Army Public Health Center

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Measuring Exosystem Operator Use Intent: The Exosystem Use Intent Model - Industrial

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1 REFERENCES

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2 PURPOSE

The purpose of this paper is to propose a methodology for the measurement of an exoskeleton operator's cognitive perceptions and attitudes, leading up to their intention to use the exoskeleton to complete future industrial work tasks. Note that this version of the EUI is meant to only measure exosystem operators in an industrial environment. Exosystem operator use intent in the medical or military fields will be addressed in future documents.

3 BACKGROUND

Human interaction with technology has been studied for thousands of years, yet modern scientific work in this field can trace its roots back only to the early 20th century, beginning with the time-motion studies of Taylor and Gilbreth, continuing towards the pioneering work of Fitts and Chapanis, Broadbent [1], and Wickens [2]. Human interaction studies have evolved as technology advancement has exploded. This explosion has enabled modern technology, specifically robotics, to perform many tasks such as assembly work in a highly controlled environment. As of the date this paper is written, however, basic human/machine function allocation still calls upon a human's adaptability and creativity to accomplish tasks that automated robotics cannot due to an uncontrolled environment. For this reason, current technology has produced "wearables" (including exoskeletons and exosuits, hereafter called exosystems). These devices are placed on the human in order to extend the human body's domain into tasks that would benefit from the productivity afforded by robotic systems, while taking advantage of the adaptability and creativity of the human mind. Exosystems can be further defined as a unique interface of the human (both cognitively and physiologically), machine hardware, and computers (hardware and software). A human's psychological aspects of this "cobotic" interaction are as of yet largely unknown [3]. This proposed methodology measures those engineering psychological factors using a modified TAMII model, as well as four existing human factor constructs: usability, workload, situational awareness (SA), and trust in automation.

The domain of prosthetic devices has yielded valuable lessons about human interaction with wearable technology—specifically about the use and abandonment of wearable technology that, while both high-tech and well-intentioned in its design, does not meet its human user's goals and expectations. Jarrasse et al. [4] point out, "While physical interaction with robots is becoming common in many domains, numerous devices are not appropriated by their users and remain unused in the cupboard. This phenomenon is observed particularly with robotic devices that are designed to interact closely with the body."

Such lack of acceptance by users of robotic prosthetics—in some cases leading to total abandonment—can be due to any number of physiological, psychological, social, cultural, and/or anthropological aspects. Discovery of these aspects will lead to a decrease in desertion of exosystem technology. The objective of this paper is three-fold:

- To propose a methodology *broad* enough to test human factor/engineering psychology aspects of exosystems used in different work tasks within the industrial work domain.
- To create a methodology *flexible* enough to catch future developments in exosystem technology; a certainty to happen in the near future.
- To create a methodology *short* enough, *inexpensive* enough, and *easy enough to apply* for small shop managers to practice while testing exosystem models for use in their facilities, while still *in-depth* enough for large, well-funded, lab-based studies.

3.1 Human/System Interaction Models

To address the problem of lack of acceptance and abandonment, earlier models of human/machine interaction have evolved to utilize and integrate technologies with human activity/task contexts.

In one attempt to solve the abandonment problem by computer users and improve human/system interaction predictions in the software domain, John Brooke [5] produced what he called a "quick and dirty" questionnaire on the user's subjective opinions of a system: the System Usability Scale (SUS). The SUS questionnaire askes subjects their level of agreement with the following post-test Likert scale questions:

- I think that I would like to use this system frequently
- I found the system unnecessarily complex
- I thought the system was easy to use
- I think that I would need the support of a technical person to be able to use this system
- I found the various functions in this system were well integrated
- I thought there was too much inconsistency in this system
- I would imagine that most people would learn to use this system very quickly
- I found the system very cumbersome to use
- I felt very confident using the system
- I needed to learn a lot of things before I could get going with this system

Use of the SUS questionnaire improved human-system interactions, but did not eliminate the abandonment problem. Valuable, well-intentioned resources also suffer from the persistent issue of abandonment by intended users in a slightly different domain, Assistive Technology (AT). AT is described as any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities [6]. To remedy abandonment, the Human Activity/Assistive Technology (HAAT) model was developed to pre-test AT users. HAAT is "a conceptual model that incorporates three common elements of a user's environment: the human/person; the activity/occupation; and the context/environment [7]." Even though SUS attempted to account for the environmental context of computer users, it fell short in ways that HAAT did not. According to Giesbrecht, "[T]he context is understood to be more than the location and physical conditions in which an activity occurs. The impact of social, cultural and institutional factors is embedded and the relevance of the activity to the individual is paramount [7]." By including the elements of the human user's occupational and environmental context the HAAT model led to a further decrease of the abandonment problem.

Returning to the software domain, an improvement upon the SUS questionnaire led to the creation of the Technology Acceptance Model (TAM) (Figure 1) [8]. Similar to the approach used by the HAAT model, TAM incorporates a focus on environmental context and is based on two closely related human psychological constructs: the Theory of Reasoned Action [9] and the Theory of Planned Behavior [10]. In the diagram presented in Figure 1, an individual's cognitive processes flow from left to right. TAM separates a user's cognitive perceptions into two separate categories: how they perceive the technology's usefulness to the task and how they perceive the technology's ease of use.

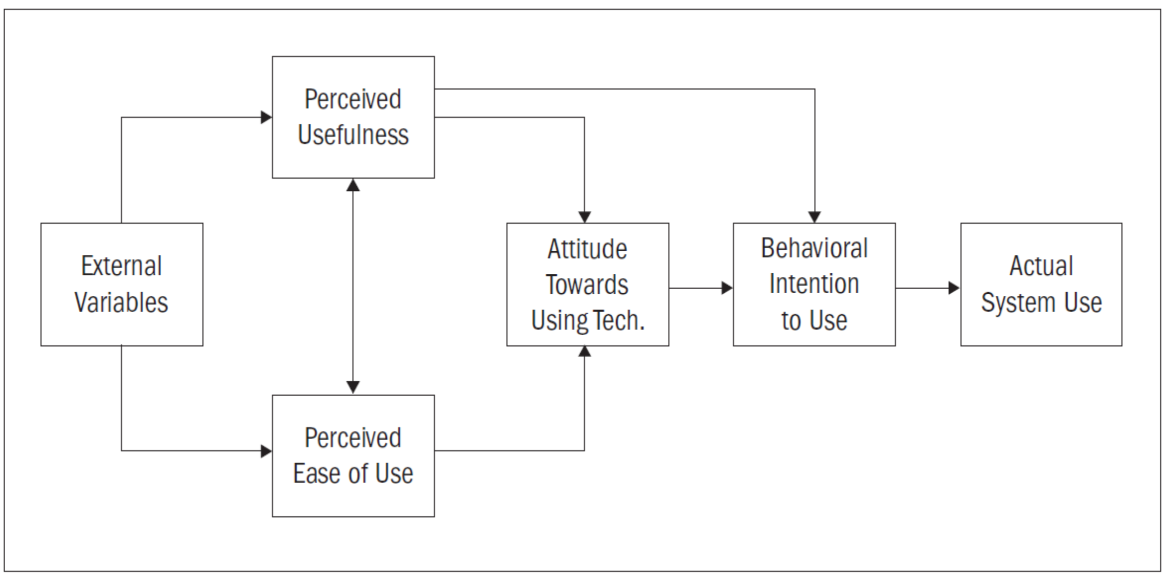

Figure 1. Technology Acceptance Model (TAM)

A later evolution to the TAM, developed by Venkatesh and Davis [11] and called the TAMII, expanded on what the TAM labels "External Variables" but still utilized a cognitive flow from external (exogenous) variables or factors through internal (endogenous) variables or factors. This flow from exogenous through endogenous factors culminates in a person's behavior towards a technological system.

TAMII continued to be extended and modified and was eventually re-labeled as the Unified Theory of Acceptance and Use of Technology (UTAUT) model [12] (Figure 2). The UTAUT posits three direct determinants of intention to use (performance expectancy, effort expectancy, and social influence) and two direct determinants of usage behavior (intention and facilitating conditions). Its main difficulty, pointed out by Elprama et al.'s study of industrial workers' intent to use exosystems [13] is that "the UTAUT model is developed for the evaluation of IT in particular rather than all forms of technology in general. As a result, future research might focus on the development of a better question battery for evaluating the acceptance of exoskeletons."

Still, some of the queries posited by the developers of UTAUT [12] on what they label "moderating influences" can be extremely valuable for developing a better exosystem question battery. Venkatesh [12] points out that in UTAUT, "[W]hile each of the (previously) existing models in the domain is quite successful in predicting technology usage behavior, it is only when one considers the complex range of potential moderating influences that a more complete picture of the dynamic nature of individual perceptions about technology begins to emerge." Researchers identified "… moderating influences of experience, voluntariness, gender, and age were confirmed as integral features of UTAUT [12]."

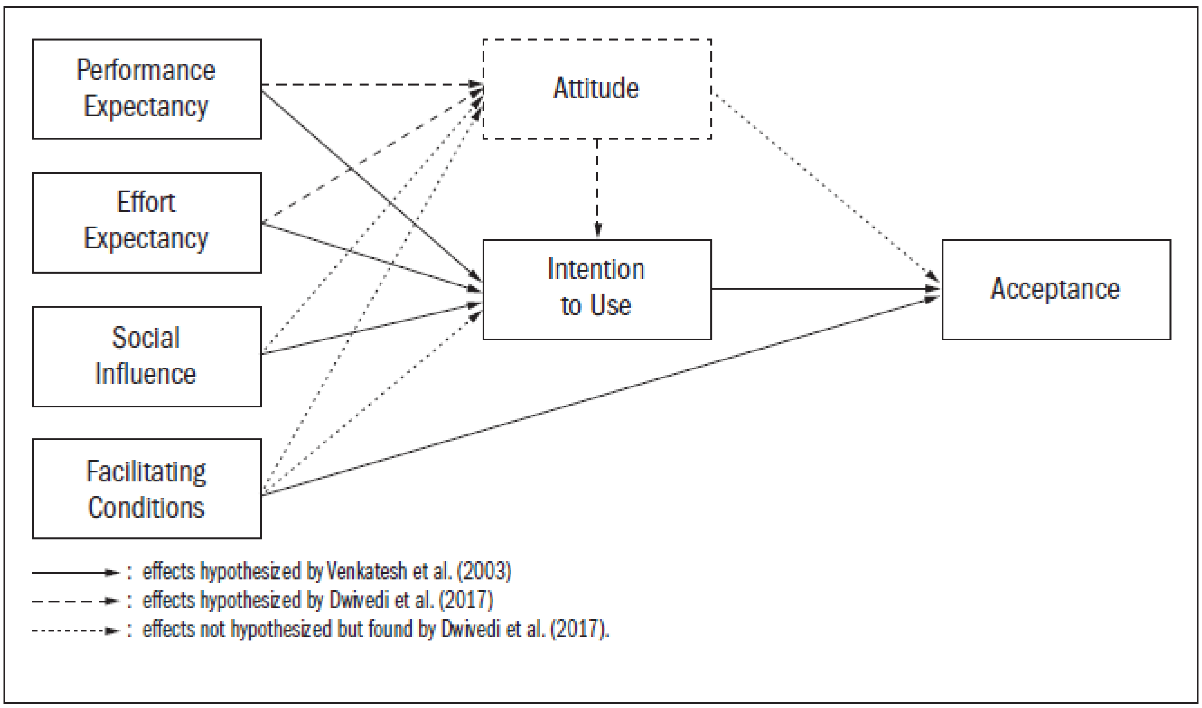

Figure 2. The Unified Theory of Acceptance and Use of Technology (UTAUT) Model

Park [14] further modified the TAMII interaction representation into what he called a "Theoretically Interesting Model" (Figure 3). This model takes into account more of the "moderating influences" described in UTAUT that effect factors in the task environment than either TAM or TAMII. In this particular case, Park addresses a computer e-learning system designed to be used by college students. He limits his model modifications to external, exogenous factors on the Y-axis, while keeping Davis' original endogenous factors [8] flowing on the X-axis. The exogenous factors include Individual Factors, Social Factors, and Organizational Factors, which together form a more complete picture of the user's environmental context. Endogenous factors include the Cognitive Domain, the Affective Domain, and the Behavioral Domain.

