

Somatosensory Event-related Potentials from Orofacial Skin Stretch Stimulation

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► **To cite this version:**

Takayuki Ito, David J Ostry, Vincent Gracco. Somatosensory Event-related Potentials from Orofacial Skin Stretch Stimulation. *Journal of visualized experiments*, 2015, 106, pp.e53621. <<http://www.jove.com/video/53621>>. <10.3791/53621>. <hal-01247041>

HAL Id: hal-01247041

<https://hal.archives-ouvertes.fr/hal-01247041>

Submitted on 31 Dec 2015

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1 **TITLE:**
2 Somatosensory event-related potentials from orofacial skin stretch stimulation
3

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41 **KEYWORDS:**

42 Cutaneous mechanoreceptors, speech perception, speech production, sensorimotor control,
43 electroencephalography
44

45 **SHORT ABSTRACT:**

46 This paper introduces a method for obtaining somatosensory event-related potentials following
47 orofacial skin stretch stimulation. The current method can be used to evaluate the contribution
48 of somatosensory afferents to both speech production and speech perception.

49

50 **LONG ABSTRACT:**

51 Cortical processing associated with orofacial somatosensory function in speech has received
52 limited experimental attention due to the difficulty of providing precise and controlled
53 stimulation. This article introduces a technique for recording somatosensory event-related
54 potentials (ERP) that uses a novel mechanical stimulation method involving skin deformation
55 using a robotic device. Controlled deformation of the facial skin is used to modulate kinesthetic
56 inputs through excitation of cutaneous mechanoreceptors. By combining somatosensory
57 stimulation with electroencephalographic recording, somatosensory evoked responses can be
58 successfully measured at the level of the cortex. Somatosensory stimulation can be combined
59 with the stimulation of other sensory modalities to assess multisensory interactions. For
60 speech, orofacial stimulation is combined with speech sound stimulation to assess the
61 contribution of multi-sensory processing including the effects of timing differences. The ability
62 to precisely control orofacial somatosensory stimulation during speech perception and speech
63 production with ERP recording is an important tool that provides new insight into the neural
64 organization and neural representations for speech.

65

66 **INTRODUCTION:**

67 Speech production is dependent on both auditory and somatosensory information. The
68 auditory and somatosensory feedback occur in combination from the earliest vocalizations
69 produced by an infant and both are involved in speech motor learning. Recent results suggest
70 that somatosensory processes contribute to perception as well as production. For example, the
71 identification of speech sounds is altered when a robotic device stretches the facial skin as
72 participants listen to auditory stimuli¹. Air puffs to the cheek that coincide with auditory speech
73 stimuli alter participants' perceptual judgments².

74

75 These somatosensory effects involve the activation of cutaneous mechanoreceptors in
76 response to skin deformation. The skin is deformed in various ways during movement, and
77 cutaneous mechanoreceptors are known to contribute to kinesthetic sense^{3,4}. The kinesthetic
78 role of cutaneous mechanoreceptors is demonstrated by recent findings⁵⁻⁷ that the movement-
79 related skin strains are appropriately perceived as flexion or extension motion depending on
80 the pattern of skin stretch⁶. Over the course of speech motor training, which is the repetition of
81 specific speech utterance with concomitant facial skin stretch speech, articulatory patterns
82 change in an adaptive manner⁷. These studies indicate that modulating skin stretch during
83 action provides a method for assessing the contribution of cutaneous afferents to the
84 kinesthetic function of the sensorimotor system.

85

86 The kinesthetic function of orofacial cutaneous mechanoreceptors has been studied mostly
87 using psychophysiological methods^{7,8} and microelectrode recoding from sensory nerves^{9,10}.
88 Here, the current protocol focuses on the combination of orofacial somatosensory stimulation

89 associated with facial skin deformation and event related potential (ERP) recording. This
90 procedure has precise experimental control over the direction and timing of facial skin
91 deformation using a computer-controlled robotic device. This allows us to test specific
92 hypotheses about the somatosensory contribution to speech production and perception by
93 selectively and precisely deforming facial skin in a wide range of orientations during both
94 speech motor learning and directly in speech production and perception. ERP recording are
95 used to noninvasively evaluate the temporal pattern and timing of the influence of
96 somatosensory stimulation on orofacial behaviors. The current protocol then can evaluate the
97 neural correlates of kinesthetic function and assess the contribution of the somatosensory
98 system to both speech processing, speech production and speech perception.

