**Proposal Number:** 1761646

**Panel Summary:**   
Panel Summary    
  
SUMMARY OF PROPOSAL   
  
In this proposal, a soft robotic exoskeleton for the upper extremity is developed. The soft robotic exoskeleton is part of a suite that includes embedded sensors to measure anxiety and stress. A human study is proposed in which the subject will wear the exoskeleton system while immersed in a virtual reality environment. A Fitt's task is performed where the subject moves a tool as quickly and accurately as possible between specified target locations. Many dependent measures of performance are collected. The researchers propose to determine the minimal sensor suite for monitoring anxiety and stress. They also plan to examine stress-relieving activities to examine the proposed measures.   
  
INTELLECTUAL MERIT   
Strengths:   
--Strong background, good team that is being brought together to develop the integrated system.   
--The proposed work aligns with the M3X goals as there is a bi-directional interaction. The system infers information about the human state and adapts based on these data to determine action. The human may also adapt based on the action of the system.   
  
Weaknesses:   
The panel had several questions and concerns about the proposed effort as itemized here.   
--The proposal is missing an operational definition of stress and anxiety. Stress and anxiety are not the same construct. These constructs also adapt over time and are affected by aging and musculoskeletal physiology. The panel would like to see a discussion of how to address time adaptation or how this might confound the interpretation of the results. Discussion of how confounds are disambiguated will enable one to make the appropriate inferences and take the appropriate follow-up actions.   
--Please also provide your definition of attentional bias and cognitive inefficiency.   
--It is not clear that the manipulations of the immersive environment would create stress in a measureable/detectable manner.   
--There are numerous dependent variables that are included in the data collection. However, it is unclear how these dependent measures align with the constructs of anxiety and stress.   
-- It is unclear how the system is being used in the context of the task. Soft robot exoskeletons have greater uncertainty than rigid systems. While the proposal states that the system would be used for load distribution and actuation profiles, it was unclear how these modes would align with the underlying task. The panel was unable to determine if the task selected would be affected by the precision available with soft actuators   
  
BROADER IMPACT   
Strengths:   
The panel believes there are good broader impacts through the proposed training opportunities between engineering and health/kinesiology students. The panel appreciates the efforts to work with K-5 and URM students.   
  
Weaknesses:   
The panel did not discuss any weaknesses in this category.   
  
SUMMARY RATIONALE FOR PANEL RECOMMENDATION   
The development of a soft-exoskeleton that can assist human performance is exciting to the panel. However, the panel believes there is additional clarity required regarding the implementation of the exoskeleton within the study, as well as the dependent measures. The panel recommends developing testable hypotheses and specifically motivating the parameters that are investigated in the context of the constructs defined. The panel recommends including a clinical psychologist as part of the team to assist in clarifying the constructs of stress, anxiety, and attentional bias and motivating measures that align with these definitions. The panel felt that selecting a sub-set of the dependent measures that could be presented in more depth may be warranted. Clarification in the experimental protocol and exoskeleton control in the context of the task should be provided.   
  
The summary was read by/to the panel and the panel concurred that the summary accurately reflects the panel discussion.  
**Panel Recommendation:**Do Not Consider

**REVIEW 1:**

In the context of the five review elements, please

evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

The overarching goal of the proposed work is to identify physical and mental stress via embedded sensors in soft robotic-exoskeletons, and intervene to alleviate stress. First, they will identify physiological markers of stress in a virtual-tool-handling task, manipulating physical effort and environmental stress. Using a dimensionality reduction technique, they will identify which intrinsic measures are best at detecting stress. Next, they will measure stress metrics without and with the exoskeleton (passive and actively employed). Finally, they will monitor stress with the embedded sensor suite in real-time.

Strengths of intellectual merit:

This is a highly interdisciplinary proposal whose primary objective is inline with the mission of the Mind, Machine, and Motor Nexus (M3X) program, as it aims to utilize soft robotic-exoskeletons to monitor human cognition in an integrated fashion. Findings from this proposal will advance to both biosensing and exoskeleton design, as well as inform differences in physiological stress during task engagement across the lifespan (testing in both young and older adults). The experimental manipulations are well-conceived (i.e., 2x2 factorial of low vs. high physical effort X low vs. high mental stress), but I do have concerns about implementation (see below). The team is well-equipped to carry out the behavioral experiments and develop the exoskeletal apparatus.

