SAFETY AND ERGONOMICS TRAINING

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Final Report

PI and Program Director:

Maury A. Nussbaum, PhD
(540) 231-6053
nussbaum@vt.edu

Co-Directors :

D.E. Dickerson, PhD
D. Srinivasan, PhD

Department of Industrial and Systems Engineering
Virginia Tech
250 Durham Hall (0118)
Blacksburg, VA 24061

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Abstract

Title: Safety and Ergonomics Training
PI/PD: Maury A. Nussbaum, Department of Industrial & Systems Engineering, Virginia Tech, Blacksburg, VA 24061
State: Virginia
Email: nussbaum@vt.edu
Telephone: (540) 231-6053
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This report summarizes the activities during the period of 07/01/16 through 06/30/21 for the VT Occupational Safety and Health (OSH) graduate training program, which is housed within the Department of Industrial and Systems Engineering (ISE) in the College of Engineering. Our aims to provide a high-quality education to trainees, to train them in conducting effective basic and/or applied research, and to provide service to our profession, to industry, and to society. A key goal of our program is to support the NIOSH goal of supplying qualified professionals for careers that address occupational safety and health (OSH) through both research and practice. Our program emphasizes three aspects of OSH at the MS (thesis) and PhD levels: safety engineering, occupational ergonomics, and occupational biomechanics. This program is characterized by a dual emphasis on breadth of trainee experience and the requirement for specialization, the latter emphasized by the need for a formal research project related to OSH. TPG funds helped us to maintain this emphasis and to attract and retain top students. A broad yet cohesive group of faculty member supported the program. Training is achieved through a combination of formal coursework, faculty advising, research, and more general exposure through seminars and interdisciplinary interactions. Candidates for our program are MS or PhD students accepted within the Human Factors Engineering and Ergonomics graduate concentration within the Department of Industrial and Systems Engineering. Prospective trainees are also actively recruited through several means. TPG funding helps support our long-standing program, which provides the only comprehensive graduate-level training in OSH in the Commonwealth of Virginia. Our program overall was quite successful during the prior period, based on the number of graduates, the number of graduates continuing in the OSH field, faculty and trainee scholarly output, awards, and the continuing high number of applications received. Program funds were used to support two trainees per year, with five different students supported. A total of 10 trainees completed the program (6 PhD and 4 MS), many of whom were subsequently employed in an OSH field or enrolled in an OSH academic program. Nearly half were women, and we have been successful recently in recruiting underrepresented minorities into the program. Many program graduates have leading administrative positions or academic appointments related to OSH. Program trainees published extensively on OSH topics in the reporting period. Several aspects of the program were modified or expanded, to enhance training opportunities and training experiences, including a new field-based OSH practicum.

Significant or Key Findings

Significant developments and accomplishments of the program during the reporting period are provided here in terms of trainees, administration, faculty participation, and facilities. Additional details are provided in the subsequent section. Virginia Tech has received funding from NIOSH training grants since 1992, and this funding has served a vital role in maintaining the program, which is the only one of its kind in the Commonwealth of Virginia. The TPG at Virginia Tech, housed in the Department of Industrial and Systems Engineering, emphasizes three aspects of occupational safety and health (OSH) at the MS (thesis) and PhD levels: safety engineering, occupational ergonomics, and occupational biomechanics. This emphasis stems from, and is supported by, the numerous faculty contributing to the program. Primary highlights of the program are: 1) the diversity of faculty expertise participating in student training; 2) the requirements for comprehensive and relevant coursework; 3) a required research experience related to occupational safety and health (OSH), and which contributes towards occupational hazard/risk recognition, avoidance, or control; and 4) professional development through participation in seminars, tours, and conferences.

During the project period, 10 trainees completed the training program (4 MS and 6 PhD). Five trainees were supported using program funds, and four funded trainees completed the program (1 MS and 3 PhD). A continued high proportion of trainees were at the doctoral level, largely as a result of: 1) continuing applicant demand; 2) continuation of our own MS students in the PhD program; and 3) an institutional emphasis on doctoral-level training across all fields. Scholarly outputs of trainees were substantial, with many publications generated in respected archival journals. Most trainees obtained employment with some aspects of occupational safety and/or health, including several who obtained tenure-track faculty positions. A recent survey indicated strong, positive support of experiences of recent graduates of the training program.

Several administrative and leadership changes occurred. Dr. Maury A. Nussbaum continued as PI/PD and Dr. Deborah Dickerson as co-director, with Dr. Divya Srinivasan joining as an addition co-director during the prior period. Drs. Joe Gabbard and Nathan Lau continued as supporting faculty, and several new faculty joined in supporting roles. Faculty participation was both high and diverse, covering a wide range of topics within safety engineering, human factors, biomechanics, ergonomics, and public health.

Translation of Findings

Basic and applied research by our program trainees can be used in several ways to prevention workplace health problems. First, all trainees are required to complete a field experience (practicum) in occupational safety, health, or ergonomics. During the project period, these experiences have made contributions that include: improving ergonomics at two major automobile manufacturers (Tesla and Ford); identifying and documenting safety concerns, and ensuring safety standards are followed, at a major logistics company (FedEx); assessing WMSD risks for a manufacturer of plastic packaging (Berry Global); and evaluating the potential of emerging technologies to improve workplace ergonomics (for Ford).

Second, published research by program trainees has either immediate or longer-term potential to address workplace health. These publications have addressed several topics, including: assessing the facilitators and barriers to the occupational use of exoskeletons, and the benefits and potential limitations of this emerging technology; quantifying the role and contribution of movement variability to musculoskeletal injuries; assessing the potential for wearable technologies for occupational exposure and risk assessments.