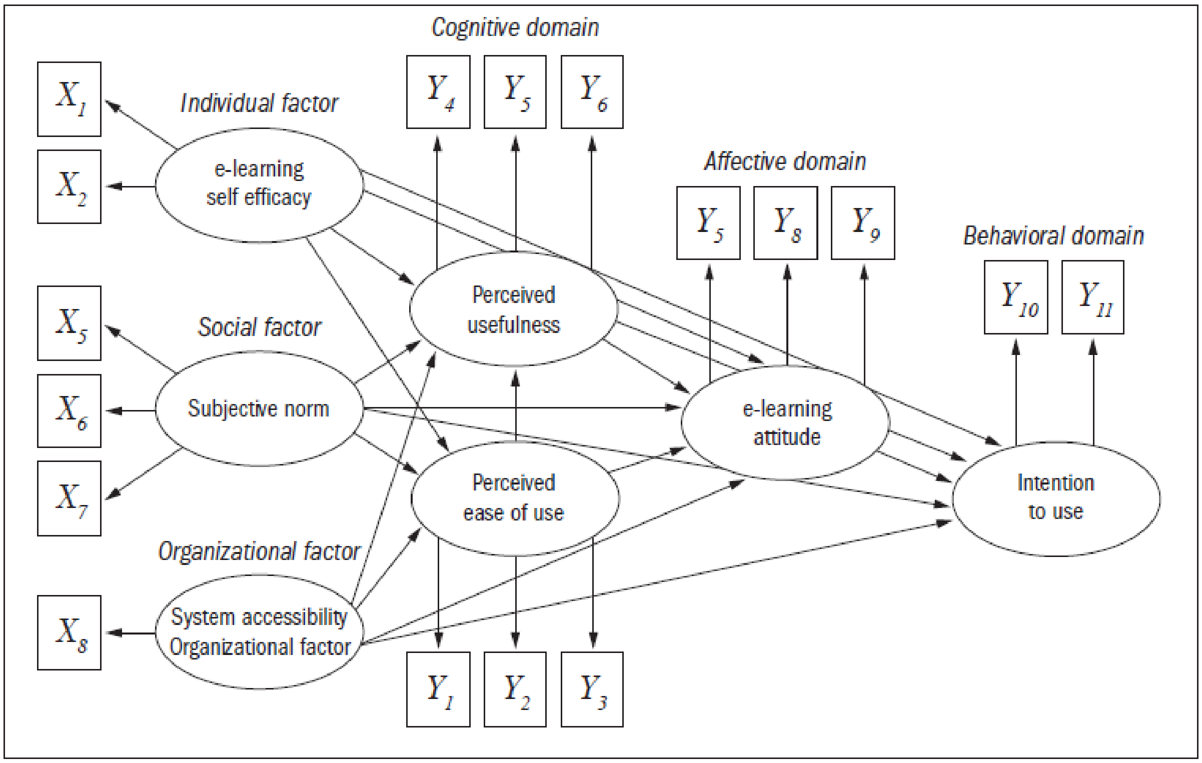

Figure 3. Park's "Theoretically Interesting Model" Based on TAMII

4 TECHNOLOGY ACCEPTANCE MODEL MODIFICATIONS: THE EXOSYSTEM USE INTENT (EUI) MODEL

Modifications to the exogenous factors of Park's TAMII model [14] can account for different task environments and the user's intent to use different technologies in those environments, in our case a cobotic exosystem. Exogenous factors, originating from outside the user, include mostly the physical and environmental aspects of the human/machine system; these include the Task Context, the Social Context, and the Individual Context. Endogenous factors are the same as in the TAMII: perceptive factors, attitude (affective or emotional) factors, and behavioral (intent) factors. As presented in Figure 4, human cognitive action flows from the exogenous factors on the left through the endogenous factors on the right. This flow from the exogenous through the endogenous factors (or domains) forms the Exosystem Use Intent (EUI) model (Figure 4), which can give us a methodology broad enough to test human factor/engineering psychology aspects of exosystems.

As presented in Figure 4, normal cognitive flow can be traced by the thicker arrows, yet almost all exogenous sub-factors can affect any endogenous sub-factor outside of the normal flow. This is shown by the thinner arrows, and represents a phenomenon similar to what Venkatesh [12] called "moderating influences."

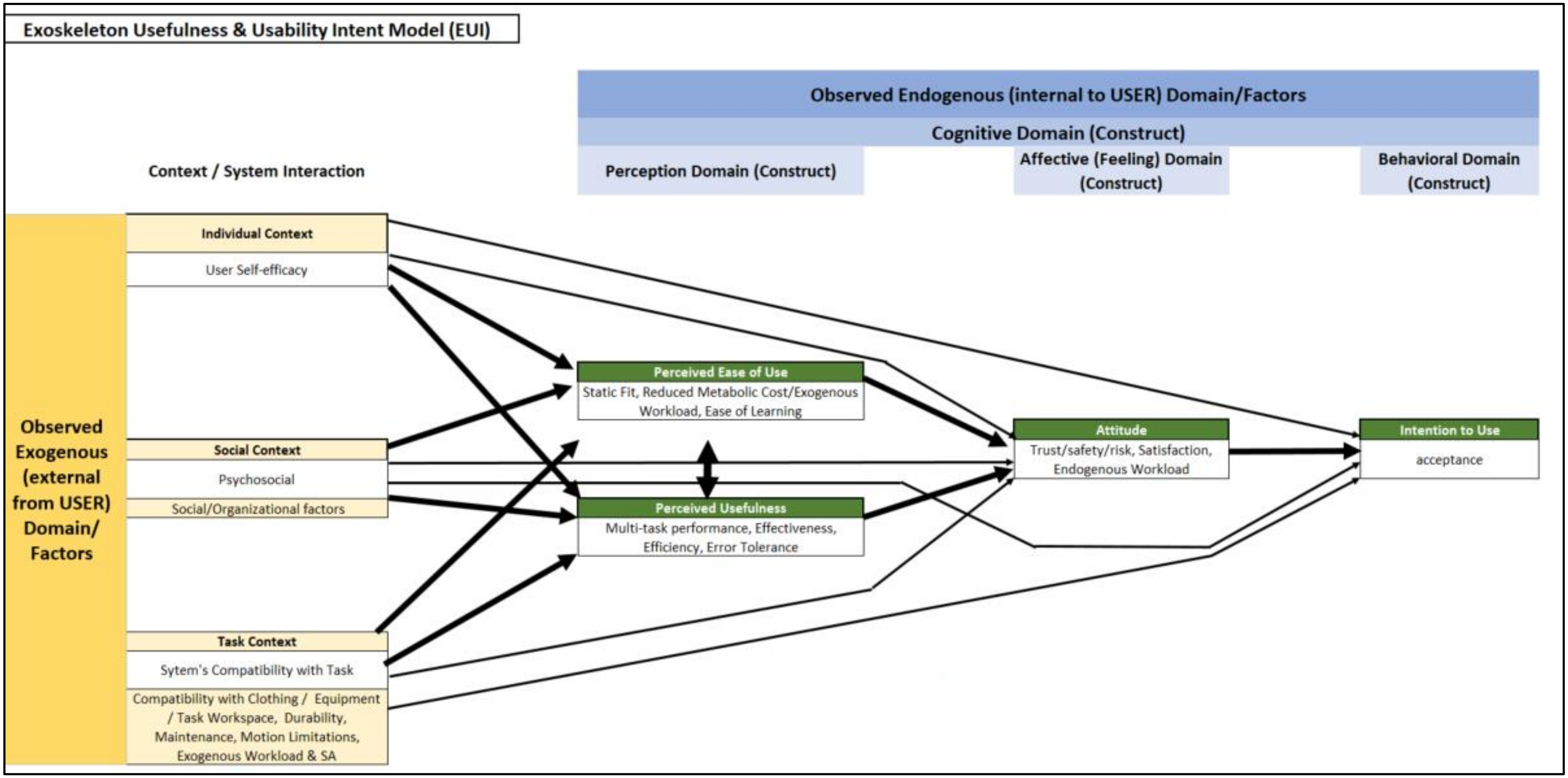

Figure 4. The Exosystem Use Intent Model (EUI)

In their work on developing a model for human interaction with automation, Parasuraman, Sheridan, and Wickens [15] developed a four-stage model of human information processing (Figure 5) that they admitted was “a gross simplification of the many components of human information processing.”

