University of Rochester
Center for Visual Science
31st Symposium

Frontiers in Virtual Reality

June 1-3, 2018
Memorial Art Gallery, Rochester, New York
**General Information**

You may not bring food or drink into the auditorium. Snacks and beverages must be consumed in designated areas only!

**Wifi**
Public wifi is available. Look for the UR Guest network.

**Shuttle Information**
Although the Memorial Art Gallery is just a 5-8 minute walk from the Strathallan hotel and East Avenue Inn & Suites, we did set up a shuttle schedule in case of inclement weather.

**East Avenue Inn & Suites:**
Individuals staying at this hotel should make shuttle arrangements directly with the hotel front desk staff

**Holiday Inn Rochester Downtown:**
7pm departure from the Holiday Inn on Thursday evening to Welcome Reception
9pm pick up from the Strathallan Hotel/Welcome Reception on Thursday evening
8:30am drop off @ meeting venue on Friday
9pm pick up from the meeting venue on Friday
8:30 am drop off @ the meeting venue on Saturday
6pm & 9pm pick up from the meeting venue on Saturday
9am drop off @ meeting venue on Sunday
Sunday to airport: You will be responsible for arranging your own transportation

**Strathallan Shuttle Info:**
8am drop off @ meeting venue on Friday & Saturday
6pm & 9pm pick up from meeting venue on Friday & Saturday
8:50am drop off @ meeting venue on Sunday
1pm pick up from meeting venue on Sunday (to airport)

**Lunch Options Friday and Saturday**
Go to [http://www.cvs.rochester.edu/symposium/logistics.html](http://www.cvs.rochester.edu/symposium/logistics.html)
Click on the interactive google map. Many nearby restaurants have been marked on the map with access to directions and reviews.

**Oculus Rift Demo Station**
Oculus Rift has a demo station set up in the Bausch & Lomb Parlor on Friday, June 1 from 12-4PM and 5:30-9PM and on Saturday, June 2 from 8:20AM-4:30PM.
Posters
Posters need to be taken down between the end of the Saturday afternoon break (4pm), and before the 6 pm cocktail hour begins.

Program Committee
Duje Tadin
Gabriel Diaz
Ed Lalor
Schedule

31st CVS Symposium, Frontiers in Virtual Reality

June 1-3, 2018 at Memorial Art Gallery, Rochester NY

Thursday, May 31

7:00 - 9:00 pm—Registration & Welcome Reception, Strathallan Hotel

Friday, June 1

***12pm – 4pm & 5:30pm – 9:00pm: Oculus Rift demo station, Bausch & Lomb Parlor

8:20 - 9:00 am—Registration & Breakfast

9:00 - 9:05 am—Welcome: David Williams, University of Rochester

9:05 - 10:05 am—Keynote: Martin Banks, Univ. of California, Berkeley
Accommodation, vergence, and stereoscopic displays

10:05 - 11:05 am—Keynote: Barry Silverstein, Facebook Reality Labs
The Opportunities and Challenges of Creating Artificial Perception Through Augmented and Virtual Reality

11:05 am - 2:00 pm—Lunch (off site)

Session 1: Multisensory Processing
Chair: Edmund Lalor, University of Rochester

2:00 - 2:30 pm—Roberta Klatzky, Carnegie Mellon University
Haptic rendering of material properties

2:30 - 3:00 pm—Amir Amedi, Hebrew University
Nature vs. Nurture factors in shaping up topographical maps and category selectivity in the human brain: insight from SSD and VR fMRI experiments

3:00 - 4:00 pm—Coffee break & posters
**Session 2: Applications**  
Chair: Krystel Huxlin, University of Rochester

4:00 - 4:30 pm—**Matthew Noyes, NASA Johnson Space Center**  
*Hybrid Reality: One Giant Leap For Full Dive*

4:30 - 5:00 pm—**Benjamin Backus, Vivid Vision Inc. and SUNY College of Optometry**  
*Mobile VR for vision testing and treatment*

5:00 - 5:30 pm—**Stephen Engel, University of Minnesota**  
*Inducing visual neural plasticity using virtual reality*

6:00 - 9:00 pm—Grazing dinner & poster session

**Saturday, June 2**

***8:20am – 4:30pm: Oculus Rift demo station, Bausch & Lomb Parlor***

8:20 - 9:00 am—Registration & Breakfast

**Session 3: AR/VR Displays and Optics**  
Chair: Michael Murdoch, RIT

9:00 - 9:30 am—**Jannick Rolland, University of Rochester**  
*Augmented reality and the freeform revolution*

9:30 - 10:00 am—**Kaan Akşit, NVIDIA**  
*Computational Near Eye Display Optics*

10:00 - 10:30 am—**Marina Zannoli, Oculus VR**  
*Perception-centered development of AR/VR displays*

10:30 - 11:00 am—**Yon Visell, UC Santa Barbara**  
*Haptics at Multiple Scales: Engineering and Science*

11:00 am - 1:15 pm—Lunch (off site)

**Session 4: Space and Navigation**  
Chair: Greg DeAngelis, University of Rochester

1:30 - 2:00 pm—**Aman Saleem, University College London**  
*Vision to Navigation: Information processing between the Visual Cortex and Hippocampus*

2:00 - 2:30 pm—**Arne Ekstrom, UC Davis Center for Neuroscience**  
*How virtual and altered reality can help us to understand the neural basis of human spatial navigation*
2:30 - 3:00 pm—Mary Hayhoe, University of Texas Austin  
Spatial Memory and Visual Search in Immersive Environments

3:00 - 4:00 pm—Coffee break & posters

Session 5: Perception and Action  
Chair: Martina Poletti, University of Rochester

4:00 - 4:30 pm—Sarah Creem-Regehr, University of Utah  
Through the Child’s Looking Glass: A Comparison of Children and Adult Perception and Action in Virtual Environments

