Haptics in Neuroscience

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1 INTRODUCTION

The neuroscience of haptics has made many breakthroughs over the last six or so decades and these scientific advances are now being leveraged to develop new therapies for patients suffering from sensorimotor disorders and new technologies to improve our everyday lives. This special section features a broad range of studies, some of which advance our basic understanding of haptics, others develop devices to further study haptics neuroscience, and still others invoke what is known about the neural basis of haptics to develop new therapeutic or augmentative devices.

2 THE SCIENCE OF HAPTICS

While our understanding of haptics has improved greatly over the last few decades, much remains to be elucidated. In particular, there is a compelling need to characterize the sense of touch in a way that will inform the development of haptic interfaces. To this end, “Vibrotactile Spatial Acuity and Intensity Discrimination on the Lower Back Using Coin Motors” by H. Christiaan Stronks, Daniel J. Parker, and Nick Barnes characterized, in a series of psychophysical experiments, the ability of human subjects to distinguish different tactile patterns delivered to the skin of the lower back using inexpensive tactile stimulation devices (coin motors) that have the potential to become commercial devices with numerous haptic applications. This work will define the capabilities of these apparatuses to convey information haptically and will set the foundation for the development of therapeutic or augmentative devices.

While the above investigated the perceptual consequences of changing the patterns of tactile stimulation, another study investigated the neural mechanisms that mediate our ability to discriminate different vibrotactile patterns. Junsuk Kim, Yoon Gi Chung, Soon-Cheol Chung, Heinrich H. Bültthoff, and Sung-Phil Kim in “Neural Categorization of Vibrotactile Frequency inFlutter and Vibration Stimulations: An fMRI Study” measured brain activity evoked by skin vibrations varying in frequency using functional magnetic resonance imaging. They identified two areas—primary somatosensory cortex and the supramarginal gyrus—whose activity was modulated by the frequency of stimulation. Furthermore, the patterns of brain activity seemed to mirror perceptual patterns that have been identified in previous behavioral studies. The research team concluded that these somatosensory cortical regions mediate our ability to distinguish the frequency of skin vibrations.

Another important question in haptics is how motor behavior influences haptic perception. Active exploration has been shown to lead to far better object recognition than passive presentation. However, touch has also been shown to be suppressed during movement [1]. To address this seeming discrepancy, Tomohiro Amemiya and Hiroaki Gomi in “Active Manual Movement Improves Directional Perception of Illusory Force” induced illusory forces by delivering asymmetric vibrations to the skin and have subjects discriminate in the presence or absence of movement. They find that the perception of force is enhanced during movement, suggesting that the interactions between movement and tactile perception are more complex than previously thought.

Touch plays a critical role in haptic object recognition, in affective communication, and in embodiment. A study by Tomohiro Amemiya, Koichi Hirota, and Yasushi Ikei in “Tactile Apparent Motion on the Torso Modulates Perceived Forward Self-Motion Velocity” suggests that it might also contribute to our perception of self-motion. The research team investigated the tactile flow created by vibrational actuators arrayed on the torso. They show that the tactile stimulation enhances the perception of forward motion that is induced by optical flow, presented on a computer monitor. This work can be leveraged to augment sensations of virtual motion in various automotive and entertainment applications.

3 DEVICES DESIGNED TO ADVANCE HAPTIC NEUROSCIENCE

Neuroscience has experienced enormous growth in the last two decades, not only in terms of the number of investigators, but also in terms of the range of technologies that have been brought to bear on the study of the nervous system. New technologies pave the way for new insights. The neuroscience of haptics is no exception. Trung Quang Pham, Takayuki Hoshi, Yoshihiro Tanaka, Akihito Sano, Takumi Kawae, and Takaki Miyata in “Two-Photon Imaging of DiO-Labelled Meissner Corpuscle in Living Mouse’s Fingertip” visualized, for the first time, the afferent axons innervating a Meissner corpuscle in the fingertip of a living mouse using two-photon microscopy. With this approach, they hope to examine axonal growth and terminal arborization during the development of a living organism, which will eventually lead to better understanding of the sensory innervation of the skin.

