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Scientists Examine How the Brain Integrates Sight, Touch, and Sound

Understanding integration of senses may help those with autism, hearing loss, other sensory impairments

WASHINGTON, DC — New research illustrates the importance of the brain's ability to integrate different senses — sight, sound, and touch — and how the brain can adapt when those sensory inputs change. The findings indicate new insight into understanding autism and potential approaches for improving the functioning of people who have lost hearing or other senses. The findings were presented today at Neuroscience 2014, the annual meeting of the Society for Neuroscience and the world's largest source of emerging news about brain science and health.

An estimated 52 million people worldwide have been diagnosed with autism spectrum disorders, and hearing loss affects more than 250 million people globally. Thus, understanding how the brain integrates senses and affects people's perception of the world around them could offer valuable insights for helping a wide array of people — including those with developmental disabilities or sensory impairments.

Today's new findings show that:

- To adapt to deafness, a brain region typically devoted to merging vision and hearing repurposes to strengthening peripheral vision instead (Jenessa Seymour, BA, 623.11, see attached summary).
- A brain region involved in integrating vision and hearing operates differently in people with autism spectrum disorders (Ryan Stevenson, PhD, 331.18, see attached summary).
- Years after a hand transplant or reattachment, brain centers responsible for movement and sense of touch continue to reorganize and have improved function (Scott Frey, PhD, 731.03, see attached summary).
- The degree of pleasure derived from a gentle touch is linked to the distribution of a specialized type of nerve fiber (Susannah Walker, PhD, 339.14, see attached summary).

"This new research deepens our understanding of how communication occurs within and across brain regions to integrate our various senses," said moderator Gordon Shepherd, PhD, of Yale University School of Medicine, an expert on how the brain processes information. "It reveals new and previously unrecognized ways the brain adapts when faced with unprecedented challenges to sensory perception."

This research was supported by national funding agencies such as the National Institutes of Health as well as other private and philanthropic organizations. Find out more about how the brain integrates the senses at *BrainFacts.org*.

Related Neuroscience 2014 Presentations:

Special Lecture: The Sensory Neurons of Touch
Wednesday, Nov. 19, 11:30 a.m.–12:40 p.m., Hall D, WCC

Presidential Special Lecture: The First Steps in Vision: Computation and Repair
Monday, Nov. 17, 5:15–6:25 p.m., Hall D, WCC

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Abstract 623.11 Summary

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Research Indicates How the Brain Strengthens Vision in Deaf Individuals

Connectivity to the brain's primary visual center appears strengthened

Scientists know that the brain adapts to deafness in part by strengthening peripheral vision. Now, a new study shows one way the brain does so: by recruiting neurons previously engaged in integrating multiple senses to focus just on vision. In addition, the connection between this newly recruited region and the brain's primary visual center is strengthened, according to findings presented today at Neuroscience 2014, the annual meeting of the Society for Neuroscience and the world's largest source of emerging news about brain science and health.

This research may provide insights into potential methods for adapting to hearing loss for the nearly 12,000 children born every year in the United States with hearing loss and the 29 million Americans who experience it later in life.

"By recruiting a multisensory part of the brain to focus solely on vision, people who cannot use sound to locate an object have the opportunity to devote additional brain power to locating objects with sight," said Jenessa Seymour of the University of Illinois at Urbana-Champaign. "This finding supports the hypothesis that in the absence of hearing, vision steps in to fill some of the sensory gap."

The study used advanced brain imaging techniques to identify where and when different parts of the brain activated while study participants sought to locate an object in their peripheral vision. The study compared the results of eight individuals who were born deaf to those of 12 hearing adults. Analysis showed that deaf and hearing individuals differed in the extent to which they recruited a portion of the right lobe of brain. In hearing people, the recruited area is engaged in multisensory integration — binding sight and sound into an integrated whole.

They also found that activation of this brain region was correlated with activation of the brain's primary visual center, which occurred shortly beforehand, suggesting a possible direct connection between the two areas.