Weaknesses of intellectual merit:

My primary concern regards the efficacy of the behavioral task to actually manipulate conditions of physical stress and mental stress in the virtual-reality environment. Previous experiments manipulating inertial loads have revealed little impact on ratings of perceived exertion (or learning), unless the loads are extreme. The authors use small loads ù only a 5 or 10 lbs. ù which many only affect fatigue, yet they provide adequate rests to mitigate fatigue. This could reduce the effects of stress. In a similar vein, it is unclear if a simulated elevated platform will induce environmental stress. The authors do not reference prior research or provide preliminary data that support that these factors affect stress ratings, either through physiological measures or questionnaires (RPE/State-Trait Anxiety Inventory). Thus, their manipulations, while well-conceived, may not be sufficient to detect the desired effect.

A lesser concern of mine is that the proposal does not elaborate or detail on how their dimensionality reduction analysis will categorize intrinsic measures of force/motion/movement strategies as low versus high stress. The description of the DDA analysis is not sufficient to evaluate the feasibility of this approach nor is it benchmarked against a standard. The proposal does not describe how relevant features of the reach trajectory will be analyzed with regard to the dimensionality reduction analysis. These details are necessary to evaluate the feasibility of the approach, which is fundamental to the build-up of objectives in the proposal.

In the context of the five review elements, please

evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Strengths of broader impacts:

Development of soft, robotic exoskeletons with embedded sensing technology could be transformative in society. The proposal is poised to make advances in this domain and the authors have specific plans to disseminate their findings within the academic community and with the broader, local community. The proposal has specific plans to target underrepresented and underprivileged groups.

Weaknesses of broader impacts:

No weaknesses noted.

Please evaluate the strengths and

weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if

applicable

Summary Statement

This is an ambitious proposal that seeks to develop soft robotic-exoskeletons with embedded sensing to monitor physical and mental stress, which could in turn be used to intervene to alleviate stress. The experimental approach is reasonable, but feasibility could be improved by inclusion of preliminary data or more specific details regarding data analysis.

**REVIEW 2:**

In the context of the five review elements, please   
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.   
  
This proposal examines human-machine interaction toward improving performance and reducing anxiety and stress-related injury and disorders during manual and repetitive tasks in industry. This is particularly targeted at older workers, a greatly increasing proportion of the workforce, for whom these effects are stronger and have more detrimental effects. To do this, a soft exoskeleton is to be developed to help affect and actuate movements, and using data discerned from perceptual and physiological indices of anxiety and stress, the exoskeleton will adapt and adjust to limit of injury.   
  
The proposed work is consistent with the mission of the M3X program. It is methodologically innovative and integrates concepts in human intent and behavior with embodied intelligent systems as mediated by motor manipulation, as well as how machines and humans cognitively interact. The work has potential to advance theory and application of industrial applications of exoskeletons, and beyond.   
  
This project has three aims: the first is to determine the specific minimum 'sensor suite' (i.e., physiological/perceptual data input) needed to sense relevant anxiety and stress, using continuous real-time monitoring of physiological data (e.g., EMG, skin conductance, ECG, etc.) in virtual reality tool handling tasks. The second is to develop a soft exoskeleton that can assist with manual tasks, alleviating stress and improving accuracy by redistributing load and actuation. Third is the development of a stable real-time feedback loop that will sense stress/anxiety and adjust to it to enhance performance and reduce risk of injury in young and old adults.   
  
The intellectual merit for the project is potentially very high. The experiments and goals are specific and well articulated, powered, and have clear analysis plans. The team is very strong and well integrated into the work. The PI is early career stage but has some relevant funding and publications and is supported by a multidisciplinary team with strong expertise and funding histories in relevant work. Five graduate assistants representing all four primary disciplinary areas are incorporated. This is an excellent opportunity for multidisciplinary training and also suggests there is sufficient manpower to accomplish the goals. There is sufficient funding for the needed materials and also sufficient other funding to assure support. The budget justification seems to have overlooked articulating a large amount of 'other' expenses that appear to be for tuition for the 5 graduate assistants.   
  