99
100 To show the utility of the application of skin stretch stimulation to ERP recording, the following
101 protocol focuses on the interaction of somatosensory and auditory input in speech perception.
102 The results highlight a potential method to assess somatosensory-auditory interaction in
103 speech.

104
105 **PROTOCOL:**

106
107 The current experimental protocol follows the guidelines of ethical conduct according to the
108 Yale University Human Investigation Committee.

109
110 **1. Electroencephalography (EEG) preparation**

- 111
112 1.1. Measure head size to determine the appropriate EEG cap.
113
114 1.2. Identify the location of the vertex by finding the mid-point between nasion and inion
115 with a measuring tape.
116
117 1.3. Place the EEG cap on the head using the pre-determined vertex as Cz. Examine Cz again
118 after placing the cap by using a measuring tape as done in 1.2. Note that the EEG cap is
119 equipped with electrode holders and the placement of the 64 electrodes (or holders) is based
120 on a modified 10-20 system with pre-specified coordinates system based on Cz¹¹. This
121 representative application uses a 64 electrode configuration to assess scalp distribution
122 changes and for source analysis. For simpler applications (event-related potential changes in
123 amplitude and latency) using fewer electrodes are possible. There are two additional electrodes
124 for ground in the EEG system used here. Those electrode holders are also included in the cap.
125
126 1.4. Apply electrode gel in the electrode holders using a disposable syringe.
127
128 1.5. Attach EEG electrodes (including ground electrodes) into the electrodes holders
129 matching the labels of the electrodes and to the electrode holders on the electrode cap.
130
131 1.6. Clean the skin surface with alcohol pads.
132

133 Note: For electrodes for detecting eye motion (electro-oculography), the skin locations are
134 above and below the right eye (vertical eye motion), and lateral to the outer canthus of the
135 both eyes (horizontal eye motion); for somatosensory stimulation the skin lateral to the oral
136 angle is cleaned.

137

138 1.7. Fill the four electro-oculography electrodes with the electrode gel and secure the
139 electrodes with double-sided tape to the sites noted in 1.6.

140

141 1.8. Secure all electrode cables using a Velcro strap. If required, tape the cables to
142 participant's body or the other locations that do not introduce any additional electrical or
143 mechanical noise.

144

145 1.9. Position the participant in front of the monitor and the robot for somatosensory
146 stimulation. Secure all electrode cables again as in 1.8.

147

148 1.10. Connect the EEG and electro-oculography electrodes (including the ground electrodes)
149 into the appropriate connectors (matching label and connector shape) on the amplifier box of
150 EEG system.

151

152 1.11. Check to see that the EEG signals are artifact free and that the offset value is in an
153 acceptable range ($< 50 \mu\text{V}$ or smaller). If noisy signals or large offsets that are usually indicative
154 of high impedance are found, correct those electrode signals by adding additional EEG gel
155 and/or repositioning hair that is directly under the electrode.

156

157 1.12. Insert the EEG-compatible earphones and confirm that the sound level is in a
158 comfortable range based on subject report.

159

160 **2. Somatosensory stimulation**

161

162 Note: The current protocol applies facial skin stretch for the purpose of somatosensory
163 stimulation. The experimental setup with the EEG system is represented in Figure 1. The details
164 of the somatosensory stimulation device have been described in the previous studies^{1,7,12-14}.
165 Briefly, two small plastic tabs (2 cm wide and 3 cm height) are attached with double-sided tape
166 to the facial skin. The tabs are connected to the robotic device using string. The robot generates
167 systematic skin stretch loads according to experimental designs. The setup protocol for ERP
168 recording is as follows:

169

170 2.1. Place the participants head in the headrest in order to minimize head motion during
171 stimulation. Remove carefully the electrode cables between the participant's head and
172 headrest.

173

174 2.2. Ask the participant to hold the safety switch for the robot.