4:30 - 5:00 pm—Gabriel Diaz, Rochester Institute of Technology  
Unrestricted Movements of the Eyes and Head When Coordinated by Task

5:00 - 5:30 pm—Jody Culham, Western University  
Differences between reality and common proxies raise questions about which aspects of virtual environments matter in cognitive neuroscience

6:00 - 9:00 pm—Banquet

Sunday, June 3

9:00 - 9:30 am—Breakfast

Session 6: Visual Perception  
Chair: Gabriel Diaz, Rochester Institute of Technology

9:30 - 10:00 am—Flip Phillips, Skidmore College  
Exploring the Uncanny Valley

10:00 - 10:30 am—Wendy Adams, University of Southampton  
Material rendering for perception: vision, touch and natural statistics

10:30 - 11:00 am—Coffee break

11:00 - 11:30 am—Laurie Wilcox, York University, Centre for Vision Research  
Depth perception in virtual environments

11:30 am - 12:00 pm—Bas Rokers, University of Wisconsin  
Processing of sensory signals in VR

12:00 - 1:00 pm—Box Lunch (on site)

End of meeting
Talk Abstracts
Accommodation, vergence, and stereoscopic displays

Martin Banks, University of California, Berkeley

Improving comfort in augmented- and virtual-reality displays (AR and VR) is a significant challenge. One known source of discomfort is the vergence-accommodation conflict. In AR and VR, the eyes accommodate to a fixed screen distance while converging to the simulated distance of the object of interest. This requires undoing the natural coupling between the two responses and thereby leads to discomfort. We investigated whether various display methods (depth-of-field rendering, focus-adjustable lenses, and monovision) can alleviate the vergence-accommodation conflict. We measured accommodation in a VR setup using those methods. The focus-adjustable-lens method drives accommodation effectively (thereby resolving the vergence-accommodation conflict); the other methods do not. We also show that the ability to drive accommodation correlates significantly with viewer comfort.

In computer graphics, the primary goal for realistic rendering has been to create images that are devoid of optical aberrations. But for displays that are meant to give human viewers realistic experiences (i.e., AR and VR), this goal should change. One should instead produce display images that, when viewed by a normal eye, produce the retinal images that are normally experienced. Creating such images reduces to a deconvolution problem that we have solved accurately for most cases. I will describe results that show that creating blur properly drives the human focusing response while creating blur in conventional fashion does not.
June 1, 2018: Keynotes
10:05 - 11:05 am

The Opportunities and Challenges of Creating Artificial Perception Through Augmented and Virtual Reality

Barry Silverstein
Facebook Reality Labs

We live in interesting times. Physics, chemistry, and biology are beginning to mesh with computer and social sciences. Advancing technologies driven by this merging of science is enabling new integrated solutions in many spaces. Today researchers are beginning to create and deliver realistic artificial human inputs. These inputs of sight, sound, motion, and touch are being woven together into virtual and augmented reality systems than can start to emulate convincing human perception. While movies have always tried to do this for groups with controlled story telling, AR and VR attempt to take this further. Simultaneously simulating multifaceted content in reaction to individual’s actions, thoughts, needs and wants is the next step in entertainment, information exchange, social interaction and more. We are not there yet, but by conquering further technical challenges we can expect a revolutionary change to the human computer interface and along with it significant opportunities to enhance our lives.
Haptics at Multiple Scales: Engineering and Science

Yon Visell, UC Santa Barbara

A longstanding goal in engineering has been to design technologies that are able to reflect the amazing perceptual and motor capabilities of biological systems for touch, including the human hand. This turns out to be very challenging. One reason for this is that, fundamentally, our understanding of what is felt when we touch objects in the world, which is to say haptic stimuli, is fairly limited. This is due in part to the mechanical complexity of touch interactions, the multiple length scales and physical regimes involved, and the sensitive dependence of what we feel on how we touch and explore. I will describe research in my lab on a few related problems, and will explain how the results are informing the development of new technologies for wearable computing, virtual reality, and robotics.


Acknowledgements:
NSF CNS-1446752, NSF CISE-1527709, NSF CISE-1751348
Humans haptically perceive the material properties of objects, such as roughness and compliance, through signals from sensory receptors in skin, muscles, tendons, and joints. Approaches to haptic rendering of material properties operate by stimulating, or attempting to stimulate, some or all of these receptor populations. My talk will describe research on haptic perception of roughness and softness in real objects and surfaces and by rendering with a variety of devices.

Acknowledgements:
NSF grant CHS 1518630.
Nature vs. Nurture factors in shaping up topographical maps and category selectivity in the human brain: insight from SSD and VR fMRI experiments

Amir Amedi, Hebrew University

“The best technologies make the invisible visible.” -Beau Lotto. My lab studies the principles driving specializations in the human brain and their dependence on specific experiences during development (i.e. critical/sensitive periods) versus learning in the adult brain. Our www.BrainVisionRehab ERC project focuses on studying Nature vs. Nurture factors in shaping up category selectivity in the human brain. A key part of the project involves the use algorithms which convert visual input to blind using music and sound.

From basic science perspective the most intriguing results came from studying blind without any visual experience. We documented that essentially most if not all higher-order ‘visual’ cortices can maintain their anatomically consistent category-selectivity (e.g., for body shapes, letters, numbers and even faces; e.g. Amedi et al TICS 2017) even if the input is provided by an atypical sensory modality learned in adulthood. Our work strongly encourages a paradigm shift in the conceptualization of our sensory brain by suggesting that visual experience during critical periods is not necessary to develop anatomically consistent specializations in higher-order ‘visual’ or ‘auditory’ regions. This also have implications to rehabilitation by suggesting that converging multisensory training is more effective.

