APPLICANT'S BACKGROUND AND GOALS FOR FELLOWSHIP TRAINING

A. Doctoral Dissertation and Research Experience

2012-2014: Department of Psychology, University of Cincinnati (Advisors: Dr. Kevin Shockley & Dr. Michael Riley)

As an undergraduate at the University of Cincinnati, I worked as a research assistant in the Cognition Action and Perception Lab, underneath Dr. Kevin Shockley, and aided in the data collection of Dr. Julie Weast-Knapp's dissertation experiments. This work introduced me to perception and action, ecological psychology, and the theory of affordances. In my study of ecological psychology, I became interested in complex systems and intrapersonal synergies between perceptual and motor systems; this led to my senior thesis project under the direction of Dr. Michael Riley, where I investigated the postural facilitation in auditory localization tasks. My thesis project led to my first conference presentation and laid the groundwork for my interest in complex perception and action systems.

2014-Present: Department of Cognitive, Linguistic, and Psychological Sciences, Brown University (Advisor: Dr. William Warren)

My interest in complex systems and perception and action led me to work with my PhD advisor at Brown University, Dr. Bill Warren, studying the self-organization of human crowd behavior.

To understand how crowd behavior might be self-organized, i.e. driven by the local perceptual interactions between "neighbors" in the crowd, my advisor and I implemented what is commonly referred to in the study of collective motion in animal groups as *the modeling cycle*. The modeling cycle combines efforts from empirical investigation, model development and simulation, with real-world observation of collective motion to create a holistic understanding of the system in question. Using our 12x14m laboratory space, I became an expert in the design of virtual reality experiments, where I would manipulate a virtual crowd stimulus and measure participant's walking trajectories as they responded to the crowd by walking alongside them in our large tracking space, all while completely immersed in our Head Mounted Display (HMD). I would then use insights gleaned from virtual reality experiments to develop and tweak our lab's model of crowd behavior. We then use this model to simulate the behavior of real human "swarms", where large groups of subjects (10-40) all participate in the experiment simultaneously in a gymnasium sized recording space. By analyzing their rigid body motion capture, and simulating individual trajectories within the real human swarms, we can test how well our data-driven model generalizes to real world behavior. This method served as the basis for understanding the complex interpersonal coordination problem of human crowd behavior, but the same method can (and will) be applied to studying other perception and action problems, such as the visuo-locomotor system.

In my early graduate career, I first characterized the zone of influence, or the "neighborhood" of individual pedestrians when walking in crowds, by testing and developing our agent-based model of human crowd behavior (Section A, below). With an understanding of an individual's neighborhood, my dissertation investigated two key components in self-organized crowd behavior: 1. The rules of recruitment, i.e. how an individual is pulled into collective motion and 2. Individual decision making within crowds, i.e. how a pedestrian following a splitting crowd chooses to align with a particular sub-group. In sum, my dissertation work has been invaluable in demonstrating how crowd behavior can indeed rise from a process of self-organization via local alignment mechanics, reflective perhaps of a world-embodied Gestalt of common fate which the human visual system is sensitive to. My dissertation studies, as outlined below, demonstrate a long and careful history of methodological empirical investigation paired with model development, and the simulation of real world crowd behavior.

Sections B. and C. make up my six dissertation experiments and are presented in summary here. Components of Section A. were started by a previous PhD student in the lab, and finished by me (analysis, simulation, and model enhancement) outside of my dissertation work.

In all my experiments, because we are interested in the most basic of coordinative behaviors, the instructions given to participants in virtual reality studies were simply "Walk with the crowd and treat them as though they are real people". This made is to that we got as close to natural crowd walking (which sometimes looked like crowd following) behavior as possible. Under different task constraints, the observed interactions would likely change; but this is an empirical question.