175

176 2.3. Attach plastic tabs to the target skin location using double-sided tape for somatosensory

177 stimulation. For the representative results^{12,13}, in which the target is the skin lateral to the oral
178 angle, place the center of the tabs on the modiolus, a few mm lateral to the oral angle with the
179 center of the tabs at approximately the same height of the oral angle.
180

181 2.4. Adjust the configuration of the string, string supports and the robot in order to avoid
182 EEG electrodes and cables.

183
184 2.5. Apply a few facial skin stretches (one cycle sinusoid at 3 Hz with a maximum force of 4
185 N) to check for artifacts due to the stimulation (usually observed as relatively large amplitude
186 and lower frequency compared with the electrophysiological response). If artifacts are
187 observed in the EEG signals, go back to 2.4.

188 189 3. **ERP recording**

190
191 3.1. Explain the experimental task to the subject and provide a few practice trials.

192
193 Note: The experimental task and stimulus presentation for ERP recording are preprogramed in
194 software for stimulus presentation.

195
196 3.1.1. In the representative test with combined somatosensory and auditory stimulation¹²,
197 apply the somatosensory stimulation associated with skin deformation to the skin lateral to the
198 oral angle. The pattern of stretch is a one cycle sinusoid (3 Hz) with a maximum force of 4 N. A
199 single synthesized speech utterance that is midway in a 10-step sound continuum between
200 “*head*” and “*had*” is used for auditory stimulation.

201
202 3.1.2. Present both stimulations separately or in combination. In the combined stimulation,
203 test three onset timings (90 ms lead and lag, and simultaneous in somatosensory and auditory
204 onsets: see Figure 3A).

205
206 3.1.3. Randomize the presentation of five stimulations (somatosensory alone, auditory alone
207 and three combined: lead, simult. and lag). Vary the inter-trial interval between 1000 and 2000
208 ms in order to avoid anticipation and habituation. The experimental task is to identify whether
209 the presented speech sound, which is the sound that is acoustically intermediate between
210 “*head*” and “*had*”, was “*head*” by pressing a key on a keyboard. In the somatosensory alone
211 condition, in which there is no auditory stimulation, the participants are instructed to answer
212 not “*head*”.

213
214 3.1.4. Record participant judgments and the reaction time from the stimulus onset to the key
215 press using the software for stimulus presentation. Ask the participant to gaze a fixation point
216 on the display screen in order to reduce artifacts due to eye-movement.

217
218 3.1.5. Remove the fixation point every 10 stimulations for a short break. (See also other
219 example of task and stimulus presentation^{12,13})

220

221 3.2. Start the software for ERP recording at 512 Hz sampling, which also records the onset
222 time of stimulation in the timeline of ERP data. Note that the time stamps of the stimulation,
223 which also includes the information about the type of the stimulation, are sent for every
224 stimulus from the software for stimulus presentation. The two programs (for ERP recording and
225 for the stimulus presentation) are running on two separate PCs that are connected through a
226 parallel port.

227
228 3.3. Set the software for the somatosensory stimulation to the trigger-waiting mode and
229 then start stimulus presentation by activating the software for stimulus presentation. Note that
230 the software for the somatosensory stimulation is also running on a separate PC from the other
231 two PCs. A trigger signal for the somatosensory stimulation is received through an analog input
232 device that is connected to a digital output device in the PC for sensory stimulation. Single
233 somatosensory stimulation is produced per one trigger. Record 100 ERPs per condition.

234

235 **REPRESENTATIVE RESULTS:**

236 This section presents representative event-related potentials in response to somatosensory
237 stimulation resulting from facial skin deformation. The experimental setup is represented in
238 Figure 1. Sinusoidal stimulation was applied to the facial skin lateral to the oral angle (See
239 Figure 3A as reference). One hundred stretch trials were recorded for each participant with 12
240 participants tested in total. After removing the trials with blinks and eye movement artifacts
241 offline on the basis of the horizontal and vertical electro-oculography signals (over $\pm 150 \mu\text{V}$),
242 more than 85% of trials were averaged. EEG signals were filtered with a 0.5– 50 Hz band-pass
243 filter and re-referenced to the average across all electrodes. Figure 2 shows the average
244 somatosensory ERP from selected representative electrodes. In frontal regions, peak negative
245 potentials were induced at 100-200 ms post stimulus onset followed by a positive potential at
246 200-300 ms. The largest response was observed in the midline electrodes. Different from the
247 previous studies of somatosensory ERP¹⁵⁻¹⁸, there is no earlier latency ($< 100\text{ms}$) potentials. This
248 temporal pattern is rather similar to the typical N1-P2 sequence following auditory
249 stimulation¹⁹. In comparison between the corresponding pair of electrodes in left and right
250 hemisphere, the temporal pattern is quite similar probably due to the bilateral stimulation.

