Integration of Somatosensory and Auditory Stimulation

Synthesis of Information

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Annotated Summaries of Somatosensory and Auditory Multisensory Stimulation

Citation 1: Schurmann M, Caetano G, Hlushchuk Y, Jousmaki V, Hari R. Touch activates human auditory cortex. *NeuroImage.* 2006; 30:1325-1331.[1]

The aim of Schurmann and colleagues study was to determine if auditory areas of the brain could be activated by somatosensory information. More specifically, the authors sought to observe and describe overlapping cortical areas, which are coactivated by vibrotactile and auditory input. Additionally, the authors investigated if differences between vibrotactile and tactile stimulation existed. This study examined the functional magnetic resonance imaging (fMRI) in 13 healthy adult participants exposed to three categories of auditory and/or tactile input. The categories were: 1) vibrotactile stimulation to the participants' right hands and fingers, 2) pressure pulsation without vibration to the fingertips, and 3) auditory information delivered via headphones. Auditory stimulation alone was used to identify the auditory regions of the brain. Vibrotactile and tactile pressure stimuli co-activate the posterior auditory belt of the left side of the brain. Each type of tactile input, vibrotactile-auditory and pressure tactile-auditory, activate the posterior auditory belt, specifically a region of 85mm3. Audio tactile events occur in the brain with vibration and pressure tactile stimuli. The finding that the audio tactile portion of the brain is activated as the hands interact with the environment is of clinical significance. This finding carries over to individual with hearing impairment demonstrating that tactile input activates their auditory areas as well.

Citation 2: Ozcan M, Baumgartner U, Vucurevic G, Stoeter P, Treede R. Spatial resolution of fMRI in the human parasylvian cortex: comparison of somatosensory and auditory activation. *NeuroImage.* 2005;25(3):877-887.[2]

The Ozcan and authors evaluated functional magnetic resonance imaging (fMRI) in the parasylvian region of the cortex. The Sylvian fissure, also known as the lateral sulcus, divides the temporal lobe from the parietal and frontal lobes. Specifically, the fissure separates the primary and secondary auditory cortices found in the temporal lobe and the secondary somatosensory cortex in the parietal lobe. The primary auditory cortex is below the Sylvian fissure. This area manages speech and pure tones. Secondary auditory regions, in close proximity to the primary auditory cortex, process "spatial discrimination, tone duration, and complex sounds." The secondary somatosensory cortex is located on the parietal lobe above the Sylvian fissure. This area and other adjoining parietal areas are responsible for multiple somatosensory experiences throughout the body's surfaces. "Mechanical stimulation", "tactile object recognition", and "noxious stimuli and pain sensation" are processed in these regions. In this study, tactile stimulation to the first and second fingers of the dominant hand was applied to activate the parietal somatosensory regions. Amplitude modulated pure tones to both ears via headphones were employed to activate the auditory cortex. Some of the results of this study were: 1) " tactile activation showed a mean distance to the Sylvian fissure of 10.3+/-3.7 mm in the right and .7+/-1.9 in the left hemisphere, 2) auditory activations were locate below the fissure at the distance of 4.5+/-2.7 mm in the right and 8.4+/-1.3 mm in the left hemisphere." Signals from the fMRI demonstrated that areas of somatosensory and auditory complexes overlapped even across the Sylvian sulcus.

Citation 3: Kayser C, Petkov CI, Augath M, Logothetis NK. Integration of touch and sound in the auditory cortex. *Neuron*. 2005;48:373-384.[3]

In this study, Kayser and associates support that multi-sensory integration occurs in uni-sensory cortices through feed forward processing and are not dependent on feedback from associated cortices. The authors' hypothesis attempts to demonstrate the integration of sound and touch in the auditory cortex of anaesthetized monkeys. When sound was delivered to the monkey, the auditory cortex was activated. When tactile information was delivered to the hand and foot of the monkey, the somatosensory area as well as the auditory cortex was activated. Used singularly, sound produced greater brain activation than touch. When both tactile and auditory stimuli were conveyed simultaneously, the response was more intense. Differences between sound and touch verses a combination of the two stimuli were significant. Again, the combined stimuli were most significant. No integration in the somatosensory center occurred as a response to the combined touch and auditory stimuli. These authors conclude that the brain's responses to tone occurred in the center of the auditory cortex, considered the primary auditory cortex. Multi-sensory responses occur in the lateral and caudal portions of the auditory belt and not exclusively in the primary auditory cortex. To support of the feed-forward concept, the authors provide two rationales: 1) integration of the combination of sound and touch occurred in the auditory belt not the primary auditory cortex and 2) the monkeys were anaesthetized minimizing influence from higher centers.