Research Outcomes/Impact

Major outcomes of the program are related to the trainees, including their subsequent employment and scholarly output. During the project period, 10 graduate students completed the training program (4 MS and 6 PhD). Five different trainees were supported using program funds, four of whom completed their training in the prior period (1 MS and 3 PhD). Of the program graduates, most were subsequently employed in an OSH field or enrolled in an OSH academic program. Given the level of under-representation of women and minorities in the fields of OSH, we were successful in training such individuals in the reporting period. Specifically, two of the funded trainees were female, and nearly half of all program trainees were women. Program trainees generated substantial scholarly output. TPG-supported trainees generated 20 publications (7 in conferences and 13 in archival journals) in the reporting period.

The major outcomes noted above are highly relevant in the context of occupational safety and health in general and in our training program specifically. First, work-related accidents, injuries, and illnesses continue at high levels across many sectors, and much of our training was focused on contributing to a better understanding of the causes and the development and evaluation of methods for alleviating these. Second, we continue to have substantial student interest in these sub-disciplines, not only from within the US, but from around the world. Third, we believe the breadth of experience we emphasized in our program is necessary to adequately prepare students in OSH areas, and to maximize the likelihood of their success after graduation. Fourth, the need for talented graduates in OSH continued, as indicated by the numerous requests from companies and consulting firms that we received for student applications. Fifth, we have graduated >150 students from our program, and a majority of these former trainees are currently working in areas related to their training. Sixth, our program is the only one in the Commonwealth of Virginia that provides depth and breadth of training in these fields. We also served a regional need, in that we are not located within close proximity to any current ERCs (the nearest being UNC-Chapel Hill and Johns Hopkins). In addition, we are located in a rural area and provided expertise and potential employees that can serve in capacities beyond the specific OSH training they receive (e.g., most receive more general training in industrial and systems engineering).

Specific impacts of the program are more difficult to identify and/or quantify. Two items, however, are worth noting. First, as mentioned above, most of our former trainees (historically, and in the recent reporting period) continue to work in areas of OSH after graduation. Many of these former trainees have leadership positions in industry and several others are conducting OSH research and training in academic positions. Second, the scholarly output generated by our trainees is often well cited by others, which indicates that their work is having an impact on others in the OSH field. In large part, the breadth of these impacts is related to the breadth of the research conducted by our trainees and faculty.

Scientific Report

Overview

Building on the academic and research strengths at Virginia Tech, our training program emphasized three aspects of occupational safety and health (OSH): safety engineering, occupational ergonomics, and occupational biomechanics. The first is a “core” discipline, and the latter are “related” disciplines. The program itself is an academic “concentration” within the ISE graduate program. A safety engineering emphasis was implemented nearly 35 years ago, and training support as a NIOSH TPG began in 1992. In 2002, the program was expanded to include MS students with training interests in occupational ergonomics and biomechanics. This expansion was done to reflect several changes that had occurred in program faculty, student interests, contemporary needs in research and industry, and ongoing research projects.

The core rationale for our proposed training project can best be summarized by our mission statement: 1) to provide a high-quality education that will prepare our graduate students for a life-long learning experience and be future leaders in the profession; 2) to conduct high-quality basic and applied research; and 3) to provide service to the profession, industry, and society to contribute to the advancement of civilization and the betterment of all.

Several points emphasize and justify the need for training in our program’s areas of focus. First, work-related accidents, injuries, and illnesses continue at high levels across many sectors. Much of our training is focused better understanding the causes of these problems, along with methods for alleviating them. Second, we continue to have substantial student interest in these sub-disciplines, from within the US and around the world. Third, we believe the breadth of experience we emphasize in our program is necessary to adequately prepare students in OSH areas, and to maximize the likelihood of their success after graduation. Fourth, the need for talented graduates in OSH continues, as indicated by the projected shortfall of OS and Ergonomics professionals to serve anticipated future needs in the US. Fifth, we have graduated over 150 students from our program, a majority of whom are currently working in areas related to their training. Sixth, our program is the only one in the Commonwealth of Virginia that provides depth and breadth of training in these fields. We also serve a regional need in that we are not located close to any current ERCs (the nearest being UNC-Chapel Hill, University of Kentucky, and Johns Hopkins). We are also located in a rural area and provided expertise and potential employees that can serve in capacities beyond the specific OSH training they receive (e.g., most receive more general training in industrial and systems engineering).

Primary purposes and objectives of our TPG are in parallel to those given above as the rationale: to provide a high-quality education (at the MS and PhD levels), to conduct high quality research, and to provide service. With respect to TPG funding, this was (and is) used primarily to attract and maintain top students, maintain a critical mass of students, support our curriculum, and facilitate meaningful research that is not otherwise funded. Program funds also allowed us to maintain our program breadth, which in turn also helped attract and support students.

Our training activities occur in four areas. The first is traditional didactic presentation of instructional material (lectures). Specific curricula requirements have been developed to ensure both breadth and depth of exposure, and these are described below. The second is hands-on experience (coaching). This is addressed through projects in several classes and a required OSH Practicum. The third is a formal research experience (coaching). All program participants

are required to generate either a thesis or dissertation, and the vast majority of these have traditionally led to multiple publications either at a conference or in an archival journal (e.g., see Progress Report). The fourth is professional development (seminar/discovery learning), which occurs through participation in seminars, tours, and conferences, with a goal of "rounding out" trainee educational experiences.