In the second part of the lecture I will focus on the dorsal visual stream and will focus on navigation in virtual environments. Humans rely on vision as their main sensory channel for spatial tasks and accordingly recruit visual regions during navigation. However, it is unclear if these regions role is mainly as an input channel, or if they also play a modality independent role in spatial processing. Sighted, blind and sighted-blindfolded subjects navigated virtual environments while undergoing fMRI scanning before and after training with an auditory navigation interface. We found that retinotopic regions, including both dorsal stream regions (e.g. V6) and primary regions (e.g. peripheral V1), were recruited for non-visual navigation after training, again demonstrating a modality-independent task-based role even in retinotopic regions.

In the last part I will also discuss initial results from our new ERC ExperieSense project. In this project we focus on transmitting invisible topographical information to individuals with sensory deprivation but also augmented topographical information to normally sighted and testing whether novel topographical representations can emerge in the adult brain to input that was never experienced during development (or evolution).
Virtual reality is ideal for generating photorealistic imagery and binaural audio at low cost, important for context-dependent memory recall in a training program. Physical reality is ideal for tactile interaction, a vital component for developing muscle memory. By combining elements of virtual and physical reality (called "Hybrid Reality"), for example by 3D printing objects of interest with accurate topology, tracking those objects in 3D space, and overlaying photorealistic virtual imagery in a VR headset, it becomes much easier to create immersive simulations with minimal cost and schedule impact, with applications in training, prototype design evaluation, scientific visualization, and human performance study. This talk will showcase projects leveraging Hybrid Reality concepts, including demonstrations of future astronaut training capability, digital lunar terrain field analogs, a space habitat evaluation tool, and a sensorimotor countermeasure against the effects of gravitational transition.
Mobile VR for vision testing and treatment

Benjamin T. Backus, PhD

Chief Science Officer
Vivid Vision, Inc.

Consumer-level HMDs are adequate for many medical applications. Vivid Vision (VV) takes advantage of their low cost, light weight, and large VR gaming code base to make vision tests and treatments. The company’s software is built using the Unity engine, which allows for multiplatform support in the Unity framework, allowing it to run on many hardware platforms. New headsets are available every six months or less, which creates interesting challenges within the medical device space. VV’s flagship product is the commercially available Vivid Vision System, used by more than 120 clinics to test and treat binocular dysfunctions such as convergence difficulties, amblyopia, strabismus, and stereo blindness. VV has recently developed a new, VR-based visual field analyzer.
Inducing visual neural plasticity using virtual reality

Stephen A. Engel, University of Minnesota

In the visual system, neural function changes dramatically as people adapt to changes in their visual world. Most past work, however, has altered visual input only over the short-term, typically a few minutes. Our lab uses virtual reality displays to allow subjects to live in, for hours and days at a time, visual worlds manipulated in ways that target known neural populations. One experiment, for example, removed vertical energy from the visual environment, effectively depriving orientation-tuned neurons of input. Results suggest that visual adaptation is surprisingly sophisticated: it has a memory that allows us to readapt more quickly to familiar environments, it acts simultaneously on multiple timescales, and it is sensitive to not only the benefits of plasticity, but also its potential costs. Current research is applying these lessons to studies of amblyopia and macular degeneration.

Acknowledgements:
Supported by NSF grant BCS1558308
Augmented reality and the freeform revolution

Jannick Rolland, University of Rochester

The ultimate augmented reality (AR) display can be conceived as a transparent interface between the user and the environment—a personal and mobile window that fully integrates real and virtual information such that the virtual world is spatially superimposed on the real world. An AR display tailors light by optical means to present a user with visual information superimposed on spaces, buildings, objects, and people. These displays are powerful and promising because the augmentation of the real world by visual information can take on so many forms. In this talk, we will provide a short historical highlight of early work in optics for AR and engage the audience on the emerging technology of freeform optics that is poised to permeate various approaches to future display technology.
June 2, 2018: AR/VR Displays and Optics
9:30 - 10:00 am
Computational Near Eye Display Optics

Kaan Akşit, NVIDIA

Almost 50 years ago, with the goal of registering dynamic synthetic imagery onto the real world, Ivan Sutherland envisioned a fundamental idea to combine digital displays with conventional optical components in a wearable fashion. Since then, various new advancements in the display engineering domain, and a broader understanding in the vision science domain have led us to computational displays for virtual reality and augmented reality applications. Today, such displays promise a more realistic and comfortable experience through techniques such as additive lightfield displays, holographic displays, always-in-focus displays, discrete multiplane displays, and varifocal displays.


Acknowledgements:
David Luebke
Perception-centered development of AR/VR displays

Marina Zannoli, Oculus VR

Mixed reality technologies have transformed the way content creators build experiences for their users. Pictures and movies are created from the point of view the artist and the viewer is a passive observer. In contrast, creating compelling experiences in AR/VR requires us to better understand what it means to be an active observer in a complex environment. In this talk, I will present a theoretical framework that describes how AR/VR technologies interface with our sensorimotor system. I will then focus on how, at Oculus Research, we develop new immersive display technologies that support accommodation. I will present a few of our research prototypes and describe how we leverage them to help define requirements for future AR/VR displays.
We constantly move from one point to another or navigate in the world: in a room, building or around a city. While navigating, we look around to understand the environment, and our position within it. We use vision naturally and effortlessly to navigate in the world. How does the brain use visual images observed by the eyes for natural functions such as navigation? Research into this area has mostly focused at the two ends of this spectrum: either understanding how visual images are processed, or how navigation related parameters are represented by the brain. However, little is known regarding how visual and navigational areas work together or interact. The focus of my research is to bridge the gap between these two fields of research using a combination of rodent virtual reality, electrophysiology and optogenetic technologies. One of the first steps towards this question is to understand how the visual system functions during navigation. I will describe work on neural coding and brain oscillations in the primary visual cortex during locomotion: we discovered that running speed is represented in the primary visual cortex, and how it is integrated with visual information. I will next describe work on how the visual cortex and hippocampus work in cohesion during goal-directed navigation, based on simultaneous recordings from the two areas. We find that both these areas make correlated errors and display neural correlates of behaviour. I will finally show some preliminary work on information processing in areas intermediate to the primary visual cortex and the hippocampus.
How virtual and altered reality can help us to understand the neural basis of human spatial navigation