A. To develop an accurate model of human crowd behavior is self-organized, one must understand the local interaction rules of an individual pedestrian. The first step in this process, is characterizing the zone of influence of an individual pedestrian within a crowd. The first steps of my graduate career were to compare two potential neighborhood models which are common in the collective motion literature: 1. A metric model, where neighborhood influence decays with distance, and 2. A topological model, where neighbor influence is independent of distance. By manipulating density in three different experiments (two virtual reality, and one real human "swarm), we were able to determine with whether a human crowd model should use a metric or a topological neighborhood, where metric neighborhoods are sensitive to density manipulations, but topological ones are not. Our results reveal that participants were sensitive to density across all three experiments, consistent with the metric hypothesis. However, the data are better explained by a visual model based on optical velocity and visual occlusion, both of which depend on metric distance. We conclude that the neighborhood of interaction in human crowds is metric, not topological, a natural consequence of the laws of optics. (Wirth, Dachner, Rio & Warren, in prep; Wirth & Warren, VSS 2016; Wirth, Dachner & Warren, VSS 2018)

B. With an understanding of the shape of an individual pedestrian's neighborhood, the next step – and the first component of my dissertation work – was to investigate the statistics of neighbor movement which elicited coordination from a participant; i.e., how is a pedestrian recruited into collective motion? To achieve this, I conducted two experiments. The first was to determine if participants would average over "noisy neighbors", i.e. neighbors that were walking in random directions. The second experiment determined if neighbor alignment (pocketed within noisy crowds) would serve as the positive feedback loop necessary for recruitment into coordinative motion. The "noisy neighbors" experiment demonstrated that participant do indeed average over neighbors walking in disparate directions, as long as the neighbors are within the "neighborhood". The second recruitment study confirmed that as subsets of a crowd become more aligned, they become more attractive to a pedestrian, establishing the framework for self-organized recruitment into collective motion for human crowds (Wirth & Warren, VSS 2017; Wirth & Warren, in prep).

C. Now, with a combined understanding from both A and B, we know that a human pedestrian neighborhood should be metric, and that within that neighborhood participants average over "noisy neighbors" but are also attracted to an aligned subset within a large crowd. To understand the dynamics of this behavior, it became critical to investigate at what point averaging behavior breaks down, i.e., is there a point when walking with a crowd when a neighbors heading is so divergent, that they will be completely ignored? Through a series of virtual reality experiments, I was able to determine that participants tend to average over two groups of completely aligned neighbors out to an angular difference of around 60°. At this point, competing goal dynamics emerge, where pedestrians are likely to follow the larger group, but once crowds start to turn too far (>100°), pedestrians will follow the smaller of the two groups, preferring to walk closer to their initial heading. The findings from this second portion of my dissertation have resulted in notable model improvements, where we have implemented competing goal dynamics into our crowd model. (Wirth, Free, & Warren, in prep).

B. Training Goals and Objectives

My research experience thus far has positioned me has set me on a path toward achieving my long term career goal of becoming a tenure track professor at a research university studying perception and action. This proposal critically pivots from my research conducted during my graduate career back toward the intrapersonal coordination I became so fascinated with as an undergraduate student: understanding the necessary synergetic relationship between sensory and motor neuroscience. This training plan provides me with the opportunities to learn and acquire the skills that I need to become the scientist I desire to be. I am thrilled to start my post-doctoral training in the study of the visuo-locomotor system at Northeastern University, where the ideal interdisciplinary environment exists by inherently within the in-house expertise at Northeastern. With talented co-sponsors with esteemed expertise in both sensory and motor neuroscience, along with my selected sponsor, a world expert at measuring the visual control of locomotion in both laboratory and real world settings, I will have the necessary support to achieve the training aims that we have agreed upon.

Training Objective 1: Visual Neuroscience

Background. As is part of the dual nature of the multidisciplinary research I have proposed, I will develop appropriate scientific background in visual neuroscience required to maximize the theoretical impact of the research I have proposed and communicate my findings effectively. I will grow my basic understanding of visual neuroscience by auditing a course or two taught by my Co-Sponsor, Dr. Peter Bex, in the psychology department (e.g., Proseminar in Sensation, Proseminar in Perception). To enhance my understanding of neural modeling, I will plan on engaging with the online Neuromatch summer conference in 2021, where I will have the opportunity to explore mechanisms of the visual cortex and superior colliculus as they relate to the data I have collected in my first experiment. In addition to courses and conference, Dr. Bex has a vision science journal club that I will plan on attending with some regularity, even leading a meeting or two as I become a greater fixture at Northeastern myself. Finally, regular annual visits to VSS will supplement and cement my learning and exposure to the hottest ideas in the visual neuroscience community.