Separate coursework and training requirements exist for MS and PhD students, which are implemented and administered as "concentrations" within the ISE graduate program. Additional details are given below. While graduate students can obtain a non-thesis MS degree, only thesis students are considered part of the training program. Our trainees usually complete their training in ~2-2.5 years for the MS and 4-5 years for the PhD. During their training, student progress is monitored and evaluated primarily by the advisor and the student's committee. Further, the Program Director meets at least once per semester with each trainee, and the ISE department completes a formal, detailed review of each student at the end of each academic year.

Program Leadership and Faculty

Dr. Maury A. Nussbaum, Professor in ISE, is PI and directed the grant and Training Program, served as the NIOSH liaison, and managed budgetary issues. Dr. Nussbaum assumed the director's role in 1999. Dr. Dickerson continued as TPG co-Director, and Dr. Srinivasan joined as a second co-Director after joining the faculty in January, 2016. Drs. Gabbard Lau continued as supporting faculty to the TPG, and in recent years several additional supporting faculty were added (see below).

This core administration also received input from two sources (internal and external advisory committees and feedback from past trainees). An *Internal Advisory Committee*, consisting of all TPG faculty, discussed the status of the program on a regular basis, to review the program performance and address any substantial operational issues. Smaller-scale issues were discussed by email, moderated by the program director. Continuing feedback regarding the program operations and opportunities for improvement was obtained early in the reporting period from an *External Advisory Committee*, but this is being reorganized to enhance interdisciplinary strengths and diversity of representation. Trainees completing the program, as well as prior trainees, provided informal feedback to the core administration.

The individuals listed below each contributed to the training program during the prior reporting period. All were full-time, on-campus faculty. This faculty represented a diverse combination of expertise in the areas of safety engineering, occupational ergonomics, occupational biomechanics, public health, and industrial hygiene.

Core Faculty	**Areas of Primary Expertise Relevant to the Program**
Dr. Maury A. Nussbaum	Occupational Biomechanics and Ergonomics; WMSDs and Fall Prevention
Dr. Deborah Dickerson	Safety & Hazard Control; Industrial Hygiene; Prevention through Design
Dr. Divya Srinivasan	Biomechanics; Occupational Ergonomics; Work Physiology
Dr. Michael Madigan	Biomechanics; Occupational slip/trips/falls
Dr. Sunwook Kim	Biomechanics; Occupational Ergonomics
Supporting Faculty	**Areas of Expertise**
Dr. Joseph Gabbard	Human-Computer Interaction; Usability Engineering

Dr. Kathy Hosig	Public Health; Obesity Prevention; Community Education
Dr. Sheila Klauer	Occupational & Transportation Safety
Dr. Nathan Lau	Cognitive Engineering; Human Performance; Situation Awareness
Dr. Kray Luxbacher	Mining Safety
Dr. Kim Niewolny	Community Education; Agricultural Disability; Action Research

Mentoring of trainees occurred through both formal and informal mechanisms. Formal mentoring occurred primarily through advising of student research at both the MS and PhD levels. A formal research project was required at both levels, and program faculty served as major advisors and committee members for trainees. Informal mentoring occurred through several mechanisms. Organized by our student HFES chapter are several "brown bag" seminars led by faculty and students each semester, and several presentations by senior and former graduate students on their own research and real-world experiences and opportunities. Typically, a free lunch is provided by the student chapter and attendance is consistently strong. Core program faculty provided mentoring as needed, pro-actively based on our tracking of student progress, and at a trainee's request.

Collaborations among our faculty are extensive. They have jointly published many journal and conference papers, as well as obtained funded collaborative projects. Of particular note is a research center in which most current and prior trainees were involved – the Occupational Safety and Health Research Center (oshrc.centers.vt.edu) – directed by Dr. Nussbaum and with Drs. Dickerson and Srinivasan as co-directors. Faculty also mutually serve as members of trainee MS and PhD committees. Program faculty are active in a diverse set of research areas and funded projects. This research support, in turn, provides increased exposure to trainees on a variety of contemporary topics, and much of this funding allows for student support in addition to that provided by the TPG.

Program Description

As noted above, separate coursework and training requirements existed for MS and PhD students. Additional details are provided below.

MS Training

MS students complete a formal research project (thesis option) and complete 31 credit hours beyond the baccalaureate. Of these, at least 22 credit hours (7 courses) are formal coursework. All MS trainees complete a set of "core" courses and a required ISE department seminar (0 credit hours). Trainees are advised to complete "foundational" courses in their first year of training. These core courses provide a fundamental exposure to major aspects of human factors and ergonomics, safety engineering, and more detailed exposure to human mental and physical abilities and limitations. MS trainees also complete a minimum of two elective courses (≥ 6 credit hours). A set of "pre-approved" electives is provided, though trainees may deviate (with advisor and committee approval) from these as warranted by their current and future interests as well as to accommodate new or irregular course offerings. Our objectives are to build expertise (on top of the foundational coursework) while allowing students the flexibility to develop specialization within a sub-discipline.

PhD Training

PhD students have the same "core" coursework requirements and pre-approved electives as MS trainees. Each PhD trainee must complete a course on mathematical modeling to fulfill an

ISE requirement. Each PhD trainee also needs to broaden their expertise and meet departmental requirements, which is achieved by taking a minimum of 14 credit hours of elective courses. An individualized, hands-on approach is taken with each trainee in terms of selecting coursework, led by the advisor and committee and with support of the TPG director. Overall, the intent is to ensure adequate breadth in OSH through coursework while also supporting the development of specific expertise in the trainee's research domain(s).