Arne Ekstrom, UC Davis Center for Neuroscience

Devices like head-mounted displays and omnidirectional treadmills offer enormous potential for gaming and networking-related applications. However, their use in experimental psychology and cognitive neuroscience, so far, have been relatively limited. One of clearest applications of such novel devices is the study of human spatial navigation, historically an understudied area compared to more experimentally-constrainable studies in rodents. Here, we present several experiments the lab has conducted using VR/AR, and describe the novel insights they provide into how we navigate. We also discuss how such devices, when combined with functional magnetic resonance imaging (fMRI) and wireless scalp EEG, also provide new insights into the neural basis of human spatial navigation.
Spatial Memory and Visual Search in Immersive Environments

Mary M Hayhoe and Chia-Ling Li, University of Texas Austin

Search is a central visual function. Most of what is known about search derives from experiments where subjects view 2D displays on computer monitors. In the natural world, however, search involves movement of the body in large-scale spatial contexts and it is unclear how this might affect search strategies. In this experiment, we explore the nature of memory representations developed when searching in an immersive virtual environment. By manipulating target location, we demonstrated that search depends on episodic spatial memory as well as learnt spatial priors. Subjects rapidly learned the large-scale structure of the space, with shorter paths and less head rotation to find targets. These results suggest that spatial memory of the global structure allows a search strategy that involves efficient attention allocation based on the relevance of scene regions. Therefore the costs of moving the body may need be considered as a factor in the search process.

Acknowledgements:
Supported by NIH EY05729
June 2, 2018: Perception and Action

4:00 - 4:30 pm

Through the Child’s Looking Glass: A Comparison of Children and Adult Perception and Action in Virtual Environments

Sarah Creem-Regehr & Jeanine Stefanucci, University of Utah
Bobby Bodenheimer, Vanderbilt

The utility of immersive virtual environments (VEs) for many applications increases when viewers perceive the scale of the environment as similar to the real world. Systematic study of human performance in VEs, especially in studies of perceived action capabilities and perceptual-motor adaptation, has increased our understanding of how adults perceive and act in VEs. Research with children has just begun, thanks to new commodity-level head-mounted-displays suitable for children with smaller heads and bodies. Children’s perception and action in VEs is particularly important to study, not only because children will be active consumers of VEs but also because children’s rapidly changing bodies likely influence how they perceive and adapt their actions. I will present an overview of our approach to studying children and teens in a variety of tasks involving perceived affordances and recalibration in VEs, showing both similarities and differences across age groups.
It is known that the head and eyes function synergistically to collect task-relevant visual information needed to guide action. Although advances in mobile eye tracking and wearable sensors have now made it possible to collect data about eye and head pose while subjects explore the three-dimensional environment, algorithms for data interpretation remain relatively underdeveloped. For example, almost all gaze event classifiers algorithmically define fixation as a period when the eye-in-head velocity signal is stable. However, when the head can move, fixations also arise from coordinated movements of the eyes and head, for example, through the vestibulo-ocular reflex. Thus to identify fixations when the head is free requires that one accounts for head rotation. Our approach was to instrument multiple subjects with a hat-mounted 2D RGB stereo camera, a 6-axis inertial measurement unit, and a 200 Hz Pupil Labs eye tracker to record angular velocity of the eyes and head as they performed a variety of tasks that involve coordinated movements of the eyes and head. These tasks, include walking through a corridor, making tea, catching a ball, and performing a simple visual search task. Four trained labelers manually annotated a portion of the dataset as periods of gaze fixations (GF), gaze pursuits (GP), and gaze shifts (GS). In this presentation, I will report some of our initial findings from our efforts to understand the principles of coordination between the eyes and head outside of the laboratory. In addition, I will report current progress towards training a Forward-Backward Recurrent Window (FBRW) classifier for the automated classification of gaze events hidden within the eye+head velocity signals.
Differences between reality and common proxies raise questions about which aspects of virtual environments matter in cognitive neuroscience

Jody C Culham, Western University

Psychologists and neuroimagers commonly study perceptual and cognitive processes using images because of the convenience and ease of experimental control they provide. However, real objects differ from pictures in many ways, including the availability and consistency of depth cues and the potential for interaction. Across a series of neuroimaging and behavioral experiments, we have shown different responses to real objects than pictures, in terms of the level and pattern of brain activation as well as visual preferences. Now that these results have shown quantitative and qualitative differences in the processing of real objects and images, the next step is to determine which aspects of real objects drive these differences. Virtual and augmented reality environments provide an interesting approach to determine which aspects matter; moreover, knowing which aspects matter can inform the development of such environments.

Acknowledgements:
This research was funded by the Natural Sciences and Engineering Research Council of Canada and the Canadian Institutes of Health Research. Research projects were led by Jacqueline Snow, with technical support from Kevin Stubbs and Derek Quinlan.
Exploring the Uncanny Valley

Flip Phillips, Skidmore College

As robots become more human-like our appreciation of them increases — up to a crucial point where we find them realistic but not *perfectly* so. At this point, human preference plummets into the so-called *uncanny valley.* This phenomenon isn’t limited to robotics and has been observed in many other areas. These include the fine arts, especially photorealistic painting, sculpture, computer graphics, and animation. The informal heuristic practices of the fine arts, *especially* those of traditional animation, have much to offer to our understanding of the appearance of phenomenological reality. One interesting example is the use of *exaggeration* to mitigate uncanny valley phenomena in animation. Raw rotoscoped imagery (e.g., action captured from live performance) is frequently exaggerated to give the motion ‘more life’ so as to appear less uncanny.