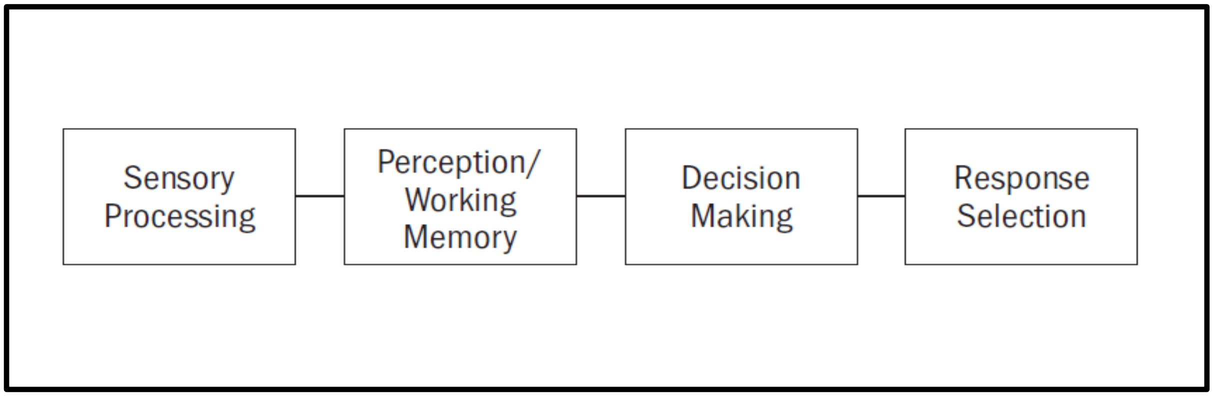

Figure 5. Simple Four-stage Model of Human Information Processing

This simple human processing model, however, was used to establish human-machine processing functions that could be automated and was created to guide future designers of human-automation interaction. The EUI functions (Figure 4) align well with those of the four-stage model (Figure 5) in their movement from left to right across their respective diagrams:

1. Exogenous factors (Sensory Processing)
2. Perspective factors (Perception/Working Memory)
3. Affective Factors (Decision Making)
4. Behavioral Factors (Response Selection)

While the EUI may represent an over-simplification of human information processing similar to the one used by Parasuraman, Sheridan, and Wickens, the EUI does acknowledge its inter-dependent nature with each of its factors. Each factor of the EUI model relates to a group of questions listed in Appendices B, C, D, and E. Any of the questions listed can either be included or not used in a final EUI questionnaire, according to the individual experiment designer’s needs. For examples of practical use, see Appendix G.

4.1 Exogenous Factors

Much like the HAAT model [7], the exogenous factors/contexts within the EUI of Task, Social, and Individual, together describe the user's perceptions of the environment in which the exosystem is used.

4.1.1 Task Context

Exogenous task factors include the human/exosystem's compatibility with the operator's specified task to be performed. Examples include exosystem compatibility with the user's task-related movements, task-related auxiliary equipment, task workspace, and weight distribution. This is analogous to Stirling's [25] "Static and dynamic fit":

> "Given that the static fit evaluates the alignment between human and the equipment, understanding the anthropometric characteristics of the target users as well as the geometric features of the equipment is critical. Dynamic fit assesses how the human and equipment move and interact with each other during functional ROM [Range of Motion] and task performance, with a focus on the relative alignment of the kinematic linkages between the two systems."

The design of exosystem technology is extremely task dependent. For example, hammers differ in design depending on their tasks – carpenter hammers, upholstery hammers, and demolition hammers all differ in design. So do exosystem designs between the domains of industrial, health/rehabilitation, and the Military, as well as specific tasks within a domain. For example, exoskeletons used for overhead work in the industrial environment differ in design from exosuits designed for manual material handling in the industrial environment. Each design will vary in the amount of risk it presents to a user, depending on the case, activity, task, and subsequent subtasks associated with the exosystem's use [7, 12, 16, 17, 28].

In one of the few field studies on exosystems, Gastaldi [19] pointed out the importance of considering the work environment: "… studies run on non-workers may suffer from a bias, since they lack the perception and acceptance assessment of the intended user. Introduction in the work environment brings in further constraints in the exoskeleton architecture and devices."

In another field study on exoskeletons, Weston et al. [20] stated that future exosystem interventions need to anticipate task contexts, specifically "…how mechanical loads might be shifted or transferred with their use." Their study, in which subjects used an exovest with an articulation tool support arm, found that use of the Exovest actually increased spinal loading by not taking into account the additional load created by task-related auxiliary equipment.

4.1.2 Social Context

Many of the previous models relevant to the "intention to use" construct discuss the influence of social factors on a user's decision. The Theory of Planned Behavior [10] and subsequent models of TAM and TAMII [8, 14, 21, 22] list what they call the "subjective norm," referring to "…the perceived social pressure to perform or not to perform the behavior [10]." The UTAUT model lists three direct determinants of intention to use, one of which is the influence of social aspects [12].

In the medical field, while designers of advanced robotic prosthetics strive for their devices to become included into the patient's "body image," often the user rejects it for a simpler, mechanical cable-based device. In their article on robotic prosthetics, Jarasse [4] points out that for prosthetics in general:

> "[S]ome patients describe their prosthesis as an external entity, sometimes a partner, sometimes an adversary, with which they are engaged in a sort of "social" relationship…
> Clinicians are regularly confronted with users who, after having tried a recent myoelectric prosthesis, prefer to go back to a mechanical cable-based device or even a purely aesthetic limb.
>
> This observation is, actually, not very surprising. The anthropology of technology, among other fields, has shown for a long time that many phenomena other than technical performance condition the appropriation and use of a technical device, particularly when the device is designed to interact with the body."

Currently, Appendix B lists six possible questions on influence of the social context that can affect an operator's intention to use an exosystem in the future. While the EUI will undoubtedly expand in all sections in the future with new knowledge coming to light, the questions surrounding social contexts are most likely to be modified.

4.1.3 Individual Context

The Individual Context effecting exosystem future use consists of only a single concept: the user's perceived self-efficacy, or how well they think they will perform the task *before* they perform their task. Ajzen [10] calls this "perceived behavioral control." Venkatesh and Davis [21] originally proposed that the perception of Ease of Use is very dependent on its antecedent judgement, self-efficacy. They define self-efficacy as "judgments of how well one can execute courses of action required to deal with prospective situations." In looking at an e-learning computer software system, the authors concluded that "(C)omputer self-efficacy acts as a determinant of perceived ease of use *both before and after* hands-on use," and that objective usability was found to be a determinant of Ease of Use only after direct experience with a system.

Self-efficacy, in relation to exosystems, is an important psychological concept to measure both before and after hands-on system use. Either an increase or decrease in scoring self-efficacy after use can relate to a user's perception of confidence to complete the task, which can be attributable to the exosystem.

In his modified TAMII model, Park [14] executed multiple bivariate analyses on his model's exogenous and endogenous factors, and similarly found self-efficacy had a large influence on perceived Ease of Use and an even larger effect on an operator's Intention to Use a system. Similar to the Park's model and questionnaire, the EUI uses self-efficacy as the only exogenous Individual Context factor in his model [Figure 4].

This concept of self-efficacy might be related to a concept in psychology best defined by the Kruger-Dunning effect: the cognitive bias of illusionary superiority [23, 24]. However, this potential relationship is beyond the scope of this paper.

4.2 Endogenous Factors

Endogenous factors, introspective elements originating from inside the user, include the user's cognitive perceptions of the exosystem's ease of use, the user's perceptions of the exosystem's usefulness, and the user's attitudes/judgments of the exosystem formed by those perceptions. Stirling

[25] defines three types of “fit” regarding the human operator and exosystems: “Exosystem fit is defined across three characteristics (static, dynamic, and cognitive). These characteristics are not independent and interact with each other within defined motor tasks.” Endogenous factors are analogous to Stirling’s cognitive fit:

> “Cognitive fit refers to supporting the perception–cognition–action decision process of the human when wearing the exosystem. This characteristic is relevant to exosystem fit as the operator’s cognitive capability must be maintained such that operational tasks, including decision-making, can be adequately performed. The operator should be free to process task- and stimulus-related information, as well as to choose and complete the appropriate physical actions that the exoskeleton supports. Issues related to cognitive fit include somatosensation, executive function, and motor-action selection.”

4.2.1 Perceptive Factors

Endogenous Perceptive factors for the EUI model remain similar to those within TAM, with two additional sub-factors: Perceived Ease of Use and Perceived Usefulness.

4.2.1.1 Perceived Ease of Use

Some previous exosystem studies have concluded that the final intention to use an exosystem is largely driven by perceived Ease of Use. Elprama [13] noted “… the intention to use exoskeletons is mostly driven by cognitively perceived ease of use of exoskeletons as opposed to the expected increase in performance. This is not surprising because exoskeletons are especially developed to reduce efforts whereas performance increase is only of secondary importance.”

To achieve this increased endogenous perception of Ease of Use, and with it Stirling’s [25] “Cognitive fit,” it is critical to have a good physiological “Static and Dynamic” fit, both exogenous factors. Without either, discomfort and even injury become risks. Stirling goes on to warn that, “The impact of poor fit on mobility may also lead to deeper changes in motor-plan selection, as well as increased attention toward task completion, increasing overall physical and cognitive workload, and risking diminished operational performance.” This highlights the highly interactive nature of exosystems, human physiology, and human psychology.

4.2.1.2 Perceived Usefulness

Much as the HATT model achieved success in decreasing abandonment of assistive technologies by taking into account the environmental context in which the assistive technology is to be used, applying context by adding the versatility factor of usefulness in regard to an operator’s attitude toward using an exosystem in the future, will enable designers to decrease exoskeleton non-use and enable purchasers to avoid systems that do not take usefulness/versatility into account.

Any task is comprised of a number of subtasks. For example, if a task entails bringing in a chair from the next room, the task’s subtasks might include walking up to the door of the next room, grasping and turning the door knob, pushing or pulling the door open, walking through the doorway, grasping the chair, then walking back through the doorway with the chair. Being unable to perform any of these sub-tasks would make the initial task impossible. A worker’s typical job would include perhaps dozens of tasks, with maybe hundreds of sub-tasks. Perceived usefulness describes the test subject’s perception of the versatility of being able to perform multiple tasks and sub-tasks.

Another consideration with the construct of usefulness is the exosystem's ability to provide feedback and furnish knowledge concerning a process or output. In their work on a student e-leaning software tool, Martinez-Argüelles et al. [27] state that:

> "Usefulness of personalized feedback perceived by the students can be subsumed under two large dimensions: the one that facilitates learning (related to its semantic dimension) and the motivational one (by allowing an easier and more fluid communication with the tutor, contributing not to leave the course, etc.). The latter dimension has been also proved to be key in order to attain improvements in the students' satisfaction with the learning process."

Whether a teacher supplying motivation to a student so they do not drop a class, or a hammer providing tactile feedback sensations up a user's arm to let them know they have hit a nail directly on its head, feedback from a tool/system can provide useful information not only for future performance improvement but motivation to continue for future use. Feedback information from exosystems will differ according to each exosystem's design and usage. Future systems may include computerized, AI "assistants" to help with an industrial task, similar to the role of a tutor in conjunction with an e-learning system.

4.2.2 Attitude (Affective) Factor

The over-simplified model of human information processing contained in both TAMM II and the EUI (Figures 3 and 4) includes Attitude Factors. The Attitude factor provides space to address a user's emotional dynamics. Pauen [29], in his research on emotion, decision-making, and mental models, holds that:

> "Rational decisions may require the participation of emotions. It would follow that an adequate model of real-world decision-making has to account for emotions in some way or other. Due to their multi-modal character and because they preserve the structure of the objects or states of affairs they represent, mental models are particularly well-suited for this undertaking."