Common Requirements for MS and PhD Training

All trainees complete a 3-credit *OSH Practicum* that provides a professional field experience in occupational and/or ergonomics. A field site is selected based upon the individual trainee's educational emphasis and a preceptor is chosen to provide mentoring and guidance in the field setting. An individualized plan is first developed and coordinated by the student, the preceptor, and the faculty advisor (one of the TPG core faculty). The plan applies measurable learning objectives to real-world practice, and it includes a minimum of 80 contact hours (this has been treated flexibly during the recent pandemic). Performance is evaluated through a mid-term progress report, a final evaluation by the preceptor and advisor, a trainee self-assessment of the accomplishment of the practicum goals and objectives, and a final written report. Industry preceptors are identified from several sources, including through prior/ongoing research projects, and advisory boards of the School of Construction and ISE Department. The latter also provide extensive contacts through senior design projects. Primary administration of the Practicum is provided by the Program Director, who also serves as the instructor of record.

Beyond the didactic course requirements indicated above, both MS and PhD trainees have requirements set by the ISE department. Each must complete a plan of study (within their first year of graduate school), in which the set of courses intended to meet the requirements is listed, and which is approved by the student's advisor, committee, and ISE graduate program director. PhD students take a preliminary exam prior to generating their research proposal, and there are several options to complete this milestone (i.e., responses to committee questions, short research proposal, review paper, technical paper). A formal research proposal is required, with a written version distributed to the student's committee followed by a formal oral presentation (proposal defense).

For trainees in our program: 1) the research must be focused on OSH; and, 2) funded trainees must be advised by one of the core faculty. Upon committee approval of the proposal, students commence their research, with a department-required progress meeting occurring at least once before the final defense. The research is presented in written form (thesis/dissertation) to the committee, again followed by an oral presentation (final defense). Consistent with graduate school requirements, all trainees must maintain a GPA ≥ 3.0 (B); otherwise, trainees are placed on academic probation and have one semester to reach compliance. No trainees dropped or were removed from the program.

Trainee Research and Interdisciplinary Experiences

All MS and PhD trainees participate in research activities. This results largely from degree research requirements, but such participation is almost always broader for several reasons. First, students become members of laboratories directed by their advisors, and hence are exposed to other work being undertaken there. Second, defenses are open, providing exposure to work throughout the OSH area. Third, students often volunteer to either serve as experimental participants or to assist with data collection. Specific student research projects are chosen at the discretion of the student and their advisor. These are typically either new topics developed by the student, or extensions of existing work being done by the faculty advisor.

Each student is expected to make a new intellectual contribution (e.g., simply performing work that had been proposed by a faculty advisor in detail would not be considered acceptable). Students are expected to broaden their educational experience by attending seminars within and outside the university, department, and option. As noted above, there are several offered by faculty and students within HFEE. In addition, our student HFES chapter is quite active, and hosts 2-3 speakers on basic and applied topics each semester. We have not formally enforced any requirements to attend seminars, as we have found that students attend these voluntarily (many are standing room only). Nearly all our students attend the annual HFES conference, either supported by their advisors or using travel supplements provided by our TPG, the university, or the student HFES chapter.

Our program works to ensure that trainees are equipped to recognize, evaluate, and control occupational hazards. They receive special knowledge in diverse areas, such as: system safety analysis, industrial fire control, ergonomics, toxicology, acoustics and hearing protection, industrial hygiene, injury epidemiology, accident analysis, occupational biomechanics, low-back pain and WMSDs more generally, radiation protection, machine guarding, electrical hazards, experimental design, and statistical analysis. It is this combination and breadth of interdisciplinary material that we believe keeps our program in demand. The combined program faculty bring substantial breadth and interdisciplinary expertise in ergonomics and safety.

Our program also fosters interdisciplinary interactions. We cooperate with faculty in several areas, including: Civil Engineering, The School of Construction, The School of Biomedical Engineering and Sciences, Computer Science, Statistics, Mechanical Engineering, and Psychology. This cooperation takes place through several means. First, students are encouraged to take classes in other areas, cross-discipline research, and committee work. Second, faculty have affiliations and joint appointments. Among the TPG leadership, Drs. Nussbaum and Srinivasan have affiliated status with Mechanical Engineering, the VT Center for Gerontology, and the VT Faculty of Health Sciences, and are core faculty in the School of Biomedical Engineering and Sciences. Third, allowing students to freely select some required committee members has also promoted a good level of interdisciplinary interaction. Fourth, faculty in the noted areas (and others) have multiple funded research projects with our TPG members and commonly serve as committee members for our trainees.

Virginia Tech also has a very strong and active student chapter of the Human Factors and Ergonomics Society (HFES). The HFES chapter is, we believe, the largest in the nation and typically receives “Gold Level” recognition each year. The student chapter regularly conducts site visits to local industries and engineering laboratories, and it hosts formal seminars and “brown-bag” lunches by safety researchers and professionals. These interdisciplinary exchanges occur on a continuing basis and are a vital part of both faculty and trainee experiences. In addition, it must be emphasized that the faculty in this program are interdisciplinary, with degree backgrounds and research interests in numerous disciplines. This diversity naturally encourages interdisciplinary activity among our trainees.