We performed a series of experiments to test the effects of exaggeration on the phenomenological perception of simple animated objects — bouncing balls. A physically plausible model of a bouncing ball was augmented with a frequently used form of exaggeration known as *squash and stretch.* Subjects were shown a series of animated balls, depicted using systematic parameterizations of the model, and asked to rate their plausibility. A range of rendering styles provided varying levels of information as to the type of ball. In all cases, balls with no exaggeration (e.g., veridically) were seen as significantly less plausible than those with it. Furthermore, when the type of ball was not specified, subjects tolerated a large amount of exaggeration before judging them as implausible. When the type of ball was indicated, subjects narrowed the range of acceptable exaggeration somewhat but still tolerated exaggeration well beyond that which would be physically possible. We contend that, in this case, exaggeration acts to bridge the uncanny valley for artificial depictions of physical reality.
Material rendering for perception: vision, touch and natural statistics

Wendy J Adams, University of Southampton

Recovering shape or reflectance from an object's image is under-constrained: effects of shape, reflectance and illumination are confounded in the image. We overcome this ambiguity by (i) exploiting prior knowledge about the statistical regularities of our environment (e.g. light tends to come from above) and (ii) combining sensory cues both within vision and across modalities.

I will discuss a collection of studies that reveal the assumptions that we hold about natural illumination. When visual scenes are rendered in a way that violates these assumptions our perception becomes distorted. For example, failing to preserve the high dynamic range of illumination reduces perceived gloss.

In addition, I discuss two quite different ways in which touch cues interact with vision to modulate material perception. First, objects can 'feel' shiny; surfaces that are more slippery to the touch are perceived as more glossy. Second, touch disambiguates the perceived shape of a bistable shaded image. The haptically-induced change in shape is accompanied by a switch in material perception - a matte surface becomes glossy.
Laurie Wilcox, York University, Centre for Vision Research

Over the past 25 years, studies of stereoscopic depth perception have largely been dominated by its precision. However, it is arguable that suprathreshold properties of stereopsis are just as relevant, if not more so, to natural tasks such as navigation and grasping. In this presentation, I will review several studies in which we have assessed depth magnitude percepts from stereopsis. I will highlight factors that impact perceived depth in 3D display systems such as prior experience, and the richness of additional depth cues.
June 3, 2018: Visual Perception
11:30 am - 12:00 pm

Processing of Sensory Signals in Virtual Reality

Jacqueline M. Fulvio, Bas Rokers, University of Wisconsin - Madison

Virtual reality (VR) displays can be used to present visual stimuli in naturalistic 3D environments. Little is known however, about our sensitivity to sensory cues in such environments.

Traditional vision research has relied on head-fixed observers viewing stimuli on flat 2D displays. Under such conditions many sensory cues are either in conflict, or entirely lacking. For example, an optic flow field will contain conflicting binocular cues, and lack motion parallax cues. We therefore investigated sensory sensitivity to cues that signal 3D motion in VR. We found considerable variability in cue sensitivity both within and between observers.

Next we investigated the possible relationship between cue sensitivity and motion sickness. Prior work has hypothesized that motion sickness stems from factors related to self-motion and that there are inherent gender differences in VR tolerance (e.g., Riccio and Stoffregen, 1991). We hypothesized that the discomfort is caused by sensory cue conflicts, which implies that a person's susceptibility to motion sickness can be predicted based on their cue sensitivity.

We found that greater cue sensitivity predicted motion sickness, supporting the cue conflict hypothesis. Inconsistent with prior work, we did not find gender differences: females did not show evidence of greater motion sickness. We speculate that prior VR results may be related to use of a fixed inter pupillary distance (IPD) for all observers.

Our results indicate much greater variability in sensory sensitivity to 3D motion in VR, than might be expected based on prior research on 2D motion. Moreover, our findings suggest motion sickness can be attenuated by eliminating or reducing specific sensory cues in VR.

Acknowledgements:
Supported by Google Daydream
**Poster Abstracts**

**P1: Rainier Barrett**  
Social and tactile augmented reality system for chemical engineering lab activities

**P2: Kamran Binaee**  
LSTM-RNN models can capture individual subject visual-motor strategies

**P3: Jonathan K. Doyon**  
Surface texture discontinuities, surface luminance, and exploration patterns affect the perception of object reachability in virtual reality

**P4: David Engel**  
Impact of oscillatory optic flow in virtual reality on quiet stance

**P5: Janis Intoy**  
The impact of retinal image motion on extra-foveal sensitivity

**P6: Nicholas Kochan**  
Design of a spatially multiplexed light field display on curved surfaces for VR HMD applications

**P7: Rakshit Kothari**  
Head free gaze classification and statistics

**P8: Sunwoo Kwon**  
Pre-saccadic motion integration drives “pursuit” for saccades to motion apertures

**P9: Paul Linton**  
How do we see distance in VR?

**P10: Juliette McGregor**  
Optogenetic vision restoration in the living macaque

**P11: Elizabeth Saionz**  
Relative efficacy of global motion versus contrast training early after stroke for recovering contrast sensitivity in cortical blindness

**P12: Sarah Walters**  
Adaptive optics ophthalmoscopy of macaque photoreceptors reveals the slowing of two-photon autofluorescence kinetics during systemic hypoxia

**P13: Séamas Weech**  
Presence and cybersickness in virtual reality are modulated by gaming experience and narrative

**P14: Zhizhuo Yang**  
Enhancing password recollection performance using augmented reality with the method of loci

**P15: Mingjian Zhang**  
Optimizing sEMG control of wrist movement in the Microsoft HoloLens HEART* project
Poster Abstracts
Social and Tactile Augmented Reality System for Chemical Engineering Lab Activities

Rainier Barrett, Heta Gandhi, Andrew White

Augmented reality (AR) has the potential to be a versatile tool for education enrichment. We have constructed an AR table to supplement traditional chemical engineering laboratory education. This AR table uses computer vision software to simulate a chemical reactor plant, building student intuition in a hands-on way that cannot be replicated with a "real-life" lab experience.