For this reason, the Attitude factor is also co-labeled as the Affective factor, and includes feelings and emotions about the exosystem.

The user's mental model of the system is formed in part by their attitude and emotions toward it. As mentioned by Pauen [29] and repeated by Stangl [32] (below), emotions play a large part in the formation of mental models:

> "Mental models are a framework in the brain for new learning situations, which are based on experiences/meanings and which are influenced by a persons' personality and the environment. Thereby, emotions and feelings are considered emotional mental models while thoughts and believes are accounted for by cognitive models. In learning situations new information is compared with existing content (believes and emotions) and structures, then; an adapted cognitive and emotional mental model is generated. Human beings' feelings, reactions, and behavior towards stimuli (person/situation/product/brand/service) are guided by emotional mental models."

This fact that emotions help build mental models is one of the reasons why Norman [30] concluded mental models are "typically incomplete, can be unscientific, are unstable (forgetting occurs), and do not have firm boundaries." The same may be said of human emotions. At the same time, Nielsen [31] optimistically notes: "Hopefully, users' thinking is closely related to reality because they base their predictions about the system on their mental models and thus plan their future actions based on how that model predicts the appropriate course.“

When learning an exosystem that is new to them, most industrial novice users tend to have a preconceived mental model of exosystem physiological control: the device should just mimic their movements. They feel they shouldn't have to "control" the exosystem at all. Exosystem designers do their best to accommodate this. As de Looze et al. [33] point out:

> "The exoskeleton has a similar skeletal structure compared to the human body involving a series of many actuated joints. The main advantage is that the footprint of the exoskeleton is relatively small as it adheres directly to the body, and the movements should in theory be unrestricted. The movements of the worker are copied by the exoskeleton, i.e. the limbs of the human and the exoskeleton are aligned during motion."

Further studies, however, have provided evidence that such control is not always the case in reality. In her work on human motor control and learning to operate a large active exosystem, Srinivasan [34] pointed out there is a learning curve, with one of her test subjects saying, "You have to think hard: you basically have another human being on your body that you are controlling." This was echoed by Bequette et al. [35], looking at military application of a lower-body active exosystem. Both studies' findings indicated a large amount of individual variability in subjects using the exosystem, suggesting that a learning effect takes place while the individual user develops both emotional and cognitive mental models according to their individual perceptions and emotions. Once formed, these mental models constantly change, which is echoed by Stirling [36] when she calls mental models an "evolving memory structure that provide a dynamic representation of the environment, as well as descriptive interrelationships for a set of objects or events."

The temporal aspect of the learning effect when developing emotional and cognitive mental models is similarly described in the work of Lowenstein and Lerner [37], who reasoned there are two emotional influences on human decisions: Immediate Affects and Expected Affects. The former influences decisions in the present, while the latter influences decisions made in the future. This conclusion, in turn, is also echoed in Endlsey's definition of the three levels of Situational Awareness [38]: 1) perception of the elements, 2) comprehension of the current situation, and 3) projection of future status, where levels 1 and 2 are influenced by Immediate Affects and level 3 is influenced by Expected Affects.

4.2.3 Behavioral Factor - Intent to Use

The EUI thus gives us a framework in which to explore user's behavior in relation to cobotic technology exosystems. While insufficient to cover all human cognitive mechanisms, the EUI model can at least address the multiplicity of work tasks, worker environments, and workers' attitudes and emotions within the industrial domain. The depth of the EUI can be improved upon by creating a questionnaire which includes optional, previously addressed human factor constructs.

5 EXOSYSTEM USE INTENT (EUI) QUESTIONNAIRE

In order to create a useful, flexible, and convenient method to test for exosystem cognitive use, a questionnaire format was chosen as the measuring tool of choice for three reasons: 1) usability, workload, situational awareness, and trust in automation are all well-known engineering psychology constructs that can be measured through user introspection through a questionnaire, 2) if given immediately after a an experimental task the rating reliability is good, and 3) a questionnaire format is relatively inexpensive, so smaller companies investigating exosystems will be able to afford to use the EUI.

The EUI test should be administered to subjects while objectively comparing performances of the specific task, both with and without the exosystem. If the experimenter is attempting to discover whether exosystems may be useful in their small business, a smaller questionnaire can be administered to test subjects. A questionnaire utilizing only the 15 “core” questions, as determined by both a literature review and the outcomes of a focus group (Appendix D), is listed in below (Table 1). For examples on scoring the questionnaires see Appendices F and G.

If the experimenter is attempting to discover more in-depth cognitive aspects of exosystem operator use, a larger questionnaire can be administered utilizing the optional human factor constructs as discussed in Appendix E. Instances of such questionnaires can be found in examples 2 and 3 in Appendix G.

5.1 Questionnaire Example 1 – Core questions only

There are 15 questions listed in Appendix B that are listed as ”core” questions. These core questions are basic and should be asked no matter the final size of the questionnaire.

Table 1. Questionnaire Example using "Core" Questions Only

Domain / Context	Question	Question # (Appendix B)
Exogenous Domain		
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task before wearing the exosystem.	1
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9

Endogenous Domain		
Ease of Use Context	**Rate how hard (1) to easy (5) you felt your task was by using the exosystem.**	**16**
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	**17**
Usefulness Context	**Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.**	**45**
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	**49**
Attitude (Affective) Context	**Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.**	**51**
	Rate how you felt your performance was in doing the task, from bad (1) to good (5).	**52**
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	**53**
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	**50**
Intention	**Rate how little (1) to much (5) you intend to use the exosystem.**	**66**

5.2 Questionnaire Example 2 – with Human Factor Constructs

This 44-question example uses the above core questionnaire, in addition to the 31 human factor construct questions. This questionnaire gives not only a EUI flow score, but also separate scores for the constructs of Usability, Workload, Situational Awareness, and Trust. For further discussion of these human factor constructs, see Appendix E.

Table 2. Questionnaire Example using Core Questions and Human Factor Constructs

Domain / Context	Question	Appendix B Question #	Construct
Exogenous Domain			
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task before wearing the exosystem.	1	
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2	
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3	
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4	
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8	
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9	
	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	10	SART - Attentional Demand - instability
	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	11	SART - Attentional Demand – variability of the situation
	Rate how well you could concentrate on the work (High) or (Low)?	12	SART - Attentional Supply - division of attention
	Rate how complex (1) to simple (5) your task was.	13	SART - Attentional Demand - complexity of situation; MIL Consortium
	Rate how performing the task seems different (1) to familiar (5) to you.	14	SART - Understanding/ Familiarity; Trust-Familiarity

Domain / Context	Question	Appendix B Question #	Construct
Endogenous Domain			
Ease of Use Perception Context	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	16	
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	17	
	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	18	Usability - error tolerance
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	Usability - error tolerance
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	TLX Workload - Effort
	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	20	Usability – Ease of Learning
	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	21	Usability – Ease of Learning
	When faced with a new or novel situation while doing your work task, how <u>well did you understand</u> what to do to solve the problem? Rate the amount from low (1) to high (5).	22	SART – Understanding of the situation - feedback quantity
	When faced with a new or novel situation while doing your work task, how <u>quickly</u> did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	23	SART – Understanding or the situation - feedback quality
	Rate how you felt your performance in doing the task, from bad (1) to good (5).	52	TLX Workload – Own Performance
	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	25	SART - Attentional supply - concentration of attention
	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	26	SART - Attentional Supply - spare mental capacity
	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	27	TLX Workload – Mental Demand; Usability - Engagingness

Domain / Context	Question	Appendix B Question #	Construct
Ease of Use Perception Context	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	29	Trust - Reliability/ Confidence
	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	30	Trust - Understanding/ Predictability
	Rate how physically strenuous (1) to easy (5) your work-task was.	31	TLX Workload - Physical Demand
Usefulness Perception Context	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.	45	
	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	46	Usability - Effectiveness
	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	47	Usability - Efficiency
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	49	
	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.	51	Trust – Reliability/ Confidence
Attitude (Affective) Context	Rate how you felt your performance in doing the task, from bad (1) to good (5).	52	
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	53	
	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	54	SART - Attentional Supply - Arousal / eagerness
	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	55	TLX Workload - frustration level
	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	56	Trust – Trust in Exosystems
	Rate your trust from Low (1) to High (5) of the exosystem.	57	Trust - Trust in Exosystems
	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	58	Trust – Understanding/ Predictability
	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	59	TLX Workload - temporal demand
	Rate how engaged in the task you felt you were, from Low (1) to High (5).	27	Usability - engagedness
	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	61	Trust - Reliability / Competence
Attitude (Affective) Context	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	50	
Intention	Rate how little (1) to much (5) you intend to use the exosystem.	66	

5.3 Questionnaire Example 3 – with Core Questions, Human Factor Constructs, and Additional Questions

The following is a 58-query example questionnaire developed from the 69-question EUI question alternatives. This questionnaire gives not only a EUI flow score, but scores for the constructs of Usability, Workload, Situational Awareness, and Trust, as well as scores to questions that are pertinent to the study/experimental situation/context.

Table 3. Questionnaire Example using Core Questions, Human Factor Constructs, and Additional Questions

Domain / Context	Question	Appendix B Question #	Construct
Exogenous Domain			
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task before wearing the exosystem.	1	
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2	
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3	
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4	
	Does your organization offer the choice of using or not using the exosystem to complete your work? No (1) to Yes (5)	5	
	Rate if others should not (1) to should (5) use exosystems.	7	
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8	
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9	
	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	10	SART - Attentional Demand - instability
	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	11	SART - Attentional Demand – variability of the situation
	Rate how well you could concentrate on the work (High) or (Low)?	12	SART - Attentional Supply - division of attention
	Rate how complex (1) to simple (5) your task was.	13	SART - Attentional Demand - complexity of situation; MIL Consortium
	Rate how performing the task seems different (1) to familiar (5) to you.	14	SART - Understanding/Familiarity; Trust-Familiarity

Domain / Context	Question	Appendix B Question #	Construct
Endogenous Domain			
Ease of Use Perception	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	16	
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	17	
	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	18	Usability - error tolerance
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	Usability - error tolerance
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	TLX Workload - Effort
	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	20	Usability – Ease of Learning
	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	21	Usability – Ease of Learning
	When faced with a new or novel situation while doing your work task, how well did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	22	SART – Understanding of the situation - feedback quantity
	When faced with a new or novel situation while doing your work task, how quickly did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	23	SART – Understanding or the situation - feedback quality
	Rate how you felt your performance in doing the task, from bad (1) to good (5).	51 52	TLX Workload – Own Performance
	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	25	SART - Attentional supply - concentration of attention
	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	26	SART - Attentional Supply - spare mental capacity
	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	27	TLX Workload – Mental Demand; Usability - Engagingness
	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	29	Trust - Reliability/ Confidence