Methods, tools & skills. One of the most critical components of my training in visual neuroscience is my familiarization and mastery of using the mobile binocular eye tracker (Pupil Labs). Dr. Jonathan Matthis is a world expert in the visual control of foot placement, having recently conducted and reported one of the most advanced studies of visuo-locomotor behavior observed in natural unconstrained environments. During Aim 1 of this proposal, I will be mentored in the recording, segmentation, and analysis of eye movements made during locomotion across our laboratory space. I will receive specific instruction on the implementation and calibration of mobile eye trackers, learning the proper placement and orientation of cameras needed to get clean images of the eye during motion. In Aim 2, I will continue to gain training in the use of mobile eye tracking in our laboratory space, but I will be encouraged to operate and conduct research with less guidance than during Aim 1 – providing myself the space to fully master this technique. Finally, in Aim 3, I will be more directly mentored again as we move from the laboratory space to using the eye tracker outside, which comes with its own unique challenges of which Dr. Matthis is well versed.

Analysis. My training in the analysis and segmentation of eye movements, as well as the mapping of gaze in 3-D space (as described in Aims 1 and 2) will be spearheaded by Dr. Matthis, where he will instruct me in one on one meeting and coding sessions. I will receive specific instruction in computational video analysis techniques in both Matlab and Python versions of the Open Computer Vision (OpenCV) toolbox. While this is Dr. Matthis's area of expertise, his tutelage will be supplemented by faculty across Northeastern, such as my co-sponsor Dr. Peter Bex and experts outside of the Department of Psychology, like Dr. Ennio Mingolla (the head of the Computational Vision Laboratory in the Department of Communication Sciences and Disorders).

Training Objective 2: Motor Neuroscience

Background. On the other side of the perception and action coin, I will receive training in motor neuroscience and motor control, such that I am able to adequately implement models of human locomotion to generate foot-steps predictions which are vital to my hypotheses. While Dr. Matthis has extensive experience in studying the biomechanics of locomotion and will be the primary mentor for me in this space, his guidance will be matched by my co-sponsor Dr. Dagmar Sternad, a renowned expert in motor control. I have already established a professional relationship with Dr. Sternad, having made it a priority throughout graduate school to attend her Boston-famous Boston Action Club throughout the past two years of my graduate training. Her excitement and passion for this project gives me great confidence that with her guidance and expertise, that I will have the instruction required to develop a detailed understanding of motor neuroscience during the length of the proposal. I plan on joining Dr. Sternad's lab meetings upon occasion, continue to participate in her Action Club seminar, as well as audit her course *Interdisciplinary approaches in motor control*. This exposure, supplemented with information I will gather at relevant conferences to motor neuroscience (SFN, AMAM, and Dynamic Walking) will provide me a strong foundation for understanding motor neuroscience as I mature as a scientist.

Methods, tools & skills. Just as critical as the eye tracking expertise will be the experience I get in the recording of full body biomechanical motion capture. While I already have expertise with the analysis and recording of rigid body motion capture data (head positions of individuals in a crowd), I do not have the experience necessary to map out the musculoskeletal system. This training again will be spearheaded by Dr. Matthis who is an expert in mapping the musculoskeletal system with marker based motion capture (Qualisys), IMU-based motion capture (Shadow), and markerless motion capture (OpenPose). I will receive training in all three of these motion capture techniques, and Dr. Matthis will provide one on one training sessions in the analysis of this sort of biomechanical data. Additionally, Dr. Matthis's lab is equipped with force plates that are in the floor and can be specifically incorporated into our experimental design (Exp. 1 & 2). Hence, I will also build my full body kinematic (motion capture) and kinetic (force plate) data recording expertise such that I can characterize low-level mechanical aspects of human movement, such as the join torques that facilitate locomotion.

Analysis. My training in the analysis of full body kinematics and force plate kinetic data will be led by Dr. Matthis and supplemented by Dr. Sternad. My training from Training Objective 1 will come together with my training in this objective, where I will combine the eye tracking data to reconstruct subject body-relative gaze behavior (Aims 1 and 2), such that we can map motion and gaze in the 3-D world. The training I will receive in the laboratory (Aims 1 and 2) will be instrumental to be able to map the more complex 3-D behavior in Aim 3. I will also gain experience in the implementation of basic models of locomotion (Kuo, 2002) such that we can generate predictions of foot placement in our experimental settings. This training will again be led by Dr. Matthis and supported by Dr. Sternad, who has extensive experience in the modeling of motor behavior.