Acknowledgements:
Dr. Marc Porosoff and Dr. Wyatt Tenhaeff
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Ziyue Yang
LSTM-RNN models can capture individual subject visual-motor strategies

Kamran Binaee, Rakshit S. Kothar, Jeff B. Pelz, Gabriel J. Diaz

Studies have demonstrated that visually guided action can be modeled as an online coupling between sources of visual information and action. However, due to occlusion (unreliable visual information) and also motor delay, online control fails to explain the behavior. Evidence show humans switch to some type of predictive mode of control to succeed. In this study, we propose a long short-term memory recurrent neural network (LSTM-RNN) model for the visual-motor processing without an internal representation of the physics of the world. The model’s predictive characteristics is the result of a learned mapping between recently sensed visual state in a head-centered frame of reference and future action. Each LSTM-RNN model was trained to reproduce data from ten subjects in a virtual reality setup while they engaged in a ball catching task. The models successfully predict gaze behavior within 3°, and hand movements within 8.5 cm as far as 500 ms in to future. To investigate the contribution of each input feature, we performed an ablation study on all models where input features were removed iteratively and model outputs were recorded. The results show, not only the models learned a mapping between visual information of the ball and motor output, but also the longer integration duration the more robust the model is when it comes to loss of input features. Furthermore, the same network architecture was trained on expert and novice groups of subjects separately. Comparing the ablation study results between these two groups shows that the models trained on successful population demonstrate more robustness facing sensory input perturbations. This suggests that the proposed LSTM-RNN model captures different visual-motor strategies employed by different group of subjects.


Acknowledgements:
Thanks to Dr. Messinger for his support
Surface texture discontinuities, surface luminance, and exploration patterns affect the perception of object reachability in virtual reality

Jonathan K. Doyon, Joseph D. Clark, Tyler Surber, Alen Hajnal

In 4 experiments, we used VR (Oculus Rift) to investigate the role of 2 surface texture variables in the perception of object-reachability. Reachability judgments were given for objects placed on a table at distances of 60-140% of arm-length. The tables had textures with both discontinuities and varying luminance (Exp 1), varying discontinuities (Exp 2), varying luminance (Exp 3), or both varying discontinuities and luminance (Exp 4). Head motion was quantified by recording the visual feed in the headset and differencing the videos. Magnitude and complexity of movement were extracted from these data using a multifractal detrended fluctuation analysis. These parameters, and discontinuity and luminance, were then used to predict participant judgments and response times using hierarchical mixed effects regression models. In all experiments, movement parameters were found to modulate the effects of luminance and discontinuity. Distance perception and exploration patterns will be discussed.
Impact of Oscillatory Optic Flow in Virtual Reality on Quiet Stance

David Engel, Adrian Schütz, Milosz Krala & Frank Bremmer

In order to maintain balance - amongst other senses - humans heavily rely on vision. When subjects perceive their body as moving relative to the environment, they trigger counter movements, resulting in body sway. This sway has typically been investigated in a real, moving room or in front of large displays to simulate self-motion in space. Here, we aimed to (i) induce body sway by simulated self-motion in virtual reality (VR) with the use of a commercially available head mounted display and (ii) provide a new method of analysis by investigating the phase coherence of subjects’ bodily responses to the stimulus across trials. We simulated sinusoidal perturbations of the environment and quantified trajectories of the subjects’ center of pressure. Phase coherence analysis revealed a coupling to the stimulus for each presented frequency, even when there were no noticeable effects in the frequency power spectrum. We conclude that subjects adjust the phase of their induced sway to the stimulus presented through VR.

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The impact of retinal image motion on extrafoveal sensitivity

Janis Intoy, Norick R Bowers, Jonathan D Victor, Martina Poletti, Michele Rucci

The human eye moves continually in periods of fixation. Previous work has shown that humans are sensitive to the modulations from these eye drifts and use them to enhance sensitivity to high spatial frequencies (Kuang et al, 2012; Boi et al, 2017), an effect that likely acts primarily in the foveola. Outside the foveola, drift is assumed to have little impact as it covers a smaller fraction of neuronal receptive fields. Here we show that ocular drift improves sensitivity to high spatial frequencies even without foveal stimulation. We measured contrast sensitivity at 16 cpd with controlled retinal image motion and a foveal scotoma. Sensitivity is (1) impaired under retinal stabilization when the retinal effects of drift are eliminated and (2) reduced when retinal image motion is artificially attenuated or amplified. These results are well accounted for by the distribution of temporal power in the retinal input conveyed by drift. They indicate that eye drift exerts its action throughout the visual field.

Boi et al., Consequences of the Oculomotor Cycle for the Dynamics of Perception, Current Biology (2017), http://dx.doi.org/10.1016/j.cub.2017.03.034

Kuang et al., Temporal Encoding of Spatial Information during Active Visual Fixation, Current Biology (2012), http://dx.doi.org/10.1016/j.cub.2012.01.050

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Design of a spatially multiplexed light field display on curved surfaces for VR HMD applications

Tianyi Yang, Nicholas S. Kochan, Samuel J. Steven, Greg Schmidt, Julie L. Bentley, Duncan T. Moore

A typical light field virtual reality head-mounted display (VR HMD) is comprised of a lenslet array and a display for each eye. An array of tiled subobjects shown on the display reconstructs the light field through the lenslet array, and the light field is synthesized into one image on the retina. In this paper, we present a novel compact design of binocular spatially multiplexed light field display system for VR HMD. Contrary to the flat lenslet array and flat display used in current light field displays, the proposed design explores the viability of combining a concentric curved lenslet array and curved display with optimized lenslet shape, size and spacing. The design of placing lenslet array on a spherical surface is investigated and the specification tradeoffs are shown. The system displays highest resolution at the direction wherever the eye gazes. The design form is thin and lightweight compared to most other VR optical technologies. Furthermore, the use of a curved display reduces the complexity of optical design and wastes fewer pixels between subobjects. The design simultaneously achieves a wide field of view, high spatial resolution, large eyebox and relatively compact form factor.