Going forward, the researchers plan to look at brain adaptation associated with age-related hearing loss and in deaf adults and children who have received cochlear implants. The results should help determine sensitive periods for the brain for adaptation to hearing loss and for sensory rehabilitation after fitting of hearing aids or cochlear implantation.

Research was supported with funds from the National Science Foundation through the Visual Language and Visual Learning Center at Gallaudet University.

Scientific Presentation: Tuesday, Nov. 18, 3–4 p.m., Halls A-C

623.11, enhanced functional connectivity between V1 and multimodal cortex in congenitally, profoundly deaf adults revealed by time-lagged cross-correlation of the "fast" optical signal

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TECHNICAL ABSTRACT: Research has shown that early deafness positively impacts peripheral visual attention. The useful field of view (UFOV) task has previously been used to show that deaf subjects have lower presentation duration thresholds for determining the location of a peripheral target among distractors while performing a concurrent central discrimination task. These appear to be effects of deafness and not using sign language, as deaf non-signers show the effect and hearing signers do not. Here we combined structural MR with diffusive optical imaging techniques to explore how deafness alters functional connectivity between visual and auditory cortices. By combining functional optical data with co-registered structural MR data, it is possible to examine functional connectivity between cortical regions with excellent spatial and temporal resolution. This permits functional connectivity analyses alongside an analysis of processing pathways with excellent temporal precision (c. 39 Hz). Results show that activity in BA17, the primary visual cortex, predicts activity 50 ms later in the posterior STG of the right hemisphere in congenitally, profoundly deaf adults but not in hearing adults. Whilst enhanced recruitment of the posterior STG in the right hemisphere of deaf adults is well known, this is the first demonstration of enhanced functional connectivity between that region and primary visual cortex. The short time lag suggests either (a) direct functional connectivity between these regions rather than a mediated connection, or (b) a common precursor region that routes neural activity to V1 more rapidly than to the posterior STG (possibly the thalamus).

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Atypical Sensory Integration May Contribute to Social, Linguistic Difficulties in Those With Autism
Scientists find less efficient responses in brain area that helps meld sight, sound

A part of the brain that is responsible for "binding" vision and hearing into a unified sensory perception functions differently in people with autism, according to findings presented today at Neuroscience 2014, the annual meeting of the Society for Neuroscience and the world's largest source of emerging news about brain science and health. These findings offer valuable insights into why individuals with autism do not perceive the world around them in the same way as people without autism and could inform therapies for people with autism.

The affected brain region, the superior temporal sulcus (STS), is also involved in speech perception, facial perception, interpreting emotion, and understanding the intentions of others — all areas that individuals with autism tend to struggle with. Typically, an individual benefits from seeing a speaker's face and mouth movements while listening to them speak. Failing to combine speech that is heard with the movements of a speaker's mouth can drastically reduce the ability to effectively communicate.

"We know that individuals with autism have more difficulty binding multiple pieces of sensory information together, leading to a more overwhelming and intensely perceived world," said lead author Ryan Stevenson of the University of Toronto. "We were able to identify how and where these differences occur in the brain."

The scientists identified the critical brain area by conducting brain scans while study participants watched three videos: a woman telling a story (social and linguistic content), a woman making non-speech sounds (social but non-linguistic content), and a video of the game "Mousetrap" (non-social, non-linguistic content). Each video was viewed twice: once with the sound and visuals in sync (bound) and once with the sound and visuals out of sync (unbound).

When the researchers compared the brain scans of a group of people with autism to a group without autism, significant differences appeared in STS function. In participants without autism, the STS always functioned more efficiently when the sensory stimuli were bound, regardless of which video they were watching. But in participants with autism, the STS only functioned more efficiently when watching the bound version of the Mousetrap video. No increase in STS efficiency related to sensory binding was observed when individuals with autism watched videos with social-linguistic content.