Citation 4: Jousmaki V, Hari R. Parchment-skin illusion: sound-biased touch *Curr Biol.*1998;8(6):R190. [4]

Jousmaki and Hari, in this often sited study, hypothesize that intersensory integration allows individuals "to make accurate tactile decisions about the roughness and stiffness of different textures they manipulate." In this study, participants were asked to rub their hands together and the auditory response was recorded. As part of the experiment, the recordings were modified by frequency or intensity. While subjects rubbed their hands together, they listened to either the original or modified recordings. The results of this pilot data indicated that as the frequency or intensity of the auditory information increased the skin was perceived as more dry or smooth. If the frequency or intensity of the auditory input decreased, the skin was perceived as being more moist or rough. This study is often documented in the literature as the "parchment-skin illusion" study.

Citation 5: Levanen S, Jousmaki V, Hari R. Vibration-induced auditory-cortex activation in a congenitally deaf adult. *Curr Biol.* 1998;8:869-872.[5]

Levanen and colleagues in a case report investigated the influence of vibration on a deaf man's auditory cortex. A control group of five was used. In this study, the participant with his left hand felt different vibrations offered through a tube. The same took place with the control subjects. In both the experimental subject and control group, the primary somatosensory cortex was activated. However, only in the subject with deafness was the auditory cortex activated following the vibratory stimuli. The experimental subject was also capable of differentiating between the various frequencies of vibration. As a result of this case report, the authors conclude that the auditory cortex of a person with deafness is activated by vibrotactile stimulation.

Citation 6: Foxe J, Wylie G, Martinez A, et al. Auditory-somatosensory multisensory processing in auditory cortex: an fMRI study. *J Neurophysiol.* 2002;88:540-543.[6]

Foxe and associates' article introduces and provides support for the premise that multisensory integration within cortical centers occurs early. Furthermore, early integration is not initiated through unisensory centers. This study, using fMRI, investigated the overlap of auditory and somatosensory information in the auditory cortex of humans. Study participants were exposed to three stimuli, auditory, tactile, and auditory and tactile combined. Auditory stimulation activated the bilateral superior temporal gyri, which includes the primary auditory cortex, belt, and parabelt areas. The somatosensory stimulation activated the left pre- and post-central gyrus, bilateral insulae. These areas represent the primary and secondary somatosensory cortex. Overlap between the auditory and tactile stimulation was demonstrated in the right and left regions of the auditory cortex. When auditory and tactile stimulation were simultaneously applied, the activation was greater in the region of overlap in the auditory cortex. Resultant from this study, the authors hypothesize that auditory and tactile integration provides a feedforward process within the auditory cortex of human beings.

Citation 7: Foxe J, Morocz I, Murray M, Higgins B, Javitt D, Schroeder C. Multisensory auditory-somatosensory interactions in early cortical processing revealed by high-density electrical mapping. *Cog Brain Res.* 2000;10:77-83.[7]

Foxe and authors in this project studied the human multisensory integration between somatosensory and auditory information using time course and scalp topography. Based on earlier studies in monkeys, the investigators hypothesize that integration of human somatosensory and auditory reactions will occur early in a feedforward process. Eight subjects were exposed to three categories of stimulation: 1) auditory, 2) electrical to the median nerve, and 3) concurrent auditory and electrical to the median nerve. In data analysis, each of the three responses was averaged. The effects of the solo auditory and somatosensory stimulations were summed, as each was considered unisensory. These summed responses were then compared to the combination auditory and somatosensory response. Statistical differences occurred between the summed and simultaneous stimulation responses. Early event-related potentials were demonstrated in the auditory and somatosensory cortices (right central sulcus) following the delivery of the auditory-somatosensory input (left-sided stimulation). Early event-related potentials occurred at 50 microseconds post-stimulus, supporting early integration of these stimuli.