Head free Gaze classification and statistics

Rakshit Kothari, Kamran Binaee, Reynold Bailey, Jeff Pelz, Gabriel Diaz

It is known that the head and eyes function synergistically to collect task-relevant visual information needed to guide action. However, investigation of eye/head coordination has been difficult because most gaze event classifiers algorithmically define fixation as a period when the eye-in-head velocity signal is stable. However, when the head can move, fixations also arise from coordinated movements of the eyes and head, for example, through the vestibulo-ocular reflex. To identify fixations when the head is free requires that one accounts for head rotation. Our approach was to instrument multiple subjects' with a 6-axis Inertial Measurement Unit and a 200 Hz Pupil labs ETG to record angular velocity of the eyes and head as they performed different types of tasks (ball catching, indoor exploration, visual search and tea making) for 5 mins each. Five experts manually annotated a portion of the dataset as periods of gaze fixations (GF), gaze pursuits (GP), and gaze shifts (GS). Each data sample was labeled by the majority vote from the labelers. This dataset was then used to train a novel 2-stage Forward-Backward Recurrent Window (FBRW) classifier for automated event labeling. Inter-labeler reliability (Cohens-kappa) was used to compare the performance of trained classifiers and human labelers. We found that 64 to 78 ms duration provides enough context for classification of samples with an accuracy above 98% on a subset of the labeled data that was not used during the training phase. In addition, analysis of Fleiss' kappa indicates that the algorithm classifies at rate on-par with human labelers. This algorithm provides new insight into the statistics of natural eye/head coordination. For example, preliminary statistics indicate that fixation occurs very rarely through stabilization of the eye-in-head vector alone, but through coordinated movements of the eyes and head with an average gain of 1.
Pre-saccadic motion integration drives “pursuit” for saccades to motion apertures

Sunwoo Kwon, Martin Rolfs, Jude Mitchell

When a saccade is directed towards a translating target, smooth pursuit movements track the target from the moment of saccade landing, indicating that motion integration occurred prior to the saccade (Gardener and Lisberger, 2001). Since, prior to saccades, perceptual performance improves at the saccade target (Kowler et al, 1995; Deubel and Schneider, 1996; White et al., 2013), we hypothesized that saccades to a motion stimulus in a stationary aperture would drive post-saccadic pursuit movements due to the pre-saccadic selection of its motion. Participants performed a saccade to one of four motion apertures, cued by a central line. Apertures consisted of random dot fields (5 deg eccentricity and diameter, 100% coherent motion) moving in one of two randomly assigned radial directions tangential to the center-out saccade. Saccades exhibited a low gain (~10%) pursuit along the target’s motion direction at saccade landing. These effects were driven by motion integration prior to the saccade, as we found consistent results when the motion stimulus offset occurred during the saccade. These effects grew as we reduced the spatial certainty of the aperture location, from a well-defined ring aperture, to no ring, or to a smoothed Gaussian envelope. Pursuit velocity increased with increasing stimulus speed with gain saturating at speeds higher than 10 deg/s. To examine what period prior to the saccade contributed to motion integration, we presented stimuli with random motion (0% coherence) that transitioned to coherent motion (either permanently or for fixed 100 ms epochs) around the time before saccade onset. We found that a minimum of 100 ms motion integration was necessary to observe an effect, with 150-50 ms before the saccade providing the strongest input. These results suggest that presaccadic attention engages motion integration for the saccade target that can be observed as an involuntarily low gain pursuit upon saccade landing.


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How Do We See Distance in VR?

Paul Linton, Centre for Applied Vision Research, City, University of London

As VR becomes increasingly concerned with social interaction, one of the key questions is how we see distances in interaction space? According to the literature the two primary sources of near distance information are 'vergence' (the angle of the eyes) and 'accommodation' (the focal power of the intraocular lens). But in two studies I demonstrate that neither vergence nor accommodation function as effective cues to distance, even at near distances. In both studies I had subjects fixate on a surface for 30 seconds. Unbeknownst to them I varied their vergence to anywhere between 20cm and 50cm. I also introduced appropriate accommodation cues in the second study. And yet these manipulations of vergence and accommodation had very little effect on their reaching responses to newly presented dot stimuli: a gain of 0.16 (vs. the 0.86+ suggested by the literature). This leads me to conclude that cognition, rather than perception, may be playing a greater role in the estimation of distances than previously thought.
Optogenetic vision restoration in the living macaque

Juliette E. McGregor, Tyler Godat, Keith Parkins, Kamal Dhakal, Sarah Walters, Jennifer Strazzeri, Brittany Bateman, David R. Williams, William H. Merigan

Optogenetics offers the prospect of restoring light sensitivity to ganglion cells when photoreceptor input has been lost due to disease or injury. Channelrhodopsin-mediated activity in primate retinal ganglion cells (RGCs) has previously been demonstrated ex-vivo, but not in the living primate. We demonstrate channelrhodopsin mediated RGC activity in an in vivo macaque model of retinal degeneration by high resolution optical recording from RGCs expressing both a channelrhodopsin (ChrimsonR) and a calcium indicator (GCaMP6s).