"Our research indicates that atypical processing of senses may underlie, or contribute to, social and linguistic difficulties in individuals with autism," Stevenson said.

Research was supported with funds from the Natural Sciences and Engineering Research Council of Canada, the Canadian Institutes of Health Research, and the National Institute on Deafness and Other Communication Disorders.

Scientific Presentation: Monday, Nov. 17, 9–10 a.m., Halls A-C

331.18, Impaired neural processing efficiency of multisensory integration in Autism Spectrum Disorders

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TECHNICAL ABSTRACT: Individuals with Autism Spectrum Disorders (ASD) exhibit deficits in perceptual binding across sensory modalities. One of the strongest factors influencing multisensory integration is the temporal relationship between sensory inputs. Recently, deficits in multisensory temporal processing

have shown behaviorally to specifically impact speech processing in ASD. The neural substrates for the temporal integration of both low-level and speech-related audiovisual stimuli are centered in the posterior superior temporal sulcus (pSTS), an area also known to differ anatomically and functionally in ASD.

This study investigates how multisensory integration processes in pSTS differ between individuals with and without ASD, and if these diagnosis-level differences are specific to social and/or communicative sensory signals. Individuals with and without ASD (N=15 per group), matched for age, IQ, and gender, underwent an fMRI scan while passively viewing auditory-only, visual-only, synchronous AV and asynchronous AV presentations with three types of stimuli: social-linguistic (speaker reading a passage of a story), social non-linguistic (speaker producing non-speech verbal noises), and non-social, non-linguistic stimuli (an object in motion). Concurrent eye-tracking ensured participants attended the stimuli. A region-of-interest (ROI) analysis localized pSTS via a conjunction analysis of activations to unisensory presentations independently for each stimulus type. BOLD responses to synchronous and asynchronous AV presentations were then extracted from these ROIs and compared within and across stimulus types and groups. Data from both groups show reduced peak BOLD activation in the pSTS in response to synchronous relative to asynchronous audiovisual presentations, reflecting increased processing efficiency associated with multisensory binding. In the control group, this increased efficiency was seen with all stimulus types, regardless of social or linguistic content. In the ASD group, however, increased efficiency was seen in non-linguistic conditions, but not seen with speech conditions. These data suggest the behavioral instantiations of impaired multisensory temporal processing seen in previous studies may be, at least in part, a result of atypical neural processing in pSTS, particularly the impairments specific to language. Interestingly, perceptual-feedback training focused on multisensory temporal processing has been shown to improve individuals' abilities to integrate audiovisual stimuli through neuro-plastic changes in the pSTS and, as such, may be a possible remediation tool in ASD.

Abstract 731.03 Summary

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With Time, Brain Adapts to Increase Feeling in Transplanted Hands

Some former amputees reached same level of feeling as those with healthy hands

A new study finds that the restoration of feeling in a reattached or transplanted hand continues to improve for years after surgery. Moreover, this ongoing improvement is likely the result of changes in the brain itself, rather than only in nerves in the hand, which may have implications for future methods of rehabilitation for such injuries. The findings were presented today at Neuroscience 2014, the annual meeting of the Society for Neuroscience and the world's largest source of emerging news about brain science and health.

The organization of the brain's sensory centers depends on neural activity originating in the body. Therefore, these brain regions undergo reorganization after limb amputation. Brain imaging studies of former amputees have suggested that these changes may be at least partially reversible, even when a donor hand is transplanted decades after their injury. However, little has been known about the relationship between these brain changes and the recovery of hand function.

"Our research finds that the ability to identify the location of touch on the hand — which is a function of the brain's primary sensory area — continues to improve for many years after surgery," said Scott Frey of the University of Missouri in Columbia. "This exciting finding speaks to the brain's potential for adaptation in response to increased training, even long after such traumatic injuries. It may also have relevance to how we approach rehabilitation of chronic injuries to the spinal cord, the brain, or other nerves of the arms and legs."