Trainees frequently interact through the mechanisms described above (meetings, gatherings, etc.) and through coursework. While trainees take elective courses specific to their interests, there is overlap among these which, along with the core course requirements the curriculum, ensures that all program trainees interact with each other on a regular basis and with students in other disciplines. Interaction among trainees is further facilitated through project requirements associated with classes. In these cases, projects are often student selected and student groups are usually selected to combine student expertise across multiple areas.

Interactions are also fostered through several hands-on experiences that occur during course-based training, particularly in the safety courses. Several courses use cases and seminar-type discussions to allow students to use problem-based approaches to apply their knowledge and skills. Students are assigned projects that are either self-selected by exploring common issues related to hazards in industry or projects that are provided by our industry partners. These projects allow students to create meaning based upon their own past experiences, knowledge, and skills, with support from scientific theory and practical industry knowledge. Student teams explore, at all levels, the causes, antecedents, and implications of different hazardous contexts.

Instruction in the Responsible Conduct of Research

Formal instruction on scientific integrity and ethical principles has been part of our graduate training for several years, continued throughout this project period, and is covered in five program courses: ISE 5024 Seminar, ISE 5615 Human Factors Research Design, ISE 5674 Systems Safety, ISE 5694 Macroergonomics, and ISE 6104 Proposing IE Research. The former three are required, while the latter two are typical electives. In each course there are units wherein the information is presented in lecture format complemented by handouts and source identification for additional information. Additional content areas covered include conflict of interest, data management and sharing, human subject use, responsible authorship, misconduct, relationship between the institution and graduate students, and professionalism and ethics in human factors and ergonomics intervention.

All trainees perform research using human subjects. As such, they are required (by the VT IRB) to complete an on-line web-based training module and successfully pass the module, or complete alternative comparable training (e.g., from the NIH website). Documentation of such training is required before an IRB application is approved. Additionally, the Office for Research Compliance at Virginia Tech provides workshops covering ethical principles related to the conduct of scientific research. All trainees are required to complete this 2-hour workshop over the course of their plan of study. In addition, STS 5444 (Issues in Bioethics) can be used to satisfy federal requirements.

Training Candidates

Trainees in our program are candidates for the MS or PhD within the Department of Industrial and Systems Engineering. Trainees all hold B.S. degrees in engineering, science, psychology, or cognate area from an accredited college or university. They are admitted competitively based on grade point average, letters of recommendation, personal statements, work experience, and standardized test scores. Graduate school admission standards are as follows: GPA (3.0), TOEFL (>90). There are no minimum requirements for the GRE, though mean values among students accepted to the ISE graduate program are 156 V, 165 Q, and 3.8 A. Admissions are handled by an admissions committee in the Department, though all faculty can provide input (via an electronic admissions system).

Prospective trainees are actively recruited through our web page, from program brochure mailings, and from active participation of both faculty and students in conferences. We draw students from around the US, and receive many international applicants from China, Iran, S. Korea, and India. Approximately 30-50 applications are received each year for the entire program (HFEE area within ISE). Of these, roughly 50% are accepted and ~10 enroll. Of the HFEE students who matriculate, roughly half pursue research in some aspect of occupational safety, ergonomics, or biomechanics. We recognize that our program has somewhat fewer graduates than some other program. However, our program emphasizes a rigorous research

training component (especially via the required MS thesis or PhD dissertation). As such, we believe that the annual number of trainees completing the program is strong.

Accepted graduate students currently in the U.S. are invited to a recruitment event held on campus (this past year the event was done virtually due to the pandemic). Departmental funds are used to offset the travel expenses involved, typically up to $600 each. The event includes an introduction to the university, department, and HFEE. Faculty are present to introduce themselves and their research and to provide laboratory tours. Student representatives from the local HFES chapter participate as well. Additional recruiting occurs through faculty affiliations with other departments at Virginia Tech, and through advertising at conferences (especially the annual HFES).

Consistent with recent college and departmental changes in focus, specifically increasing their emphasis on doctoral-level training, we have had more applications and more enrolled students at this level in our program. We have worked to increase our recruiting efforts on MS trainees. For example, we advertise the program more widely, to our own ISE undergraduates and regional undergraduate programs. Our program continues to contribute to the role of TPGs in ensuring “an adequate supply of qualified professional occupational safety and health practitioners and researchers.” While year-to-year we have, and likely will continue, to have a changing balance between practitioner- and researcher-focused trainees, our overall goal in recruiting and training will be to achieve both products to the extent possible.

TPG funds are awarded based on several criteria, which are implemented by the core TPG faculty. Top priority for funding is given to continuing trainees. Specifically, we continue funding from the TPG as long as the trainee is making good progress (we have never had to “cut” such support in the history of our program). If funding is available in a given year, the core faculty evaluate new and continuing trainees to identify an awardee. This evaluation is based on academic and research performance and goals indicated by trainees regarding their participation in the program. Trainees who are in their second year in the program and are ready to conduct a research project are given priority. TPG funding is limited to those who meet citizenship requirements as described in the RFA. PhD trainees making good progress who do not receive TPG funding receive other support, typically in the form of Graduate Research Assistantships, Graduate Teaching Assistantships, and Graduate Fellowships.