The friction between the skin and a surface plays an important role both in our ability to interact with objects.
Indeed, we exert just enough force to avoid dropping an object, and the necessary amount of force depends critically on friction. However, our understanding of skin/surface interactions and our ability to measure these are still relatively primitive. To fill this gap, Allan Barrea, David Cóordova Bulens, Philippe Lefèvre, and Jean-Louis Thonnard in “Simple and Reliable Method to Estimate the Fingertip Static Coefficient of Friction in Precision Grip” describe a simple method to reliably measure friction. The approach consists of moving a finger back and forth on the surface of a fixed six-axis force and torque sensor then computing the static coefficient of friction as the ratio of tangential to normal force at slip onset. The research team shows that the relationship between the friction coefficient and normal force during a precision grip follows a power law with a negative exponent. Importantly, this method can be used to continuously estimate the friction coefficient during object manipulation and is sure to provide insights into how tactile feedback is integrated to guide object interactions.

4 HAPTIC THERAPEUTIC AND AUGMENTATIVE DEVICES

Haptics play a critical role in everyday life and somatosensation—touch and proprioception—are intimately linked to motor control. Accordingly, attempts to restore motor function often involve therapies targeting the somatosensory system. For example, one approach to restore sensorimotor function in amputees and tetraplegic patients consists in equipping them with bionic arms which they can control either through myoelectric or neural signals, respectively. Given the critical importance of somatosensation in object manipulation, however, these bionic arms will not be clinically viable until this sensory feedback is restored [2], [3]. One critical component of the tactile feedback is the sensorization of the robotic fingertip, from which the sensory signals originate. Benoit P. Delhaye, Erik W. Schluter, and Sliman J. Bensmaia in “Robo-Physchophysics: Extracting Behaviorally Relevant Features from the Output of Sensors on a Prosthetic Finger” investigated the degree to which the robotic finger can convey tactile information critical to object manipulation. To this end, they test the finger’s sensory abilities using psychological paradigms that have been extensively used to probe human sensory abilities. They find that the finger’s performance on these tasks matches that of human observers. They conclude that the sensorization of the finger will not constitute a bottleneck in conveying sensory feedback in bionic hands.

In a related study, Maria C. Dadarlat and Philip N. Sabes in “Encoding and Decoding of Multi-Channel ICMS in Macaque Somatosensory Cortex” investigated a novel approach to convey haptic feedback by electrically stimulating the somatosensory cortex (S1)—the region of the brain that receives haptic input from the hand—using penetrating electrodes implanted in non-human primates (Rhesus macaques). Specifically, they have the animals move their arms towards invisible targets, the location of which is indicated through patterns of electrical stimulation of S1. In a previous study [4], they had shown that animals can use this artificial haptic feedback to perform the task. In the present study, they degrade the sensory feedback to investigate how the animals used the haptic feedback to perform the task. They are able to show that the animals use a systematic strategy to interpret this artificial feedback efficiently.

Another approach to conveying haptic feedback consists in electrically stimulating the brain using electrodes placed on the surface of the brain, just beneath the dura, rather than penetrating the cortex as done in the Dadarlat and Sabes study described above. Little work has been done, however, to investigate the potential of this less invasive approach to stimulate the S1. To fill this gap, Jeneva A. Cronin, Jing Wu, Kelly L. Collins, Devapratim Sarma, Rajesh P. N. Rao, Jeffrey G. Ojemann, and Jared D. Olson in “Task-Specific Somatosensory Feedback via Cortical Stimulation in Humans” have a subject perform a task guided by artificial feedback consisting of electrical stimulation of S1 delivered through electrocorticographic electrodes. Specifically, they show that a human subject can use this artificial feedback to track a target aperture width with their hand. This study constitutes the first demonstration that non-penetrating electrodes can be used to guide behavior in a human subject.