Frey and colleagues at the Christine M. Kleinert Institute for Hand and Microsurgery in Louisville, Ky., tested the ability of eight patients and 14 healthy adults to identify, without vision, where on their palms or fingers light touches were being applied. Four of the patients had undergone replantation of their own hand immediately after amputation, and four had received a transplanted donor hand between two and 13 years after the traumatic loss of their own hand.

For all patients, the ability to accurately locate the touched skin was related to the amount of time since their surgeries — the longer the time, the more accurate their responses. Four of the patients, including two hand transplant recipients (eight and 10 years post-surgery), were able to identify the location of the touch nearly as accurately as the healthy participants.

Research was supported with funds from the Department of Defense and the U.S. Army Medical Research and Materiel Command.

Scientific Presentation: Wednesday, Nov. 19, 10–11 a.m., Halls A-C

731.03, Localization of touch on a replanted or transplanted hand: Evidence for late improvements that may reflect central adaptations

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TECHNICAL ABSTRACT: Former amputees that have had their injured hands replanted (heterotopic hand replants), or received transplantations of a donor hand (allogeneic hand transplants) provide a unique opportunity to evaluate whether the effects of deafferentation on the central nervous system can be reversed. Following sensory nerve transection and repair, peripheral nerve regeneration is estimated to proceed at a rate of up to 2mm per day. However, patients that undergo surgical nerve repairs of the arm or hand show persistent difficulties in localization of touch without vision. This may reflect chronic disorganization of finger maps within the primary sensory (S1) cortex, as suggested by studies in nonhuman primates. We tested the hypothesis that central adaptations associated with extended experience can mitigate these functional limitations in right-handed heterotopic replant recipients (N = 4) and allogeneic hand transplant recipients (N = 3). We adapted the locognosia technique (Nordenboos, 1972) to measure the ability to localize light touch (100mN) on the ventral surface of the hand and

fingers. This method allowed participants to see the position of their hand (eliminating proprioceptive demands), but not the location of the stimulus. On average, healthy adults localized touch with a very high level of precision, and exhibited no differences between sides (Right: Mean ± SD=4.00 ± 3.76, Left: 3.70 ± 3.40). Patients showed substantial variability (Affected hand: 26.03 ± 24.75, Unaffected hand: 4.77 ± 5.16), and a positive correlation between localization accuracy and time since hand replantation or transplantation. Two complete hand transplant recipients (8 and 10 years post-surgery), one mid-palm replant recipient (3 years post-surgery), and one full hand replant recipient (1.5 years post-surgery) exhibited the ability to localize stimuli on their affected hands on average within 95% confidence intervals of the control group. Time since the transplant/replant was correlated with performance (r=-.63). Our findings suggest that hand transplant and replant recipients may recover a very high level of accuracy in touch localization. This ability may continue to improve for years following peripheral nerve repair and regeneration, and is perhaps attributable to central adaptations.

Abstract 339.14 Summary

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Study Suggests Distribution of Specialized Nerves Determines Pleasure of Touch

Scientists theorize that these nerves play prominent role in our 'emotional body map'

New research shows that people's perceptions of how pleasurable a touch feels matches an anatomical map of specialized nerve fibers that respond to slow, gentle touches. Scientists theorize that the anatomical distribution of these nerve fibers determines people's emotional responses to touch, thus forming an emotional body map. The findings were presented today at Neuroscience 2014, the annual meeting of the Society for Neuroscience and the world's largest source of emerging news about brain science and health.

Previous research has demonstrated that seeing another person being touched produces the same emotional responses as feeling that touch oneself. This research extends these previous findings by showing that, similar to the brain's classic sensory map of the body — which reflects tactile sensitivity — there is also a separate body map that reflects the emotional value of touch.

"Our results support the theory that a specialized system of nerves has evolved in mammals that signal the positive emotional value of gentle touch in human relations," said Susannah Walker of Liverpool John Moores University. "We believe this system of nerves is essential because it provides the neurobiological basis for the formation and maintenance of social bonds and attachment relationships."