Domain / Context	Question	Appendix B Question #	Construct
Usefulness Perception Context	Rate how physically strenuous (1) to easy (5) your work-task was.	31	TLX Workload - Physical Demand
	Rate your imbalance (1) to balance (5) while wearing the exosystem.	33	
	Rate how overheated (1) to cool (5) wearing the exosystem made you feel.	36	
	Rate the difficulty (1) to ease (5) of the initial set-up/adjusting of the exosystem	37	
	Rate slowly (1) to quickly (5) you can move while wearing the exosystem in your work environment.	42	
	Rate jerky (1) to smooth (5) you can move while wearing the exosystem.	43	
	Rate the restraint (1) to freedom of movement (5) in doing your task while wearing the exosystem (i.e., can you sit on ground/chair, kneel, lay down, climb stairs, etc.)	32	
	Rate the clumsiness (1) to agility (5) you felt from the exosystem.	34	
	Rate how inaccurate (1) to accurate (5) you felt with the exosystem in the completion of your work/task.	35	
	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.	45	
	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	46	Usability - Effectiveness
	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	47	Usability - Efficiency
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	49	
Attitude (Affective) Context	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.	51	Trust – Reliability/ Confidence
	Rate how you felt your performance was in doing the task, from bad (1) to good (5).	52	
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	53	
	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	54	SART - Attentional Supply - Arousal / eagerness
	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	55	TLX Workload - frustration level

Domain / Context	Question	Appendix B Question #	Construct
Attitude (Affective) Context	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	56	Trust – Trust in Exosystems
	Rate your trust from Low (1) to High (5) of the exosystem.	57	Trust - Trust in Exosystems
	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	58	Trust – Understanding/Predictability
	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	59	TLX Workload - temporal demand
	Rate how engaged in the task you felt you were, from Low (1) to High (5).	27	Usability - engagedness
	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	61	Trust - Reliability / Competence
	Rate how little (1) to how much (5) the exosystem extended your limits? (i.e. I could do less/more repetitions, I had less/better quality to my work, etc.)	63	
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	50	
Intention to Use	Rate how little (1) to much (5) you intend to use the exosystem.	66	
	Rate the statement: "I would not use (1) to use (5) the exosystem for my task if it were available to me."	67	
	Rate how worse off (1) to how well (5) the exosystem met your needs?	68	
	Rate your overall experience, bad (1) to good (5) wearing the exosystem.	69	

6 DISCUSSION

Park [14], using Ajzen's conceptual frameworks [10] and the data from his modification into the TAMII model, examined multiple correlations between different factors. He found large effects of self-efficacy (self-confidence of task completion before using the system) and social norm (social factors) on behavioral intention (intent to use). He concluded that:

> "One of interesting results of the study is that both e-learning self-efficacy and subjective norm play an important role in affecting attitude towards e-learning and behavioral intention to use e-learning. One possible explanation for this may be justified by motivational theory. E-learning self-efficacy may be considered an intrinsic motivational factor and subjective norm may be an extrinsic motivational factor that could help the university students self-regulate their motivation on e-learning."

This finding is echoed in the work of Giesbrecht with the HAAT model as well as Davis' and, separately, Bandura's social motivation theory [7, 8, 39].

Adopting an exosystem requires changes in human activity, both physical and cognitive. Posing new coordination demands using exosystems can be extremely complex and introduce new risks. Stirling describes an exosystem study that found some novice exoskeleton users' tried to initially 'fight the device,' leading to an increase in the activity rate of muscle groups that the device was designed to decrease activity in; "This example highlights the complexity of developing tightly coupled human-in-the-loop systems, where there is a time-varying response of the human to the system and the potential for different steady-state performance characteristics depending on the user [36]."

In their work on human interaction with automation, Parasuraman, Sheridan, and Wickens [16] concluded, "This work has shown clearly that automation does not simply supplant human activity but rather changes it, often in ways unintended and unanticipated by the designers of automation, and as a result poses new coordination demands on the human operator." This is also true of semi-automated systems, and illustrates why it is essential to compare the questions of self-efficacy (individual context) with the question of self-confidence (attitude). Self-efficacy is defined as how well the user thinks they will perform the task *before* use of the exosystem to aid in their task. Self-confidence is defined as how well the user thinks they performed the task *after* use of the exosystem to aid in their task. This difference in self-efficacy/self-confidence and how it changes over time will be directly contributable to the learning period the user of the exosystem needs and how well the user adapts to the changes the exosystem requires.

Jarasse [4] points out that in order to address the complexities of the changes in human/system interaction with the human body, we need more than just technological progress: "Social and cultural phenomena influence the use of the devices as much as, or even more than, the devices technical performance." The EUI tries to account for some of these social influences.

However, unlike Jarasse, we are not looking at prosthetic users that are looking for physical integration of a prosthetic into their body image. Instead, we are looking at industrial workers using a new tool/process in the completion of their tasks. Industrial workers don't really care if their exoskeletons are seen by them as "part of their body;" they just want to accomplish their work tasks. But, what if this incorporation takes place anyway? Unbeknownst to the user? Jarasse uses the analogy of a sculptor, who "will over the years of use, displace the boundary of his body beyond his tool which becomes an extension of his hand." He goes on to point out that there are numerous examples of this in scientific research:

> "For neuroscientists, the relationship between sensory-motor loops and physical integration appear obvious. Several studies have demonstrated this: research on the subject of the physical integration of vibrotactile devices used to substitute visual loss; work on the development of the sense of orientation through long-term wearing of a "compass-belt" which provides constant vibrotactile information on the direction of North, or the "rubber hand" experiments in which the combination of sensory signals (visual and tactile) generate the sensation that a rubber hand is a part of the subject's own body."

7 CONCLUSIONS AND RECOMMENDATIONS

In his research providing a conceptual framework to explain the human behavior of intention, Ajzen [10] describes the Theory of planned Behavior'… to be well supported by empirical evidence. Intentions (intent) to perform behaviors of different kinds can be predicted with high accuracy from attitudes toward the behavior (attitude), subjective norms (social context), and perceived behavioral control (individual context)…" Park [14] heavily used this theory in his work on TAMII which in turn was modified into the EUI.

Not every question listed in the EUI questionnaire list (Appendix B) will be relevant to every experiment. For example, not every EUI question listed under "trust" in the system will apply if one is studying a passive exoskeleton. The individual lead investigator choosing to use the EUI needs to take different environmental use contexts into account.

The EUI questionnaire, while designed to be cheap and easy to administer, should also be regarded as a "first cut." If significant findings or "red flags" result from this simple, subjective questionnaire, more in-depth methodologies are recommended as follow-up studies. For example, in their study on warfighters using a lower-body exoskeleton to reduce the burden of carrying heavy equipment, Bequette et al. [35] found that exosystem performance was negatively affected while attending a secondary task radio call. Manufacturers of lower-body exoskeletons designed for this domain might produce a follow-up study using Endsley's' more in-depth SAGAT to measure objective Situational Awareness, as well as the Borg Rating of Perceived Exertion to further measure workload.

The relationship between sensory-motor loops and human physical integration of exosystems raises more questions than answers and must be further explored. By including the previously developed human factor constructs of usability, workload, situational awareness, and trust in automation, the EUI questionnaire corrects what Parasuraman, Sheridan, and Wickens [15] termed a "gross over-simplification" and deepens the EUI's similarly simplified model of human information processing. The EUI model, with its inclusion of the exogenous factor of social context, should be able to alert the investigator to the adaptations that the human operator may or may not make because of their changed work context with the introduction of an exosystem. While it is not designed to address the entirety of the field of anthropology of technology, the EUI model and questionnaire will be attentive to the relationship between human beings and the tools/systems/techniques they have created [4].

8 POINT OF CONTACT

Kevin Purcell
Ergonomist
Occupational Health Sciences
8977 Sibert Rd, Bldg E-1570
Aberdeen Proving Ground, MD 21010

kevin.p.purcell2.civ@mail.mil
410-417-2833
https://phc.amedd.army.mil/topics/workplacehealth/ergo/Pages/default.aspx

Appendix A

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Appendix B

EUI Question Alternatives

C = Core Question — Core questions should always be included in questionnaires.
HF = Construct Question — Construct questions belong to various human factor constructs. Depending on which constructs the experimental designer wishes to include - Usability, NASA TXL Workload, Situational Awareness Rating Technique, and/or Trust in Automation - these questions can be optionally included in questionnaires.

The Origin column lists not only which questions go with which construct, but also lists where the question originates from. Some questions have more than one source listed; others could theoretically belong to multiple factors in different domains.

B-1. [EUI Questionnaire Alternatives]

Number	**CORE OR CONSTRUCT**	**Domain/ Context**	**Question**	**Origin**
EXOGENOUS DOMAIN				
1	C	Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task <u>before</u> wearing the exosystem.	UTAUT - Self-efficacy; TAMII [7,15, 38] – Self-efficacy
2	C	Social Context	Rate your feeling of anxiety of using an exosystem because of your age.	UTAUT – social influence
3	C		Rate your feeling of anxiety of using an exosystem because of your gender.	UTAUT – social influence
4	C		Rate your feeling of anxiety of using an exosystem because of what your co-workers might think.	
5			Does your organization offer choices of exosystems to use to help you with your task?	UTAUT - significant factor of voluntariness; MIL Consortium
6			Does your organization offer the choice of using or not using the exosystem to complete your work	UTAUT - significant factor of voluntariness; MIL Consortium
7			Rate if others should not (1) to should (5) be required to use exosystems.	Elprama [11]

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
13	HF	Task Context	Rate how complex (1) to simple (5) your task was.	SART - Attentional Demand - complexity of situation
14	HF HF		Rate how performing the task seems different (1) to familiar (5) to you.	SART - Understanding/Familiarity; Trust - Familiarity
15			Rate how much (1) to how little (5) weight is added to you while wearing this exosystem.	MIL Consortium
8	C		Rate the non-compatibility (1) to compatibility (5) of the exosystem with the systems/equipment that you're going to be using it with vehicles, controls, clothing, load carriage, PPE, tools	MIL Consortium
9	C		Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces ex. narrow openings/hatches, vehicle aisles, etc.	MIL Consortium
10	HF		Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	SART - Attentional Demand - instability
11	HF		Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	SART - Attentional Demand – variability of the situation
12	HF		Rate how well you could concentrate on the work (High) or (Low)?	SART - Attentional Supply - division of attention