Training Facilities and Resources

Our training facilities included several laboratories that were used on a regular basis for OSH-relevant research and instruction:

COGENT:
This lab conducts a variety of research of usability, human performance, human-system interaction, and worker health and safety. Major equipment includes: Computer workstations, Cognitive Assessment Battery, Personality and Individual Difference Questionnaires, Safety Self Efficacy Questionnaire, Atlas.TI (qualitative analysis and modeling tool). Additional equipment includes: Optical see-through AR displays (Google Glass, NVIS ST50, Sony Glasstron), Oculus Rift VR HMD, Intersense IS-900 for motion tracking analysis, Tobii X2-60 Eye tracker for Gaze and Scan Path Analysis, Large Tabletop Stereoscopic Display, Full-scale Driving Simulator for Virtual and Augmented Reality, several iPad and iPhones for Tablet-based User Interaction, GSR 200 Galvanic Skin Response for User Analysis (Biofeedback), Gyro Trackers for User Analysis (motion), Polar RS 800 for Heart Rate Variability, and OCZ-OCZMSNIA Neural Impulse Actuator for Cognitive Analysis

OEB:
The OEB labs are comprised of five distinct areas (one located off campus), with a total space of ~4,000 ft^2. Major equipment includes: human motion capture (10-camera Vicon Vera system; 12-camera Qualisys Oqus 500+ system with 64 channels of A/D; two full-body, XSens MVN systems; Faro SMM); 2) six AMTI force platforms, one Bertec force platform, 3-axis load cells, and a Novel Pedar system; 3) metabolic measurements (CosMed K4b2 and K5); 4) measures of muscle activity (32 channels of wireless EMG (Noraxon) and 24 channels wired; 5) dynamometry (two Biodex System 3 Pro; one Humac Norm); 6) instrumented split-belt treadmill (Bertec); and 7) software for biomechanical analyses (AnyBody, Visual3D, 3DSSPP). These labs also house one of the largest collections of commercially-available occupational exoskeletons.

Healthy Work Design:
This lab is researching ways to improve the health of workers through design of work, management systems, and the physical and psychosocial work environment. To investigator the control of health hazards, the lab is fully equipped with industrial hygiene field sampling equipment, as well as bench-top analytical equipment. The following is a list of the major field data collection equipment available. All are available for TPG trainees for use in research and practicum experiences. Polarized Light Microscope Olympus, Buck TO14 Gas Chromatograph with PID and FID (DELCD), Quest IAQ Kit AQ-5001Pro IAQ Monitor Kit, Sensor, Logging, Temp/Humidity/CO2/CO Monitor, RAE IAQ Monitor with PID, Tramex Moisture Encounter Plus Meter, BioStage Pump Kit-DC, with QuickTake 30 Pump, 100-240V, Carpet sampling kit SKC Carpet Sampling Pump Kit, Testo Model 625-1 Thermo- Hygrometer, TA9515 Kit includes meter and probe calibration certificate, Carbon Dioxide Monitor Testo Model 535 Carbon Dioxide Monitor, Thermo Scientific XLi800 NITON XRF (X-ray fluorescence) alloy analyzer, IEQ Monitor with Datalogging GreyWolf IAQDirectSense, IR-Spectrophotometer Miran SappIRe, Industrial Hygiene Particulate Monitor TSI Sidepak AM510 Personal Aerosol Monitor, Kanomax Model 3887 Particle Counter, NiMH, Logging, Laser Particle Counter, Masimo Rad57 Model 2200, Puritan Bennett Spirometry System, Drager X-am 1700 confined space monitor, RAE EntryRAE, Testo 317-3 Carbon Monoxide Monitor STICK, Testo Model 545 Light (Lux) Meter/Logger (datalogging), Quest 210 Economy Type 2 sound level meter.

VACSE:
Work in this lab investigates worker performance, particularly in safety-critical domains such as nuclear power plants, petrochemical plants, and healthcare systems. VACSE features 500 square feet of development and experimental space for building and testing technology to support operators in their situation awareness, workload, and stress. VACSE is equipped with portable Advanced Brain Monitoring B-Alert EEG system, two pairs of SMI eye-tracking glasses, and one SMI REDn remote eye-tracker. VACSE also hosts a full-scope nuclear power plant simulator running on five computer workstations with eighteen 4K monitors to provide a complex, industrial work environment to study human-machine interaction, operator affective states, and objective task performance.

Other facilities included those normally found at a major University and include dedicated, multimedia classroom space, computer laboratories, and faculty and student office space. Additional research support was provided by the Industrial and Systems Engineering Department in the form of office space for all graduate students (each office containing a networked computer with software), supplemental funds for subject fees and travel, and a fully equipped machine and electronics shop with four full-time staff members.

Program Outcomes and Accomplishments

The Virginia Tech TPG is a component of the graduate program in the Department of Industrial and Systems Engineering (ISE). During the reporting period, the program consisted of MS (thesis) students with specific concentrations (Safety Engineering, Physical Ergonomics, and Occupational Biomechanics) and PhD students conducting research in occupational safety and health. Our program was very active over the past project period. This activity included several sponsored projects, numerous research publications, and awards to the faculty and trainees. The program also generated several program graduates (see below), who have been productive in research and gone on to careers in occupational safety and health.

Our program has been quite successful at recruiting and retaining students overall, and especially in enhancing program diversity. With respect to recruiting, we had applications from around the country and the world, from individuals with diverse backgrounds (engineering, psychology, math, physical therapy, etc.). In the prior reporting period, no trainees left the program, and the vast majority completed the program in a reasonable time period (i.e., 2.5 years for the MS and 4-5 years for the PhD); any exceptions to these have mainly been students who worked full or part time during their training. Roughly half of our prior trainees are female, and a substantial number are from minority and/or underrepresented groups.