251

252 *[Place Figure 1 and 2 here]*

253

254 The first result shows how the timing of stimulation affects multisensory interaction during
255 speech processing¹². In this study, neural response interactions were found by comparing ERPs
256 obtained using somatosensory–auditory stimulus pairs with the algebraic sum of ERPs to the
257 unisensory stimuli presented separately. The pattern of auditory-somatosensory stimulations
258 are represented in Figure 3A. Figure 3B shows the pattern of event-related potentials in
259 response to somatosensory-auditory stimulus pairs (Red line). The black line represents the
260 sum of individual unisensory auditory and somatosensory ERPs. The three panels correspond to
261 the time lag between two stimulus onsets: 90 ms lead of the somatosensory onset (Left),
262 simultaneous (Center) and 90 ms lag (Right). When somatosensory stimulation was presented
263 90 ms before the auditory onset, there is a difference between paired and summed responses
264 (the left panel in Figure 3B). This interaction effect gradually decreases as a function of the time

265 lag between the somatosensory and auditory inputs (see the change between the two dotted
266 lines in Figure 3B). The results demonstrate that the somatosensory-auditory interaction is
267 dynamically modified with the timing of stimulation.

268

269 *[Place Figure 3 here]*

270

271 The next result demonstrates that the amplitude of the somatosensory ERP increases in
272 response to listening to speech¹³. The pattern of somatosensory stimulation is the same as
273 noted above. Figure 4 shows somatosensory ERPs, which are converted into scalp current
274 density²⁰ in off-line analysis, at electrodes (FC3, FC5, C3) over the left sensorimotor area.
275 Somatosensory event-related potentials were recorded while participants listen to speech in
276 the presence of continuous background sounds. The study tested four background conditions:
277 speech, non-speech sounds, pink-noise and silent¹³. The results indicated the amplitude of
278 somatosensory event-related potentials during listening to speech sounds was significantly
279 greater than the other three conditions. There was no significant difference in amplitude for
280 the other three conditions. Figure 4B shows normalized peak amplitudes in the different
281 conditions. The result indicates that listening to speech sounds alters the somatosensory
282 processing associated with facial skin deformation.

283

284 *[Place Figure 4 here]*

285

286 **Figure 1: Experimental setup.**

287

288 **Figure 2: Event related potentials in response to somatosensory stimulation produced by**
289 **facial skin stretch.** The ERPs were obtained from representative electrodes.

290

291 **Figure 3: Event-related potentials reflect a somatosensory-auditory interaction in the context**
292 **of speech perception.** This Figure has been modified from Ito, et al.¹² **A:** temporal pattern of
293 somatosensory and auditory stimulations. **B:** Event-related potentials for combined
294 somatosensory and auditory stimulation in three timing conditions (lead, simultaneous, and
295 lag) at electrode Pz. The red line represents recorded responses to paired ERPs. The dashed line
296 represents the sum of somatosensory and auditory ERPs. The vertical dotted lines define an
297 interval 160–220 ms after somatosensory onset in which differences between “pair” and “sum”
298 responses are assessed. Arrows represent auditory onset.

299

300 **Figure 4: Enhancement of somatosensory event-related potentials due to speech sounds.** The
301 ERPs were recorded under four background sound conditions (Silent, Pink noise, Speech and
302 Non-speech). This Figure has been modified from Ito, et al.¹³ **A:** Temporal pattern of
303 somatosensory event-related potentials in the area above left motor and premotor cortex. Each
304 color corresponds to a different background sound condition. The ERPs were converted to scalp
305 current density²⁰. **B:** Differences in z-score magnitudes associated with the first peak of the
306 somatosensory ERPs. Error bars are standard errors across participants. Each color corresponds
307 to different background sound conditions, as in Panel A.