Touch plays a prominent role in intimate relationships, with important neurodevelopmental, emotional, and social consequences. For example, the high death rates in 19th-century orphanages — where infants were fed but not held — plummeted after the introduction of gentle physical contact. In adults, social touch has been shown to promote trust and increase liking of a person. But little attention has been paid to the neurobiological basis of these observations.

Recently discovered nerve fibers, called C-tactile afferents, don't code pain or itch like other C-nerve fiber types, but rather respond best to gentle, slow touch. Studies in mice have found these fibers are most densely distributed on the back, sparsely present in the limbs, and completely absent from paw skin. In humans, they have been identified in the hairy skin of the body, but never found on the palm of the hand or soles of the feet.

To determine the impact of C-tactile afferents on emotional responses to touch, researchers showed study participants 12 five-second videos. Each clip showed an individual being touched on the back, shoulder, forearm, or palm at one of three speeds. Immediately after viewing each clip, participants rated how pleasant they perceived the touch to be.

Participants rated touch on the back, where C-tactile afferents are likely abundant, as most pleasant, and touch on the forearm, where they are likely to be sparse, as least pleasant. Generally, the most pleasant touch was also associated with a slow-paced stroke, rather than a more rapid one or a static touch. However, on the palm, where these nerve fibers have not been found, the speed of touch made no difference.

Research was supported with funds from the Leverhulme Trust.

Scientific Presentation: Monday, Nov. 17, 9–10 a.m., Halls A-C

339.14, Perceived pleasantness of social touch reflects the anatomical distribution and velocity tuning of C-tactile afferents: An affective homunculus
***S. C. WALKER**, F. P. MCGLONE; Liverpool John Moores Univ., Liverpool, United Kingdom

TECHNICAL ABSTRACT: Recently, a subclass of c-fibers have been discovered that respond preferentially to low force/velocity stroking touch, which is typically perceived as pleasant (Vallbo et al 1999). It has been proposed that these C-tactile afferents (CT) form the first stage of encoding of socially relevant and rewarding tactile information resulting from affiliative behaviors in humans and other mammals (McGlone et al 2007). Molecular genetic visualization of these

fibers in mice revealed a denser distribution in dorsal than ventral thoracic sites, scattered distal limb innervation, and a complete absence from glabrous paw skin (Liu et al 2007). Here we used third-party ratings to examine whether affective responses to social touch reflect the anatomical distribution and velocity tuning of CTs. Participants viewed and rated a sequence of 12 short (five-second) videos depicting one individual being touched by another at four different skin sites (back, shoulder, forearm and palm) and at three different velocities (static, 3cm/second, 30cm/second). Immediately after viewing each clip, participants were asked to rate how pleasant they perceived the touch to be. A significant effect of speed was found, with 3cm/second rated more positively than the other two velocities. There was also a significant effect of location. Simple main effects analysis revealed that vicarious preferences matched the previously reported anatomical innervation density of CTs, with touch on the back being rated significantly higher, and the forearm lower, than any other location. Furthermore, a significant "location x speed" interaction reflected that, in contrast to all other skin sites, CT optimal (3cm/second) touch on the palm of the hand was not preferred to static touch, consistent with the absence of CTs in glabrous skin. In line with previous research showing that seen touch produces the same subjective and affective responses as felt touch (Morrison et al 2011), these results demonstrate that humans have a preference for CT optimal, caressing touch. Furthermore, this preference reflects the specific anatomical distribution of CTs. This finding has significant implications for future CT research in humans; with studies to date focusing on the relatively sparsely innervated and non-preferred, forearm. Penfield's iconic sensory homunculus is based on how discriminative touch is represented in the brain. fMRI studies have demonstrated an anatomical dissociation of discriminative (Aβ/AΔ mediated) from emotional (C fiber mediated) neural representations of touch (Francis et al 1999). The findings from the present study suggest a second, affective homunculus exists to be mapped.