We supported five different trainees during the reporting period using TPG funds. Four completed their training, one obtaining the MS (and continuing for the PhD) and three obtaining the PhD. An additional six students completed training in the program, 4 MS and 2 PhD. There was a continued increasing proportion of trainees at the doctoral level, largely as a result of: 1) changes in applicant demand; 2) continuation of MS students in the PhD program; and 3) an increased institutional emphasis on doctoral-level training across all fields.

Given the level of under-representation of women in the fields of OSH, we believe we were successful in training such individuals in the reporting period. Specifically, nearly half of our funded trainees were women, and almost half of the total trainees in the program. One underrepresented minority (African-American) completed MS training in the reporting period, and subsequently continued for PhD training. A woman whose ancestry is part Native American completed PhD training in the reporting period.

Diverse research products were generated by the program in the reporting period. Trainees supported by the program generated 7 and 13 papers in journals and at conferences, respectively. For the program as a whole, there were several dozen additional scholarly contributions.

In September 2020, we developed and distributed an evaluation survey for use as a summative assessment of the program during the prior funding period. This anonymous survey was submitted to all (*n* = 10) program graduates during the funding period up to that time. The response rate was 100%. Questions posed and responses received are summarized below.

Responses to several statements using the following Likert-scale alternatives: 1 = Strongly Disagree (SD); 2 = Disagree (D); 3 = Neutral (N); 4 = Agree (A); 5 = Strongly Agree (SA).

Statement	SD	D	N	A	SA	N/R	Mean
1. My current career involves occupational safety and/or ergonomics	2	1	0	2	4	1	3.56
2. My graduate studies at VT prepared me for my current career	0	0	0	1	8	1	4.89

3. My graduate studies at VT allowed me to gain experience in conducting formal research	0	0	0	1	9	4.90
4. My graduate studies at VT enhanced my understanding of the major problems, theories, technologies, and tools in the fields of occupational safety and/or ergonomics	0	0	0	2	8	4.80
5. The VT program prepared me for professional practice in occupational safety	0	0	2	5	3	4.10
6. The VT program prepared me for professional practice in occupational ergonomics	0	0	0	2	8	4.80
7. The VT program enhanced my appreciation of the need for lifelong learning	0	0	0	4	6	4.60
8. The VT program helped me to develop skills to work/collaborate effectively with people from different backgrounds	0	0	0	4	6	4.60
9. I would recommend the graduate program at VT for any student interested in occupational safety and/or ergonomics training	0	0	0	0	10	5.00

The following categories were indicated as best describing their current employment: academia, industry, healthcare, technology development.

Third, open-ended questions asked about the “most positive aspects” of their graduate studies and “suggestions for improvements”. Among the positive aspects noted were: range of coursework, options for collaborations with other students; research addressing real-world problems, diverse faculty experts, preparation to be an independent researcher encouragement and support of advisors; ability to work with companies; and strong resources available. Among the suggestions for improvement provided were: more information on alternative career paths and more visits to industries. Our program leadership is working to try to address these latter aspects.

Conclusions

Our program occupied a niche that is somewhat unique, given both the program breadth and depth. Diverse outputs and accomplishments were achieved, in terms of program graduates and research products. It was oriented strongly towards engineering aspects of OSH, while also being influenced by its place within the larger ergonomics and human factors engineering graduate concentration. Trainees were exposed to a wide variety of health and safety issues, including such topics as system safety, industrial hygiene, traditional physical ergonomics, engineering design, and human factors research methods.

The program was successful in terms of graduating a consistent number of well-qualified trainees, who generated substantial research products (e.g., journal and conference papers) and who have gone on to future careers emphasizing occupational safety and health. As was described above, however, the effects of TPG funds went well beyond the direct influence on student tuitions and stipends. The award was a key aspect in the maintenance and continual improvement of the training curriculum, and it facilitated numerous other activities both intra- and extra-curricular.

The program has undergone some revisions during the prior project period. Among these, the more substantial ones have been changes in faculty involvement, an increasing focus on doctoral-level training, and an expansion of the program to emphasis practical experiences. A continual evolution will likely occur, as we strive to both improve and grow the program in the future.

Publications from Trainees

The list immediately below contains publications that were generated by trainees supported by the training grant, and which represent work completed during their training period. Funded trainees are underlined. In addition to these, other trainees generated numerous journal papers (published or in-press) and conference presentations on topics related to occupational safety and health in the reporting period.

Journal Articles:

1. Sedighi A, Nussbaum MA: [2017] Temporal changes in motor variability during prolonged lifting/lowering and the influence of work experience. Journal of Electromyography and Kinesiology, 37: 61-67.
2. Sedighi A, Ulman S, Nussbaum MA: [2018] Information presentation through a head-worn display ("smart glasses") has a smaller influence on the temporal structure of gait variability during dual-task gait compared to handheld displays (paper-based system and smartphone). PLoS ONE, 13(4): e0195106.
3. Kelson D, Mathiassen SE, Srinivasan D: [2019] Trapezius muscle activity variation during computer work performed by individuals with and without neck-shoulder pain. Applied Ergonomics 81: 102908.
4. Kim S, Moore A, Srinivasan D, Akanmu A, Barr A, Harris-Adamson C, Rempel DM, Nussbaum MA: [2019] Potential of exoskeleton technologies to enhance safety, health, and performance in construction: industry perspectives and future research directions. IISE Transactions on Occupational Ergonomics and Human Factors, 7: 185-191.
5. Sedighi A, Nussbaum MA: [2019] Exploration of different classes of metrics to characterize motor variability during repetitive symmetric and asymmetric lifting tasks. Scientific Reports, 9: 9821.
6. Ulman S, Ranganathan S, Queen R, Srinivasan D: [2019] Using gait variability to predict inter-individual differences in learning rate of a novel obstacle course. Annals of Biomedical Engineering, 47(5): 1191-1202.
7. Sedighi A, Rashedi E, Nussbaum MA: [2020] A head-work display ("smart glasses") has adverse impacts on the dynamics of lateral position control during gait. Gait & Posture, 81: 126-130.