Citation 8: Murray M, Molholm S, Michael C, et al. Grabbing your ears: rapid auditory-somatosensory multisensory interactions in low-level sensory cortices are not constrained by stimulus alignment. Cereb Cor. 2005;15:963-974.[8]

In a 2005 publication, Murray and colleagues examined if early auditory somatosensory stimulation in humans resulted in spatiotemporal neural effects, irrespective of the arrangement of the stimuli presented. In their introduction, the authors discuss three principles pertaining to animal sensory-perceptual courses. The first is the “spatial rule”. This rule states “multisensory interactions are dependent on the spatial alignment and/or overlap of receptive fields responsive to the stimuli.” The second rule, “temporal rule”, maintains “that multisensory interactions are also dependent on the coincidence of the neural responses to different stimuli.” The “inverse effectiveness rule” reports “that the strongest stimuli, when presented in isolation, are minimally effective in eliciting a neural response.” Using twelve healthy human participants, the authors measured electrophysiological recordings from the scalp to determine if “spatially aligned and misaligned auditory somatosensory stimulation share a common neural mechanism of multisensory interaction.” Each subject was exposed to the following stimulations: 1) somatosensory alone, 2) auditory alone, 3) auditory and somatosensory presented simultaneously to same location such as left hand and ear (spatial aligned), 4) auditory and somatosensory offered to different locations, such as left hand and right ear (spatially misaligned). Responses to the combination auditory and somatosensory stimuli were observed in the auditory regions of the superior temporal plane in the hemisphere contralateral to the hand stimulated. Multisensory responses were compared to the summed unisensory responses. Event related potentials between unisensory and multisensory were not linear. The multisensory stimuli responses, both for aligned and misaligned, were larger in amplitude than for the summed unisensory responses. Multisensory stimulation reaction was greater than unisensory reaction, for both spatial aligned and misaligned arrangements. Spatially aligned and misaligned stimulation follow similar early sensory courses. Findings suggest early auditory somatosensory inter-relationships across space occur before perceptual-cognitive events.

Citation 9: Schroeder C, Foxe J. Multisensory contributions to low-level, 'unisensory' processing. *Curr Opin Neurobio.* 2005;15:454-458.[9]

Schroeder and authors' article reviews the early auditory system's neurophysiology, anatomical structures influencing non-auditory stimulation, and the neurological hierarchy of auditory processing. Human studies utilizing magnetoencephalography and functional magnetic resonance imaging have identified the auditory cortices in the superior temporal plane. Multisensory interactions (audio-visual and audio-somatosensory) register within the region. Intracranial studies of macaque monkeys have demonstrated multisensory (auditory, somatosensory, and visual) input with the auditory cortex. When evaluating stimuli entering the auditory cortex, stimuli sources are not equal in quality or response. Electrically evoked, median nerve stimulation may be mediated subcortically from the extralemniscal structures, while the tactile, vibratory responses may arise through specific lemniscal structures. Nonetheless, both cortical and non-cortical somatosensory and visual information unite onto the auditory cortex. Multiple thalamic structures cause auditory cortex responses when exposed to visual and somatosensory stimulation. Two possibilities exist to explain the activation of the auditory cortex by somatosensory and visual input. They are 1) "the somatosensory and visual inputs, due to their greater spatial precision, might support auditory localization" or 2) "visual and somatosensory inputs to the auditory cortex could predictively 're-set' ongoing auditory cortical activity, thus enhancing the local response to subsequent auditory input." The sensory processing hierarchy is constantly evolving. Current evidence and philosophy primarily support that sensory processing is a collaborative and dynamic system between "new sensory input and ongoing cortical processes." Where and how early multisensory processing fits into this model is yet to be determined.

Citation 10: Ortique S, Jabaudon D, Landis T, Michel C, Maravita A, Blanke O. Preattentive interference between touch and audition: a case study on multisensory alloesthesia. *NeuroReport.* 2005;16:865-868.[10]

Ortique's case report examined alloesthesia in an eighty-four woman. An infarction was located in the right frontoparietal cortex. Symptoms included moderate tactile deficits in the left upper and lower extremities; moderate weakness in the left arm and leg, which resolved; and no visual or auditory deficits. Tactile extinction occurred when unisensory tactile stimulation was applied to the face, hand, and foot. Auditory extinction was noted with left unisensory auditory stimulation. Mild extinction was noted with left visual input. No extinction occurred when unisensory information was applied bilaterally. With respect to multisensory stimulation, mild extinction occurred between vision and touch and marked extinction presented between audition and touch. During testing for multisensory detection between audition and touch, the participant perceived left sided sensory input on the right side. The participant was tested blind folded with somatosensory and auditory stimulation being applied. In general, results indicate that relevant right-sided stimuli were perceived correctly, while left-sided information was mostly perceived on the right. Furthermore, right-sided stimulation with both modalities (touch and sound) often resulted in perception on the left side of the other modality. Specific details of stimulation and results (stimulus location, type, and response) are documented within this article. In conclusion, the results of this case study support that multisensory integration preattentively occurs.