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
ENDOGENOUS DOMAIN				
16	C	Perception of Ease of Use Context	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	MIL Consortium
17	C		Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	MIL Consortium
18	HF		If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	Usability - error tolerance
19	HF, HF		How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	Usability - error tolerance ; TLX Workload - Effort
20	HF		Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	Usability – Ease of Learning
21	HF		Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	Usability – Ease of Learning
22	HF		When faced with a new or novel situation while doing your work task, how well did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	SART –Understanding of the situation - feedback quantity
23	HF		When faced with a new or novel situation while doing your work task, how quickly did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	SART – Understanding or the situation - feedback quality
24			Rate how weak (1) to strong (5) you felt while using the exosystem.	MIL Consortium
25	HF		Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	SART - Attentional supply - concentration of attention
26	HF		Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	SART - Attentional Supply - spare mental capacity
7	HF		Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	TLX Workload – Mental Demand
28	HF		Rate the difficulty (1) to ease (5) in using the exosystem's computer interface?	TLX Workload – Mental Demand (for use only with exosystems with computer interfaces)
29	HF		Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	Trust - Reliability/Confidence

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
30	HF	Perception of Ease of Use Context	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	Trust - Understanding/Predictability [changing modes]
31	HF		Rate how physically strenuous (1) to easy (5) your work-task was.	TLX Workload - Physical Demand
32			Rate the restraint (1) or freedom (5) of movement in doing your task while wearing the exosystem (for example, can you sit on ground/chair, kneel, lay down, climb stairs, etc.)	MIL Consortium
33			Rate your imbalance (1) to balance (5) while wearing the exosystem.	MIL Consortium
34			Rate the clumsiness (1) to agility (5) you felt from the exosystem.	MIL Consortium
24			Rate how weak (1) to strong (5) you felt while using the exosystem.	MIL Consortium
25	HF		Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	SART - Attentional supply - concentration of attention
26	HF		Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	SART - Attentional Supply - spare mental capacity
7	HF		Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	TLX Workload – Mental Demand
28	HF		Rate the difficulty (1) to ease (5) in using the exosystem's computer interface?	TLX Workload – Mental Demand (for use only with exosystems with computer interfaces)
35			Rate how inaccurate (1) to accurate (5) you felt with the exosystem in the completion of your work/task.	MIL Consortium
36			Rate how overheated (1) to cool (5) you felt working with the exosystem.	MIL Consortium
37			Rate the difficulty/ease of the initial set-up/adjusting of the exosystem	MIL Consortium

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
38		Perception of Ease of Use Context	Rate your soreness (1) to not being sore (5) the next day after using the exosystem.	MIL Consortium
39			Rate the difficulty (1) to ease (5) of operating controls of the exosystem	MIL Consortium
40			Rate the difficulty (1) to ease (5) of reading and understanding the system interface controls on the exosystem.	
41			Rate the difficulty (1) to ease (5) of reaching the system interface controls on the exosystem.	
42			Rate slowly (1) to quickly (5) you can move while wearing the exosystem.	MIL Consortium
43			Rate jerky (1) to smooth (5) you can move while wearing the exosystem.	
44			Rate how tired (1) to not tired (5) you felt after the day's work.	Dollar and Herr, Ferris - metabolic cost; MIL Consortium
37			Rate the difficulty/ease of the initial set-up/adjusting of the exosystem	MIL Consortium
38			Rate your soreness (1) to not being sore (5) the next day after using the exosystem.	MIL Consortium
39			Rate the difficulty (1) to ease (5) of operating controls of the exosystem	MIL Consortium
40			Rate the difficulty (1) to ease (5) of reading and understanding the system interface controls on the exosystem.	
41			Rate the difficulty (1) to ease (5) of reaching the system interface controls on the exosystem.	
42			Rate slowly (1) to quickly (5) you can move while wearing the exosystem.	MIL Consortium
5	C	Perception of Usefulness Context	I find exosystems not useful (1) to useful (5) in my job.	Elprama - Performance Expectancy
46	HF		Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	Usability - Effectiveness
47	HF		Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	Usability - Efficiency
48			Rate how much slower (1) to quicker (5) you were in completing your work/task?	Usability - Efficiency
49	C		Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
50	C	Attitude (Affective) Context	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	
51	C, HF		Rate how not confident (1) to confident (5) you are or being able to complete future work tasks after you've used the exosystem.	Trust - Reliability/Confidence
52	C, HF		Rate how you felt your performance was in doing the task, from bad (1) to good (5).	TLX Workload - Own Performance
53	C		Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	
54	HF		Rate how you felt not eager (1) to eager (5) you felt to perform your task.	SART - Attentional Supply - Arousal / eagerness
55	HF		Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	TLX Workload - frustration level
56	HF		Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	Trust – Trust in Exosystems
57	HF		Rate your trust from Low (1) to High (5) of the exosystem.	Trust - Trust in Exosystems
58	HF		Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	Trust – Understanding/Predictability
59	HF		Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	TLX Workload - temporal demand
60	HF		Rate how engaged in the task you felt you were, from Low (1) to High (5).	Usability - engagedness
61	HF		Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	Trust - Reliability / Competence
62			Rate how bad (1) to well (5) the exosystem interpreted the task you were performing	Trust - Reliability / Competence
63			Rate how little (1) to how much (5) the exosystem extended your limits? i.e. I could do less/more repetitions, I had less/better quality to my work, etc.	
64			Rate how doubtful (1) to confident (5) you felt that the system could take over and complete your task.	Trust - Reliability / Competence
65			Rate the similarity from Low (1) to high (5) to other exosystems you have used.	Trust - Familiarity

Number	CORE OR CONSTRUCT	Domain/ Context	Question	Origin
66	C	Intention	Rate how little (1) to much (5) you intend to use the exosystem.	MIL Consortium
67			Rate the statement: "I would not use (1) to use (5) the exosystem for my task if it were available to me."	
68			Rate how worse off (1) to how well (5) the exosystem met your needs?	
69			Rate your overall experience, bad (1) to good (5) wearing the exosystem.	

Appendix C

Core Questions

There are 15 questions listed in Appendix B, EUI Questionnaire Alternatives, which are listed as Core (C) questions. These core questions are basic and should be asked no matter what the final size of the questionnaire.

Table C-1. Core Questions

Domain/Context	Question
Exogenous Domain	
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task before wearing the exosystem.
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)

Endogenous Domain	
Ease of Use Context	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.
Usefulness Context	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)
Attitude (Affective) Context	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.
	Rate how you felt your performance was in doing the task, from bad (1) to good (5).
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.
Intention	Rate how little (1) to much (5) you intend to use the exosystem.

Appendix D

Military Consortium on Exosystems Focus Group

On January 31, 2019, a focus group was held at the Boeing plant in Charleston, North Carolina. At this focus group were active members of the U.S. military, who were asked about potential questions and issues they would want to know about potential exosystem use. Dr. Christopher Reed, from Boeing Corporation, was the focus group leader. Dr. John Pentikis and Kevin Purcell, civilian members of the U.S. Army Public Health Center, were also in attendance. The following table are the questions the military members were concerned with.

Table D-1. Focus Group Questions

Rate how ineffective/effective you were at the completion of your work/task BEFORE you used the exosystem.
Rate how ineffective/effective you were at the completion of your work/task AFTER you used the exosystem.
Rate how much slower/quicker the exosystem effected the completion time for your work/task?
Rate how weak/strong you felt while using the exosystem.
Rate how inaccurate (1) to accurate (5) you felt with the exosystem in the completion of your work/task.
Rate the noncooperation/coordination of the exosystem.
Rate the clumsiness/agility of the exosystem.
Rate how worse off/ how well the exosystem meet your needs?
Rate how little/much the exosystem extended your task limits? (i.e. less/more repetition, less/better quality, etc.)
Rate how much worse/better you feel after the day by using the exosystem?
Rate how little/how much load is taken by the exosystem off of your back muscles.
Rate how ineffective/effective the exosystem system is at supporting the load (tool/payload/weight of arm).
Rate the difficulty/ease ability of either yourself of someone else to do a quick, emergency doffing of the exosystem.
Rate how fragile/durable the exosystem is.
Rate the difficulty/ease of maintenance/repair of the exosystem.
Rate how hard/easy it is to use your exosystem.
Rate how hard/easy it was to perform your task using the exosystem.
Rate the difficulty/ease of becoming skillful at using the exosystem.
Rate how complex/simple the exosystem was to use.
Rate your soreness/not sore the next day after using the exosystem.
Rate how hard/easy it was to clean the exosystem (both from human biology or industrial processes)

Rate how much/little you needed to learn or train before using your exosystem?
Rate how much inconsistency/consistency there was in the exosystem.
Rate how well the exosystem misunderstood/understood what you wanted to do.
Rate how badly/well the exosystem responded to your movements.
Rate while using the exosystem your focus was on the exosystem (1) or your work task (7).
Rate the amount of load, from none (1) to entire load (5), the exosystem took off your back/targeted muscles.
Rate your overall experience, bad (1) to good (5) wearing the exosystem.
Rate the statement: "I would not use/use the exosystem for my task if it were available to me."
Rate how little/much the exosystem increased my task performance?
Rate how little/much the exosystem increased my performance, regardless of your industrial task/work?
Rate how often do you utilize the exosystem (1=daily, 4=weekly, 7=monthly)
Rate how little/much you intend to use the exosystem.
Rate your overall dissatisfaction/ satisfaction with the exosystem
Rate how bad/well the exosystem does what it claims to do (i.e. reduce injury, muscle fatigue, perceived workload, and/or increase productivity, etc.)
Rate amount of training required to learn system (1=Less, 7=more)
Rate your non-confidence/confidence in the exosystem to effectively help/aid you while working.
Rate how unsafe/safe you feel when using the exosystem.
Rate how unsafe/safe the exosystem made performing your task.
Rate how unsafe/safe you felt donning/doffing exosystem
Rate the undependability/dependability of the exosystem.
Rate your distrust (1) to trust (5) for the exosystem to provide the correct force magnitude and timing. (Not sure if you want to combine force and timing or have two separate questions)
Rate your distrust (1) to trust (5) for the exosystem to appropriately transition support for the tasks you were performing.
Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.
Rate if the exosystem operated too slowly (1), appropriate speed (3), too quickly (5).
Rate if you do not believe (1) to believe (5) the exosystem is supporting your task.
Rate if you believe there is too little (1), just right (3), too much (5) feedback from the exosystem on how it will support your actions.
Rate if you believe there is high (1) to low (5) risk in using the exosystem for your mission.
Rate how much/how little the exosystem changes your natural movements/biomechanics (ex. running, walking, rolling, squatting, kneeling, prone, crawling, climbing, jumping, stairclimbing).