The proposal does, however, lack some clarity. How and when stress and anxiety are relevant to the workplace tool handling type tasks for which the exoskeleton can assist is not entirely clear. Weight, repetition-related fatigue, etc. are fairly obvious for such tasks but the psychological stress and anxiety that is addressed in the background sections is not very well tied to the context. More clarity on previous findings using fNIRS with older adults during gait would be helpful. The constructs of 'stress' and 'anxiety' are often conflated in ways that are not necessarily helpful or realistic. It is clear that there is intent to use both motor/joint/physiological stress measures as well as perceived stress or anxiety during tasks to best adapt to changing conditions. Yet it is a bit unclear how these will be disambiguated to best achieve the goals and to assure appropriate action. For example, one tends to have much higher state anxiety when initially learning or experiencing a task, which improves through experience. It is not entirely clear how these experiments will address or adapt to that. In addition, autonomic arousal and stress responses are not synonymous. It is not entirely clear which conditions are of primary importance to providing load distribution and actuation. Some of this will obviously need to be evaluated during the work, but a bit more clarity of their distinctions would aid confidence in the proposal. Attentional bias and cognitive inefficiency is raised and both are directly relevant, yet, it is not clear how these will be incorporated into the modeling (neither seems to actually be assessed). Aging affects musculoskeletal conditioning and strength, stress and anxiety response regulation, and attention and cognitive efficiency. While the proposal is not designed to interrogate these independently, can the system that will be developed function effectively if they are not?   
  
  
In the context of the five review elements, please   
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.   
  
Multiple benefits to society are described and apparent in the proposal regarding the enhancement of human-machine interaction functioning, as well as understanding the dynamics of anxiety and stress on manual labor tasks and how those could be reduced to protect from injury. Thus it addresses both the enhancement of exoskeleton robotics for tool handling and injury in industrial applications and the fundamental understanding of and adjustment too stress-related impairment in performance in manual tasks. The proposal also lists broad dissemination of the findings and availability of raw data, as well as multiple directions for enhancing student learning, community outreach, recruitment of students into robotics and emphasis on recruitment of underrepresented students.   
  
Please evaluate the strengths and   
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if   
applicable   
  
  
  
Summary Statement   
  
This proposal is intriguing and has high potential value especially for industry in an era of a rapidly aging workforce. The rating of Good is based on a solid match with the M3X program goals; intellectual merit in advancing ability to adequately sense stress/anxiety (important risk factor for injury) and use the information to allow a unique exoskeleton to adapt in real time; and broader impacts that include important societal value and well rounded dissemination, data sharing, and education, training and outreach plans. The rating is modestly tempered by some shortcomings in the precision and clarity of some of the experimental details.

**REVIEW 3:**

In the context of the five review elements, please   
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.   
  
The investigators, Hernandez and colleagues at UIUC, propose an interdisciplinary project aimed to combine the real-time sensing of physical and mental stress in humans with state-of-the-art active soft robotic exoskeletons. The major objective is to bring us closer to the development of integrated and responsive human-machine systems for use in stressful industrial work environments. They propose to lay foundational benchmarks in modern human-machine interfaces using soft robotic-exoskeletons and build an engineered system which can be of real benefit to workers in industrial settings. To meet these goals, they plan to 1) identify the minimal sensor suite for monitoring anxiety and stress changes in real time; 2) create and validate stress-relieving active soft robotic exoskeleton; and 3) validate body-in-the-loop control of soft robotic exoskeleton.   
The engineering aspects of the development of the soft exoskeleton are excellent, at least to my limited understanding. However, the experimental parts of the proposal are a bit underdeveloped. For example, in the first set of experiments where a Fitts task is performed in a virtual environment, the investigators would like to look at the effect of stress on a whole smorgasboard of variables that include: physiological (skin conductance, muscle activation, electrocardiogram, and cortical hemodynamics) and mechanically intrinsic (force, kinematic motion capture data, and inertial data) time series data. While they specify that they will use delay differential techniques, no specific predictions are made about what would happen to these variables. This kitchen-sink approach is less likely to be successful, compared to a more carefully developed hypothesis based research program where each of these variables is chosen more carefully. For e.g. I have no idea how cortical hemodynamics will change as function of stress and tool use. If the investigators can address this, they can make a strong contribution to multiple areas, both fundamental and applied.   
  
  
In the context of the five review elements, please   
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.   
  
This project has important implications for significantly enhancing our understanding of subject-specific dynamics of anxiety or stress during manual labor tasks. This could lead to the active development of wearable devices. In addition, the proposed research may provide significant insight into how a soft robotic device may shape tool handling performance and risk of injury in both industry settings and in the general community. Applications for prosthetics and orthotics exist. There are several training opportunities and the PIs take special efforts to work with groups underrepresented in STEM disciplines.   
  
  
Please evaluate the strengths and   
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if   
applicable   
  
  
  
Summary Statement   
  
The research team appears to be well poised to carry out the research. The engineering sections of the proposal however need to be complemented by equal sophistication on the human experimental/testing side.