Outline of somatosensory and auditory integration synthesis

I. Introduction
II. Locations within the brain

A. Auditory centers

B. Somatosensory centers

C. Multisensory overlap

III. Multisensory findings and characteristics of auditory and somatosensory stimulation

IV. Feedforward processes

V. Clinical indications

Synthesis of Information Concerning Somatosensory and Auditory Multisensory Stimulation and Integration

Human beings in their interaction with the world do not perceive sensory events as singular events. Sound, touch, sight, taste, smell, proprioception, and vestibular information interact to form the processes and mechanics by which humans learn and experience. Integration of sensory information provides a foundation on which behavior and cognition develop and mature.

Theories concerning multisensory processing have evolved over the past decade. Traditional sensory theories maintained that unisensory centers responded to a specific sensory input. These unisensory centers then integrated to multisensory centers in the higher hierarchy of the brain. Functional MRI, topography, and electrophysiological studies of sensory centers in the brain have altered traditional theories. Today, research indicates that integration of multisensory information occurs early in the hierarchy.[3, 6, 8] In addition, centers previously believed to be unisensory are in fact multisensory.[1, 2]

While primary auditory and somatosensory centers in the brain exist, areas of their sensory overlap are well documented. The location of the primary auditory cortex and belt is in the superior temporal gyri. [2, 3, 6, 9] Tactile information stimulates the primary and secondary somatosensory cortical center located in the left pre- and post-central sulcus of the parietal region of the brain.[2, 6] With respect to tactile and auditory multisensory stimulation, cortical activation occurs in the auditory cortex or auditory belt region and can even cross the Sylvian sulcus.[1-3, 5, 6, 9]

Multisensory studies involving tactile and auditory input provide important findings. Somatosensory stimulation activates the auditory cortex in humans and monkeys.[1, 6, 9] Vibrotactile input has been demonstrated in the auditory cortex of an individual with hearing impairment.[5] In monkeys, sound activated the auditory cortex before touch.[3] However, when sound and touch were activated simultaneously, the activation of the auditory cortex was strongest. In both humans and monkeys, intense responses in the auditory cortex were demonstrated with simultaneous auditory and somatosensory input.[3, 8] Auditory information in conjunction with tactile input assists with making tactile decisions.[4]

Early multisensory feedforward processing exists. Multisensory integration takes place in early cortical centers. The auditory cortices of anaesthetized monkeys responded to multisensory input with little availability from higher centers. [3] In human beings, time course and scalp topography as well as functional MRI display the overlap of tactile and auditory stimulation in the auditory cortex region. Overlapping areas of coactivation within the auditory cortex supports the feed forward and early integration multisensory concepts.[6-8, 10] Early cortical centers are no longer thought to be unisensory.[6]

Findings of multisensory stimulation research provide solid footing for clinical sensory practices. When combined with theories of neural plasticity, sensory and multisensory experiences may assist with neural development or rehabilitation. For instance, tactile information provides stimulation of the auditory cortices in individuals with hearing impairments; multisensory stimulation results in greater activation of cortical centers; and sound permits individuals to make tactile decisions. All of these instances offer value to clinical practice.

The integration of somatosensory and auditory stimulation activates the auditory cortex of the brain. This multisensory stimulation affords more intense cortical activation than unisensory stimulation. Somatosensory and auditory integration is a feed forward process, not dependent on higher centers, and occurs early in the auditory center. Tactile and auditory stimulation simultaneously and individually may positively impact neuroplastic changes in individuals with neurological deficits or impairments.

Six Questions

1. Does the brain demonstrate different areas or types or intensities of activation with respect to various types of tactile stimulation, such as median nerve electrical stimulation, vibrotactile input, pressure input, pinprick stimulation, light tactile input, or others?
2. As most studies use the hand when providing tactile stimulation, do other areas of the body respond differently than the hand when exposed to simultaneous tactile and auditory stimulation?
3. What is ventriloquism with respect to multisensory integration?
4. What cortical influence does visual stimulation have when added to the multisensory stimulation of somatosensory and auditory systems?
5. What types or characteristics of sounds best activate the auditory cortex?
6. In a child with cortical hearing impairment, does activation of the auditory cortex through somatosensory input, change the neuroplasticity of the brain to change hearing?

References

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