Rate how hard/easy it was to don the exosystem.
Rate how hard/easy it was to doff the exosystem.
Rate the slowness/speed required to don/doff the exosystem.
Rate the difficulty/ease of the initial set-up/adjusting of the exosystem
Rate the amount of training the exosystem requires to don/doff/adjust to fit you ?
Rate how badly/well weight distributed on around you while wearing an exosystem.
Rate how much/little weight is added to you while wearing an exosystem.
Rate how poor/well the exosystem fits you after adjustment?
Rate your imbalance/balance while wearing the exosystem.
Rate the difficulty/ease of operating controls of the exosystem
Rate the difficulty/ease of reading and understanding the system interface controls on the exosystem.
Rate the difficulty/ease of reaching the system interface controls on the exosystem.
Rate how overheated/cool wearing the exosystem makes you
Rate your limitations/freedom of doing your task while wearing the exosystem (i.e., can you sit on ground/chair, kneel, lay down, climb stairs, etc.)
Rate how much the system restricts joint range of motion of arms, neck, torso, and legs.
Does your organization offer choices of exosystems to use to help you with your task? (1=no, 7=yes)
Does your organization offer the choice of using or not using the exosystem to complete your work (1=no, 7=yes)
Rate your inability/ability to move while wearing the exosystem in your work environment (i.e., does it allow stepping/climbing over obstacles/allows uneven or changing gaits, etc.)
Rate slowly/quickly you can move while wearing the exosystem in your work environment.
Rate jerky/smoothness you can move while wearing the exosystem.
Rate how disconnected/integrated the various functions in the exosystem were.
Rate the non-compatibility/compatibility of the exosystem to fit in or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)
Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)
Rate how incompatible/compatible the exosystem is with the tools/equipment you need to complete your work task.
Rate how incompatible/compatible the exosystem is with your PPE/fall-protection gear/work clothing.
Rate the difficulty/ease of maintenance of the exosystem towards hygiene, battery swapping

Appendix E

Construct Questions

Appendix B lists 31 questions as "construct" questions. These human factor/engineering psychology construct questions can be broken out into 4 sub-questionnaires to measure the following constructs: Usability (as defined by the Usability Professionals' Association [40]), Workload (as defined by the NASA TLX Workload Assessment [41]), SA (as defined by the Situational Awareness Rating Technique [44], and Trust in Automation (as defined by the modified Trust in Automation questionnaire [49]). These individual, well researched, well verified constructs can be broken out to pin-point areas of interest. Some of the question alternatives, such as "How badly (1) to well (5) did the system support you when you needed it during your work task?" is relevant to 2 construct sub-questionnaires (Usability and the NASA TLX Workload Assessment).

Usability

The concept of usability was first largely discussed surrounding computer software [5]; however exosystems are not solely computer software. Exosystems are a unique interface of the human (both cognitively and physiologically), hardware, and computers (hardware and software). While the use of computers is currently limited to mostly active exosystems, computers will play a large part in all future exosystems.

It's been stated before that the word "usability" has become a blanket term for ease of use; not only the general public but many researchers have been guilty of this. The International Standards Organization defines usability in ISO 9241-11 as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. " Bevin (56) points out that this definition is very broad; a more detailed definition comes from the Usability Professionals' Association [40], which lists 5 criteria for a product to meet to become usable:

- Effectiveness
- Efficiency
- Engagingness
- Error Tolerance
- Ease of Learning

Table E-1. Capturing Usability Constructs with EUI Relevant Questions

Construct Question	EUI Relevant Question
Effectiveness	Rate how effective you felt you were at doing the task, from Low (1) to high (5)
Efficiency	Rate how efficient you felt you were at doing the task, from Low (1) to high (5)
Engagingness	Rate how engaged in the task you felt you were, from Low (1) to High (5).
Error Tolerance	Rate how tolerant of errors you felt the exosystem was, from Low (1) to High (5).
Ease of Learning	Rate how easy you felt the exosystem was to learn, from Low (1) to High (5).

The usability of an exosystem is important information as it could be compared to the usability of other systems judged under similar guidelines, and has become a de facto standard.

Workload (NASA Task Load Index (TLX))

Workload and usability are two non-overlapping human factor constructs that "can be jointly employed to greatly improve the prediction of human performance" [16]. Longo goes on to define Mental Workload (MWL) as:

"…the total cognitive work necessary for a human to accomplish a task over time. It is believed that is not an elementary property, rather it emerges from the interaction between the requirements of a task, the circumstances under which it is performed and the skills, behaviours and perceptions of the operator."

In regards to exoskeleton use, Sterling [25] states, "Cognitive capabilities should remain available to process task- and stimulus-related information in the presence of an exosystem."

To quantify the cognitive cost associated to performing a task, Hart and Staveland [41] developed the NASA TLX Workload Assessment. The TLX consists of 6 Subscales:

MENTAL DEMAND - How much mental and perceptual activity was required (e g, thinking. deciding, calculating, remembering, looking, searching etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

PHYSICAL DEMAND - How much physical activity was required (e g . pushing, pulling . turning, controlling, activating . etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TEMPORAL DEMAND - How much lime pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

PERFORMANCE - How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

EFFORT - How hard did you have to work (mentally and physically) to accomplish your level of performance?

FRUSTRATION LEVEL - How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Table E-2. Construct Questions and EUI Relevance

Construct Question	EUI Relevant Question
Rate the mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?	Rate how mentally taxing (1) to easy (5) your task was.
Rate how much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?	Rate the physical demands the task imposed on you from small (1) to large (5).
How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and fast?	Rate the time pressure you felt to complete your task, from none (1) to a lot (5)
How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing your goals?	Rate how you felt your performance was in doing the task, from bad (1) to good (5).
How hard did you have to work (mentally and physically) to accomplish your level of performance?	Rate the effort you felt, mentally and physically, to accomplish your level of performance, from High (1) to Low (5)
How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5)

In the original NASA TLX these subscales were weighted. In her paper on the many uses of the TLX by the research community 20 years after its introduction, Hart [42] pointed out:

> "The most common modification made to NASA-TLX has been to eliminate the weighting process all together or weighting the subscales and then analyzing them individually. The former has been referred to as Raw TLX (RTLX) and has gained some popularity because it is simpler to apply; the ratings are simply averaged or added to create an estimate of overall workload. In the 29 studies in which RTLX was compared to the original version, it was found to be either more sensitive (Hendy, Hamilton, & Landry, 1993), less sensitive (Liu & Wickens, 1994), or equally sensitive (Byers, Bittner, Hill, 1989), so it seems you can take your pick."

This weighting has been eliminated in the EUI, instead just asking questions from the 6 subscales of Mental, Physical, Temporal demand as well as Frustration, effort and own performance. These subscales have shown robustness over a 40-year span.

Situational Awareness (Situational Awareness Rating Technique (SART))

The user's awareness of the environment and context is not included in the concept of workload. However, workload needs to be at a low level so that a user's cognitive abilities can be clear to process stimuli presented to them [25]. This ability to process stimuli presented to the user is key to facilitate Situational Awareness (SA). Endsley's [42] definition of SA is the "perception of the elements of the environment within a volume of time and space (Level 1), the comprehension of their meaning (Level 2) and the projection of their status in the near future (Level 3)." This concept of SA embraces environment and context, and is a key measure that adds depth to exosystem studies. Regarding the importance of SA to exosystem use, Stirling [36] points out:

"While a user may be able to perceive information in the environment (Level 1 SA), it may not be apparent how these cues would affect the use of the exoskeleton (Levels 2 and 3 of SA). Thus, an inappropriate action may be taken. Breakdowns in SA can occur in any of the three levels and therefore evaluation of SA in the context of exosystem use is important for understanding the ability of a user to make operational decisions. Consider an exosystem ankle that nominally actively assists rotation based on the interaction force recorded with the ground, except in a separate mode where the interaction force is used to stiffen the joint and limit motion. If the user perceives (Level 1 SA) cues that lead to projecting (Level 3 SA) that the exosystem should be actively assisting, but the joint instead stiffens, the user would expect assistance and may then lose balance and fall when the joint stiffens instead."

Unfortunately, Endsley's measurement methodology, the Situation Awareness Global Assessment Technique (SAGAT) [43], while extremely valid and sensitive, is not possible to use to develop an EUI questionnaire. SAGAT is a freeze technique first used in flight simulators, while the EUI is designed to be used in either in the field or during real-time lab studies. Taylor's paper-based Situational Awareness Rating Technique (SART) [44] is a much more viable candidate for EUI use. It is measured post-trial, involves participants subjectively rating each EUI dimension on a seven point rating scale (1 = Low, 7 = High) based on their performance of the task, and was originally based on 10 dimensions:

Instability of situation	Variability of Situation
Complexity of Situation	Arousal
Spare mental Capacity	Concentration
Division of Attention	Information Quantity
Information Quality	Familiarity

These ratings are then combined to calculate a measure of participant perceived SA. The EUI modifies the SART to be used on a 5-point scale. There are drawbacks to this approach, however. As Endsley indicates in a paper comparing SAGAT and SART methodologies [30], "SAGAT provides an objective measure of SA based on queries during freezes in a simulation. SART provides a subjective rating of SA by operators."

As the EUI model and questionnaire is aimed towards ascertaining a person's intent to use the exosystem, using SART to ascertain a user's perception of SA is logical. According to Endsley [30], SART is highly correlated with self-confidence and subjective performance. It was discussed previously that the antecedent to self-confidence and ease of use is self-efficacy, both major factors in intention to use.

To quote Endsley [30] again, "As the SART scores were so highly correlated with confidence level and subjective performance, it is recommended that subjective SA ratings be viewed as good indices of these aspects, but perhaps not veridical representations of SA." Subjective versus objective SA may be a critical distinction for some exosystem operators in particular environments, such as those industrial workers working with heavy machinery in very dynamic environments and require enhanced levels of objective SA. In these particular use cases, *or* if a high level of user workload is found in conjunction with a high level of subjective level of SA (which could be indicative of overconfidence [23, 24]), it is highly recommended that further lab testing take place.

Determining objective SA is beyond the scope of a simple questionnaire. This testing of objective SA should either use the SAGAT simulation freeze technique or using a technique in a lab setting similar to the Bequette study [35, 45], where the experimenter can ask the test subject specific questions about the presented environment where specific SA behaviors are known and/or expected.

Table E-3. SART Questions and EUI Relevance

SART Construct Question	EUI Relevant Question
Likeliness of the situation to change suddenly. *SART attentional demand (instability of the situation)*	"Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?"
Number of variables that require attention *SART attentional demand (variability of the situation)*	Are there are large number of variables that are changing with the situation (high) or are there very few variable changing (low)?
Degree of complication of the situation. *SART attentional demand (complexity of the situation)*	Rate how complex (1) to simple (5) your task was.
Degree on is ready for activity. *SART Attentional Supply (AROUAL/eagerness)*	Rate how you felt not eager (1) to eager (5) you felt to perform your task.
Degree that one's thoughts are brought to bear on the situation. *SART Attentional supply (concentration of attention)*	Rate how well you could concentrate on the work (High) or (Low)?
Division of attention in the situation. How much is your attention divided in the situation? Are you concentrating on many aspects of the situation or focused only on one? *SART Attentional supply (Division of Attention)*	Rate how well you could concentrate on the work (High) or (Low)?
Rate the how much mental capacity you have to spare in the situation? Amount of mental capacity available for new variables. How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables	Rate how little (1) or how much (5) much focus and attention you have to spare during the work. Do you feel you have a lot of extra attention to attend to many variables (High) or nothing to spare at all (Low)?