Proceedings:

1. Sedighi A, Kim S, Nussbaum MA: [2016] Comparing motor variability between experienced workers and novices. Proceedings of the 40th Annual Meeting of the American Society of Biomechanics, Raleigh, NC. August 2-5. (Online only, 2pp.).
2. Kim S, Ulman S, Nussbaum MA: [2017] Effects of head-worn display use on obstacle crossing performance in a simulated occupational task. Proceedings of the American Society of Biomechanics, Boulder, CO, August 8 – 11 (2pp.)
3. Nussbaum MA, Kim S, Sedighi A, Rashedi E, Mokhlespour Esfahani, M: [2017] Development of acceptable hand impact force limits. Applied Ergonomics Conference, Orlando, FL, March 27-30. Abstract only.
4. Kelson D, Srinivasan D, Mathiassen SE: [2018] Differences in trapezius muscle activation patterns in office workers with and without chronic neck-shoulder pain, as quantified through exposure variation analysis. Proceedings of the Human Factors and Ergonomics Society, Philadelphia, PA, pp. 962-966.
5. Kelson D, Srinivasan D, Mathiassen SE: [2018] Trapezius Muscle Activity Variation during computer work performed by individuals with and without chronic neck shoulder pain, Proceedings of the 20th Congress of International Ergonomics Association, Florence, Italy.

(1 page).
6. Ulman S, Queen R, Srinivasan D: [2018] Gait variability to predict motor learning of a novel motor task. Proceedings of the American Society of Biomechanics Conference, Rochester, MN (2pp.)
7. Kelson DM, Kim S, Nussbaum MA, Srinivasan D: [2019] Effects of passive upper-extremity exoskeleton use on motor performance. Meeting of the International Society of Biomechanics and American Society of Biomechanics, Calgary, Canada, July 31-August 4. (Abstract only).
8. Kelson DM, Kim S, Nussbaum MA, Srinivasan D: [2019] Effects of passive upper-extremity exoskeleton use on motor performance in a precision task. Proceedings of the Human Factors and Ergonomics Society 63rd Annual Meeting, Seattle, WA, October 28 – November 1, pp. 1084-1085.
9. Kelson D, Kim S, Nussbaum MA, Srinivasan D: [2019] Effects of using passive upper extremity exoskeletons on physical demands and motor performance of force control and precision-control tasks. 10th International conference on Prevention of work-related Musculoskeletal Disorders (PREMUS), Bologna, Italy (1 page).
10. Lee Y, Ulman S, Kim S, Srinivasan D: [2019] Effects of mental and physical fatigue inducing tasks on balance and gait characteristics. Proceedings of the Human Factors and Ergonomics Society 63rd Annual Meeting, Seattle, WA, October 28 – November 1, pp. 1103-1104.
11. Rashedi E, Nussbaum MA, Sedighi A: [2019] Different information displays have a varying effect on local gait stability. Meeting of the International Society of Biomechanics and American Society of Biomechanics, Calgary, Canada, July 31-August 4. (Abstract only).
12. Ulman S, Nussbaum MA, Srinivasan D: [2019] Experience-related differences in gait variability during a military-relevant load carriage task. Meeting of the Biomedical Engineering Society, Philadelphia, PA, October 16-19. (Abstract only).
13. Ulman S, Nussbaum MA, Srinivasan D: [2019] Gait variability for predicting performance and adaptability in military-relevant tasks, in Military Health System Research Symposium, Kissimmee, FL.

Ph.D. Dissertations:
1. Goldberg AJ: [2016] Industry usage, stakeholder perceptions, and usability characteristics of hazard controls leading to the development of a design process and taxonomy for large handheld powered equipment, Ph.D. Dissertation, Virginia Tech.
2. Sedighi A: [2017] Applications of motor variability for assessing repetitive occupational tasks, Ph.D. Dissertation, Virginia Tech.
3. Ulman S: [2019] Gait variability for predicting individual performance in military-relevant tasks. Ph.D. Dissertation, Virginia Tech.

M.S. Theses:
1. Kelson DM: [2018] Muscle activation patterns and chronic neck-shoulder pain in computer work, MS Thesis, Virginia Tech.

The following lists additional Dissertations and Theses generated by unfunded trainees who graduated in the reporting period

Ph.D. Dissertations:
1. Alabdulkarim S: [2017] Assessing the relationship between injury risk and performance: the efficacy of adding adjustability and using exoskeletons in the context of a simulated drilling task, Ph.D. Dissertation, Virginia Tech.

2. Mokhlespour Esfahani MI: [2018] Development and assessment of smart textile systems for human activity classification, Ph.D. Dissertation, Virginia Tech.

M.S. Theses:

1. Duan X: [2017] Influence of gender and obesity on motor performance, neuromuscular control and endurance in older adults, M.S. Thesis, Virginia Tech.
2. Han, W: [2019] A connected work zone hazard detection system for highway construction work zones, M.S. Thesis, Virginia Tech.
3. Lee, Y: [2019] Effects of fall technique training on impact forces when falling from standing, M.S. Thesis, Virginia Tech.