Seyed Farokh Atashzar, Mahya Shahrzadi, Christopher Ward, Olivia Samotus, Mehdi Delrobaei, Fariborz Rahimi, Jack Lee, Mallory Jackman, Mandar S. Jog, and Rajni V. Patel in “Haptic Feedback Manipulation During Botulinum Toxin Injection Therapy for Focal Hand Dystonia Patients: A Possible New Assistive Strategy” conducted a study aimed at designing therapies for focal hand dystonia (FHD). To this end, they investigate the effects of combined botulinum toxin treatment and robotics-assisted writing in patients with writer’s cramp, which is a common type of FHD. They find that reducing the rigidity of surfaces significantly reduces the severity of dystonia and, in some cases, eliminates it completely. These results highlight the sensory contribution to FHD and suggest ways in which haptic manipulation strategies and specially designed haptic tools may lead to better control over the patient’s grip force and thus to a restoration of the ability to write.

Sara Contu, Charmayne Mary Lee Hughes, and Lorenzo Masia in “The Role of Visual and Haptic Feedback During Dynamically Coupled Bimanual Manipulation” investigated the effect of combining haptic and visual feedback in a virtual reality bimanual task involving grasping and moving a virtual object. In contrast to previous efforts studying dynamically uncoupled movements of the two limbs, the authors implement a task that requires the coordination of both wrists to manipulate a single virtual object. The wrist exoskeleton is used as a kinesthetic feedback device to display the dynamics of the virtual object as it is manipulated by both limbs. They find that haptic feedback is necessary to complete the task and plays a critical role in guiding the subjects to accurately grasp the virtual object. The results may have important implications for applications requiring bimanual manipulation of virtual environments, for example, remote surgery, where the implementation of haptic feedback is still relatively primitive.

5 CONCLUSION

As summarized above, this special section on Haptics in Neuroscience highlights the breadth of haptics research and
the powerful interactions between haptics engineering and neuroscience. Engineers are developing ways to better interrogate the somatosensory system and neuroscientists are achieving a deeper understanding of the neural basis of haptics, which in turn is informing the development of therapeutic and augmentative haptic devices. It is an exciting time to be in the field of haptics!

REFERENCES


Ingvars Birznieks received the PhD degree from Umeå University in Sweden and got research experience at the University of Melbourne, Australia. He is a sensory neurophysiologist interested in sensory information encoding mechanisms. During his postdoctoral studies at the Prince of Wales Medical Research Institute in Sydney, he broadened his research competence investigating pain mechanisms, proprioception, and function of the autonomic nervous system. After his postdoc studies, he had the opportunity to pursue his long time ambition to establish his own research network centered around cross-disciplinary research linking neuroscience, biomedical engineering, and clinical neurology. From 2011 to 2014, he held the academic position of senior lecturer (physiology) in the School of Science and Health, Western Sydney University where he engaged in the Biomedical Engineering and Neuroscience (BENS) research program at the MARCS Institute for Brain, Behaviour & Development. Since 2014, he has been a senior lecturer in the Department of Physiology, School of Medical Sciences, UNSW Medicine in Sydney. In the role of a senior research fellow, he leads the Tactile Research Group at the Neuroscience Research Australia (NeuRA).

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Sliman Bensmaia received the BA degree in cognitive science from the University of Virginia, in 1995, and the PhD degree in cognitive psychology from the University of North Carolina, Chapel Hill, in 2003, under the tutelage of Dr. Mark Hollins. He then joined the laboratory of Dr. Kenneth Johnson, at the Johns Hopkins University Krieger Mind/Brain Institute, as a postdoctoral fellow. In 2009, he joined the faculty in the Department of Organismal Biology and Anatomy at the University of Chicago, where he is also a member of the Committees on Neurobiology and on Computational Neuroscience. He is a leading expert on the neural basis of somatosensation in human and non-human primates, which his laboratory investigates by combining psychophysics, neurophysiology, and computational modeling. He also seeks to apply insights from basic science to develop approaches to convey sensory feedback in upper-limb neuroprostheses.

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