<u>Training Objective 3: Professional Development Toward Independent Research</u>

The final, but critical training objective is the professional development that I will need to become a competitive tenure-track faculty applicant by the end of the grant period. To achieve this, I will plan to communicate my scientific findings by writing high-quality peer-reviewed journal articles and presenting at major conferences, spanning visual and motor neuroscience. The quality of oral presentations will be workshopped in internal lab meetings, one on one meetings, and meetings with my co-sponsors and their respective labs when appropriate. By regularly attending and presenting at conferences in vision science (e.g., VSS) and motor neuroscience (e.g., Dynamic Walking) I will become professionally recognized within both aspects of the interdisciplinary research with which I am studying.

Additionally, I will be provided opportunities to guest lecture in perception and action, my area of established expertise, as well as mentor incoming graduate students, current and incoming co-op students, and undergraduate researchers. These opportunities, along with participation in workshops related to responsible conduct of research and diversity and inclusiveness in science workshops will be critical to my formation as a member of the academic community.

This training will satisfy my personal long term career goals by providing the necessary insights into both visual and motor neuroscience, such that I can build a career explaining the critical connections that exist between the two systems. Together, these three training objectives will provide me with the interdisciplinary expertise I need to transition to my next professional phase as a competitive applicant for tenure track positions for experts in perception and action.

C. Activities Planned Under this Award

For all three years of the award period, I will devote 80% of my time to scientific research, methods training, and writing. The remainder of time will be spent improving my written and oral communication skills, my knowledge of visual and motor neuroscience, attending journal clubs, talk seminars, and conferences, participating in responsible conduce of research workshops, and improving my teaching and mentoring skills.

As stated in Objective 3, attending a variety of conferences, investing time in mentorship and teaching, and honing my scientific communication skills are vital to my career goals of becoming a promising academic job candidate.

The chronological order of activities including conferences to attend, courses to audit, and experiments to complete are outlined in the *Proposal Timeline* on the next page.

Proposal Timeline

Year 1

Activity	% of Time	Details/Description
Coursework and External Training	5%	Audit one of the following courses, or similar: Proseminar Perception, Proseminar Sensation. Take Neurmoatch Summer Course (Training Obj. 1). Continue RCR training (Training Obj. 3).
Conferences	5%	Present at 2-3 major meetings: VSS, AMAM, or Dynamic Walking. Attend relevant small workshops. (Training Objectives 1, 2 and 3)
Internal Training and Advisement	5%	Biweekly lab meetings in sponsor's lab as well as independent reports. Occasional lab meetins in co-sponsor labs. Biannual progress meetings with both sponsor and co-sponsors. (Training Obj. 3)
Mentoring and Teaching	5%	Mentor co-op students, undergraduate students, and graudate students in the lab. Occasional guest lectures. (Training Obj. 3)
Scientific Research	70%	Finalize design for Exp. 1. Collect Exp. 1. Analyze Exp. 1.
Scientific Writing	10%	Complete & submit manuscript for Exp 1. Revise & resubmit as needed.

Year 2

Activity	% of Time	Details/Description
Coursework and External Training	5%	Audit the following course, or similar: Interdisciplinary approaches in motor control (Training Obj. 2). Continue RCR training (Training Obj. 3).
Conferences	5%	Present at 2 major meetings: VSS and SFN. Attend relevant small workshops. (Training Objectives 1, 2 and 3).
Internal Training and Advisement	5%	Similar to Year 1.
Mentoring and Teaching	5%	Similar to Year 1.
Scientific Research	70%	Finalize design for Exp. 2. Collect Exp. 2. Analyze Exp. 2.
Scientific Writing	10%	Complete & submit manuscript for Exp 2. Revise & resubmit as needed.

Year 3

Activity	% of Time	Details/Description
Conferences	5%	Present at 2-3 major meetings: VSS, SicB, or Dynamic Walking. Attend relevant small workshops. (Training Objectives 1, 2 and 3)
Internal Training and Advisement	5%	Similar to Year 1.
Mentoring and Teaching	5%	Similar to Year 1.
Scientific Research	70%	Finalize design for Exp. 3. Collect Exp. 3. Analyze Exp. 3.
Scientific Writing	10%	Complete & submit manuscript for Exp 3. Revise & resubmit as needed.
Career Development	5%	Apply for faculty positions. (Training Obj. 3)