308

309 **DISCUSSION:**

310 The studies reported here provide evidence that precisely controlled somatosensory
311 stimulation that is produced by facial skin deformation induces cortical ERPs. Cutaneous
312 afferents are known as a rich source of kinesthetic information^{3,4} in human limb movement^{5,6}
313 and speech movement^{7,8,21}. Stretching the facial skin in a manner that reflects the actual
314 movement direction during speaking induces a kinesthetic sense similar to the corresponding
315 movement. The current method combining precisely controlled skin stretch and ERP recordings
316 can be used to investigate the neural basis of orofacial function during a wide range of speech
317 behaviors.

318
319 Using mechanical stimulation and simultaneous EEG recording, it is important to monitor the
320 ongoing signals for artifact. In particular, since the strings used to stretch the skin are located
321 close to the EEG electrodes and cables, there is the possibility of electrical and motion artifacts
322 being induced in the EEG signals. This artifact is distinguishable because of relatively large
323 amplitude and lower frequency compared with the electrophysiological response. Before
324 recording, the stimulation setup including the string configuration needs to be checked
325 carefully to identify and eliminate any mechanical artifacts due to the stimulation. Although
326 artifacts can be removed by post signal processing, such as filtering or independent component
327 analysis²² similar to eye movement and blinking, cleaner signals are always more desirable.

328
329 The previous studies of somatosensory event-related potentials have mostly used brief
330 somatosensory stimuli that were produced using mechanical²³, electrical¹⁸ or laser nociceptive
331 stimulation¹⁵. Somatosensory inputs arising from these kinds of stimulation are not associated
332 with any particular articulatory motion in speech, and hence, they may not be suitable for
333 investigating speech-related cortical processing. Möttönen, et al.¹⁷ had failed to show a change
334 of magnetoencephalographic somatosensory potentials using simple lip tapping during listening
335 to speech sounds. In contrast, deformation of the facial skin provides kinesthetic input similar
336 to that which occurs in conjunction with speech articulatory motion²¹ and sensorimotor
337 adaption⁷. These stimuli also interact with speech perceptual processing^{1,14}. The somatosensory
338 ERP from the current skin stretch perturbation is more suitable for the investigation of speech-
339 related cortical processing than the other methods currently available for somatosensory
340 stimulation. Several different characteristics were found between the current skin stretch
341 stimulation and the previous methods. Further investigation including the source location is
342 required.

343
344 Although deformation of the facial skin occurs to varying degrees during speech motion⁸, the
345 skin lateral to the oral angle is densely innervated with cutaneous mechanoreceptors^{10,24} and
346 may be predominantly responsible for the detection of skin stretch during speech. The skin at
347 the corners of the mouth may be especially important for speech motor control and speech
348 motor learning. The current approach is somewhat limited because the stretch of the skin can
349 only be done in one direction and at one location per EEG session. Using a more complex skin
350 deformation and evaluating multiple directions and/or multiple locations in one EEG session
351 will provide further insight into the specific role of somatosensation in speech processing.

352

353 There are long-standing interests in speech communication studies concerning the nature of
354 representations and processing in speech production and perception²⁵⁻²⁷. The discovery of
355 mirror neurons^{28,29} reinforced the idea that motor functions are involved in speech perception.
356 The involvement of the motor system (or the motor and premotor cortex) has also been
357 investigated³⁰⁻³⁵ in the perception of speech sounds. Nevertheless, the link between speech
358 production and perception is still poorly understood. Exploring possible somatosensory
359 influences on speech perception can help us understand the neural bases of speech perception
360 and production, and whether they overlap or link. The current technique for modulating
361 somatosensory function has provided a new tool to investigate this important area of inquiry.
362 The current technique has the additional advantage that it can be used in investigations of
363 somatosensory function more generally and how it interacts with other sensory modalities in
364 neural processing.

365

366 **ACKNOWLEDGMENTS:**

367 This work was supported by National Institute on Deafness and Other Communication
368 Disorders Grants R21DC013915 and R01DC012502, the Natural Sciences and Engineering
369 Research Council of Canada and the European Research Council under the European
370 Community's Seventh Framework Programme (FP7/2007-2013 Grant Agreement no. 339152).

371

372 **DISCLOSURES:**

373 The authors have nothing to disclose.

374

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