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Relative efficacy of global motion versus contrast training early after stroke for recovering contrast sensitivity in cortical blindness

Elizabeth L. Saionz, Duje Tadin, Krystel R. Huxlin

Stroke to V1 causes cortical blindness (CB). In chronic (>6 months post-stroke) CB patients, this is characterized by a complete deficit in contrast sensitivity (CS) and complex motion discrimination in the CB field. Global direction discrimination (GDD) training in chronic CB recovers GDD but CS remains impaired. Here, we investigate the effect of training on CS in subacute (<3 months post-stroke) CB. 7 CBs trained on GDD; 2 CBs had normal blind field GDD and trained on static orientation discrimination with varying contrast. We assessed change in static and motion CS with the qCSF. We found that GDD, always reduced in chronics, may be preserved in subacutes along with motion CS. GDD training improved CSFs only for motion, but contrast training led to robust improvement in static CSFs. Contrast-trained subacutes also improved more on luminance detection vs. GDD-trained subacutes. Thus, early training takes advantage of preserved vision in subacute CB, inducing greater recovery. Such training may be critical to prevent degradation of enhanced perceptual abilities present in the early post-stroke period.


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Adaptive optics ophthalmoscopy of macaque photoreceptors reveals the slowing of two-photon autofluorescence kinetics during systemic hypoxia

Sarah Walters, Christina Schwarz, Amber Walker, Louis DiVincenti, Jennifer J. Hunter

The kinetics of two-photon excited fluorescence (TPEF) from photoreceptors in response to visual stimulation are indicative of all-trans-retinol production and clearance and show promise as an objective, non-invasive measure of visual cycle function in both healthy and diseased retina. As changes in oxygen supply play a role in many diseases leading to retinal degeneration, we induced systemic hypoxia in macaque as a model of altered physiological state and tracked the TPEF kinetics of photoreceptors using adaptive optics (AO) ophthalmoscopy. Macaques were anesthetized, paralyzed, and ventilated with 100% O₂ (pre-hypoxia). Repeatedly, systemic hypoxia was induced by ventilating with 10% O₂/90% N₂, followed by recovery with 100% O₂ (post-hypoxia). An AO scanning light ophthalmoscope was used to collect TPEF (ex: 730nm, em: <550nm) in each condition from the photoreceptors of 3 macaques, and TPEF time courses were fitted with an exponential function. Hypoxia produced no significant change in the fractional TPEF increase; however, it significantly slowed TPEF response, increasing the time constant by 11 ± 2% on average. TPEF responses were not significantly different pre- and post-hypoxia. Systemically reduced oxygen supply slows the time course of TPEF in photoreceptors, yet the total TPEF increase is unaffected, potentially indicating visual cycle slowing in response to hypoxia. This demonstration broadens the utility of two-photon AO ophthalmoscopy to detect changes in visual cycle function that occur with disease or altered physiological state.
Presence and cybersickness in virtual reality are modulated by gaming experience and narrative

Séamas Weech, Sophie Kenny, Markus Lenizki, Michael Barnett-Cowan

Minimizing cybersickness and maximizing presence are important considerations in the design of virtual reality applications. Can top-down interventions be used to drive high presence and low sickness, without altering game mechanics? We gathered data from a diverse convenience sample (N = 153) over one week at a public museum. Participants explored an interactive virtual environment for 7 min after listening to either a short (~40 secs) low or enriched narrative context. We collected self-reported presence and sickness, as well as demographics, gaming experience, engagement, and task performance. Presence was associated with lower sickness severity, although the relationship was weaker for regular gamers. Participants who played games for less than five hours a week reported stronger sickness symptoms if they were assigned to the low-narrative condition. Conversely, regular gamers were unaffected by narrative context. The results show the potential for modulation of cybersickness with narrative intervention.

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Enhancing Password Recollection Performance using Augmented Reality with the method of Loci

Zhizhuo Yang, Reynold Bailey, Joe Geigel, Alberto Scicali

Recalling passwords and other sequences of letters and digits has become a routine activity of modern life. To ease the difficulty of remembering passwords, we explore if human memory performance can be improved by leveraging Augmented Reality (AR) during memorization. In this paper, we seek to use visual augmentation to reinforce the association of each character of a password with an object or spatial region in the real-world 3D environment. This approach is known as the method of loci. A Microsoft HoloLens was used to provide the user with real-time visualization overlaid on the physical environment. Users can associate each digit of the password with an object in the environment with simple voice command, and reorienting towards one of these regions will display the corresponding digit. We hypothesize that this will make the memorization process more efficient. We conduct a user study where participants were asked to recall randomly generated numeric passwords using the following methods: memorization using the participant’s own devised method, the method of loci, and the method of loci with AR visualization. We measure the accuracy of password recollection and response time and report the subjective feedback.


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Optimizing sEMG control of wrist movement in the Microsoft HoloLens HEART* project

Mingjian Zhang, Reza Rawassizadeh, Mohammed (Ehsan) Hoque, Ania C. Busza

Stroke is a major cause of adult disability in the United States. Current treatment paradigms for post-stroke motor recovery generally focus on encouraging the patient to do multiple repetitive exercises daily with the affected limb, which presumably stimulate neuroplasticity. In recent years, there is increased promise in using new technologies in rehabilitation games to motivate patients to perform more exercises. Unfortunately, such systems are often not usable for patients with severe weakness who are not able to lift the affected side against gravity. In this project, we are designing a rehabilitation exercise system for patients with severe weakness. Our system uses electromyographic (EMG) signals from the forearm of patients with weakness due to stroke to control a virtual limb which is presented to patients using Mixed Reality (Microsoft HoloLens). We have developed an initial prototype where EMG fluctuations in the user's forearm control wrist movement in the virtual arm displayed to the wearer. We are now optimizing the system to make the model arm movement patterns feel more realistic to the wearer. In this poster, we present our current work using different machine learning algorithms on EMG signals from healthy controls for transforming EMG signal to smooth wrist movement in our arm model displayed with the Microsoft HoloLens.

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