi, S., Maris, E., 2014. Attentional modulations of somatosensory alpha, beta and gamma oscillations dissociate between anticipation and stimulus processing. *Neuroimage*. <https://doi.org/10.1016/j.neuroimage.2014.04.047>.
- Vanderwal, T., Eilbott, J., Castellanos, F.X., 2019. Movies in the magnet: naturalistic paradigms in developmental functional neuroimaging. *Dev. Cogn. Neurosci.* 36 <https://doi.org/10.1016/j.dcn.2018.10.004>, 100600.
- Vanderwal, T., Kelly, C., Eilbott, J., Mayes, L.C., Xavier, F., 2015. Inscapes: a movie paradigm to improve compliance in functional magnetic resonance imaging. *Neuroimage* 122, 222–232. <https://doi.org/10.1002/cncr.27633>. Percutaneous.
- Voisin, J.I.A., Marcoux, L.A., Canizales, D.L., Mercier, C., Jackson, P.L., 2011. I am touched by your pain: limb-specific modulation of the cortical response to a tactile stimulation during pain observation. *J. Pain* 12, 1182–1189. <https://doi.org/10.1016/j.jpain.2011.06.005>.
- Voisin, J.I.A., Rodrigues, E.C., Hétu, S., Jackson, P.L., Vargas, C.D., Malouin, F., Chapman, C.E., Mercier, C., 2010. Modulation of the response to a somatosensory stimulation of the hand during the observation of manual actions. *Exp. Brain Res.* 208, 11–19. <https://doi.org/10.1007/s00221-010-2448-3>.
- Wang, Q., Webber, R.M., Stanley, G.B., 2010. Thalamic synchrony and the adaptive gating of information flow to cortex. *Nat. Neurosci.* 13, 1534–1541. <https://doi.org/10.1038/nn.2670>. Thalamic.
- Wark, B., Lundstrom, B.N., Fairhall, A., 2008. Sensory adaptation. *Curr. Opin. Neurobiol.* 17, 423–429.
- Wiesman, A.I., Heinrichs-Graham, E., Coolidge, N.M., Gehringer, J.E., Kurz, M.J., Wilson, T.W., 2017. Oscillatory dynamics and functional connectivity during gating of primary somatosensory responses. *J. Physiol.* <https://doi.org/10.1113/JP273192>.
- Zopf, R., Giabbiconi, C.M., Gruber, T., Müller, M.M., 2004. Attentional modulation of the human somatosensory evoked potential in a trial-by-trial spatial cueing and sustained spatial attention task measured with high density 128 channels EEG. *Brain Res. Cogn. Brain Res.* 20, 491–509. <https://doi.org/10.1016/j.cogbrainres.2004.02.014>.