(High) or nothing to spare at all (Low)? *SART Attentional (spare mental capacity)*	
Amount of knowledge received and understood. *SART Understanding/information quantity*	While you were performing you work, how much feedback information did you receive from the exosystem that you needed to complete your task? Rate the amount from low (1) to high (5).
Quality of knowledge received and understood. *SART Understanding/information quantity*	While you were performing you work, did whatever feedback information that you received from the exosystem help you to complete your job? Rate not valuable (1) to valuable (5).
Degree of acquaintance with the situation experience. *SART Understanding/familiarity*	"Rate how performing the task seemed different (1) to familiar (5) to you." NOTE: This question will only work when there are other systems to compare it to.

Trust (Trust in Exosystems (TiE))

Trust in automation/semi-automation is based on well-established work, such as Lee and Moray [46] and Lee and See [47]. Lee and See state, "Trust is one example of the important influence of affect and emotions on human-technology interaction. Emotional response to technology is not only important for acceptance, it can also make a fundamental contribution to safety and performance." They go on to define trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability." Here they quote Barley [48], "More generally, trust seems to be an example of how affect can guide behavior when rules fail to apply and when cognitive resources are not available to support a calculated rational choice." This reliance on human affect can easily lead to an inappropriate, over-reliance on automated control [46].

An example of this can be found in the earlier study by Lee and Moray [46], which included an experiment in which study subjects ran a pasteurization plant using a feedstock pump, choosing to switch control of the plant between either an automatic or manual scheme. During the simulation, a fault would appear in the operation of the feedstock pump. Their results showed an *increase* in operators using automation use during the fault, rather than a *decrease*. In light of these results, the authors propose, "If trust alone guided use of the automatic controller, a drop in the use of the automatic controller might be expected. The operators' level of self-confidence may explain why they tended to use the feedstock pump more often when faults occurred."

Additionally, Lee and See [47] viewed the behavior of choosing the automated control as dependent not solely upon the operator's self-confidence, but also upon dynamic interactions between the operator's individual, organizational, and environmental contexts. This echoes the exogenous factors of the individual, social, and task contexts in the EUI.
Köber [49] developed a questionnaire to measure Trust in Automation (TiA), using 19 Questions, developed on 6 scales; Reliability/Competence, Understandability/Predictability, Propensity to Trust, Intention of Developers, Familiarity, and Trust in Automation:

The system is capable of interpreting situations correctly.	Reliability/Competence
The system works reliably.	Reliability/Competence
A system malfunction is likely.*	Reliability/Competence
The system is capable of taking over complicated tasks	Reliability/Competence
The system might make sporadic errors.*	Reliability/Competence
I am confident about the system's capabilities.	Reliability/Competence
The system state was always clear to me.	Understanding/Predictability
The system reacts unpredictably.*	Understanding/Predictability
I was able to understand why things happened.	Understanding/Predictability
It's difficult to identify what the system will do next.*	Understanding/Predictability
I already know similar systems.	Familiarity
I have already used similar systems.	Familiarity
The developers are trustworthy.	Intention of Developers
The developers take my well-being seriously.	Intention of Developers
One should be careful with unfamiliar automated systems.*	Propensity to Trust
I rather trust a system than I mistrust it.	Propensity to Trust
Automated systems generally work well.	Propensity to Trust
I trust the system.	Trust in Automation
I can rely on the system.	Trust in Automation

The questions with an asterisk are what Köber calls an "inverse item", where the same question is asked only using opposite wording. These inverse item questions are left out of a modified Trust in Exosystems (TiE) questionnaire only to minimize the total number of questionnaire choices. In addition, as our exosystem questionnaire is more interested in the opinions of trust surrounding an exosystem rather than individual user's opinions on whether they trust the developers of the systems or not, as well as whether they as individuals have a pre-disposition to trust, the questions in the subscales "Intention of Developers" and "Propensity to Trust" will not be used in the modified TiE questionnaire.

A few questions of the TiE will only apply to computer assisted (mostly active) systems; for example one such question only applies to systems that can completely take over completing the task. It is left to the experiment designer to modify or exclude questions accordingly.

Table E-4. Trust in Exosystems (TiE) modifications

TIA Construct Question	Construct	TIE Question Modification	Notes
The system might make sporadic errors.	Trust - Reliability/Confidence	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	
I am confident about the system's capabilities.	Trust - Reliability / Competence	Rate how not confident (1) to confident (5) you are or being able to complete future work tasks after you've used the exosystem.	Compare this to self-efficacy before exosystem use.
The system works reliably.	Trust - Reliability / Competence	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	
The system is capable of interpreting situations correctly. *	Trust - Reliability / Competence; MIL Consortium	Rate how bad (1) to well (5) the exosystem interpreted the task you were performing.	This question only applies to exosystems that have this capability.
The system is capable of taking over complicated tasks. *	Trust - Reliability / Competence	Rate how doubtful (1) to confident (5) you felt that the system could take over and complete your task.	This question only applies to exosystems that have this capability.
The system state was always clear to me.	Trust - Understanding/Predictability [changing modes];	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	
I was able to understand why things happened.	Trust – Understanding/Predictability;	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	
	Trust - Familiarity	Rate how performing the task seems different (1) to familiar (5) to you.	
I have already used similar systems.	Trust – Familiarity	Rate the similarity from Low (1) to high (5) to other exosystems you have used.	This question only applies if subjects have previously used exosystems
I can rely on the system.	Trust – Trust in Exosystems	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	
I trust the system.	Trust - Trust in Exosystems	Rate your trust from Low (1) to High (5) of the exosystem.	

Appendix F

Analyzing the EUI Questionnaire – Industrial

In order to create a useful, flexible, and convenient method to test for exosystem cognitive use, a questionnaire format was chosen as the measuring tool of choice for 3 reasons: a) usability, workload, situational awareness, and trust in automation are all well-known engineering psychology constructs that can be measured through user introspection through a questionnaire, b) if given immediately after a an experimental task the rating reliability is good, and c) a questionnaire format is relatively inexpensive, so smaller companies investigating exosystems will be able to afford to use the EUI.

Not all questions listed in Appendix B will apply to every exosystem experiment; for example some questions listed in the TiE will only apply to computer-assisted active exosystems that have different levels of automation (15). The core questions listed in Appendices B and C were chosen to be selected by all experimenters no matter what their particular study needs based on the existing exoskeleton literature.

The questionnaire was designed to have a score for each listed context under the factors of exogenous to endogenous, following the operator's cognitive flow. Park [14] performed multiple variance and statistical validity checks on his TAMII model, and found a large effect of self-efficacy (self-confidence) on the behavioral intention (intent to use) factor on his model of an e-learning system. He found a similar if slightly smaller effect of social norm (social factors) on the behavioral intention (intent to use) factor. As these were so important a numerical weighting component for these 2 factor scores was considered for the EUI, however exosystem use environments can differ greatly. For example, it is likely that some environmental contexts may create a much higher (or lower) social factor than others. Certain exosystem experiment designers in the future may wish to consider weighting certain questions according to their specific use environments.

The questionnaire was also designed to optionally include any or all 31 "construct" questions that are listed in Appendix E. These 31 questions can be broken down into the measurements of Usability (as defined by the Usability Professionals' Association [40]), Workload (as defined by the NASA TLX Workload Assessment [41]), SA (as defined by the Situational Awareness Rating Technique [44]), and TiE (as defined by the modified Trust in Automation questionnaire [49]). Scores from these individual sub-questionnaires can be broken out into their respective constructs to pin-point areas of specific interest. For an example, see Appendix G example 2. NOTE: due to inherent biases, a Likert scale questionnaire can be considered ordinal data, where the numbered responses 1 – 5 are *not* equidistant from each other. Therefore a mean average within each context should *not* be used. Likert scale responses could differ due to individual differences, therefore using a mean score would lead to misinterpretation. Rather, the median and/or mode of scores within each context should be used. It must also be noted that currently, much meaningful statistical analysis using the EUI beyond descriptive statistics is difficult, as it is hard to get a large n value to achieve statistical significance. This fact is due to the current expense of exosystems. This expense factor will theoretically change; the larger number of systems are created and put out in industry the lower the cost should become. Finally, in order to compare operators' cognitive flow scores while using exosystems you must use the same questions in all questionnaires within a single experiment.

Appendix G

Questionnaire Examples

The following are example questionnaires developed from the 69 question EUI question alternatives (Appendix B). The questionnaires can be shorter or longer - it is up to the experiment lead to choose the most relevant of the 69 alternatives according to their experiment's requirements. The examples are followed by examples of scoring the questionnaires. The example below is the shortest recommended.

Example 1 – Core questions only

This 15-question example is the shortest questionnaire recommended:

Domain / Context	**Question**	**Appendix B Question #**					
Exogenous Domain			Circle the most appropriate number.				
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task <u>before</u> wearing the exosystem.	1	1	2	3	**(4)**	5
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2	1	**(2)**	3	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3	1	2	**(3)**	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4	1	2	3	**(4)**	5
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8	1	2	**(3)**	4	5
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9	1	**(2)**	3	4	5

Domain / Context	Question	Appendix B Question #					
Endogenous Domain							
Ease of Use Context	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	16	1	2	3	4	**5**
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	17	1	2	3	**4**	5
Usefulness Context	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.	45	1	2	3	4	**5**
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	49	1	2	**3**	4	5
Attitude (Affective) Context	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.	51	1	2	3	**4**	5
	Rate how you felt your performance was in doing the task, from bad (1) to good (5).	52	1	2	3	**4**	5
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	53	1	2	3	4	**5**
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	50	1	2	3	**4**	5
Intention	Rate how little (1) to much (5) you intend to use the exosystem.	66	1	2	3	**4**	5

Example 1 - Scores

The Context scores within the exogenous and endogenous domains should be added together, and all context scores should then also be added forming a Total EUI score. As the responses to this Likert scale questionnaire can be considered ordinal data, where the numbered responses 1 – 5 are *not* equidistant from each other, a mean average within each context should *not* be used. The Likert scale responses could differ due to individual differences, therefore using a mean score would lead to misinterpretation. Rather, the median and/or mode of scores within each context should be used. Note: in order to compare operators cognitive flow scores while using exosystems you must have the same questions in your questionnaires for both exosystems. Example 1 Scores:

Factors	Total Scores
Individual context-(self-efficacy)	4
Social context	9
Task context	5
Ease of Use perception context:	9
Usefulness perception context:	8
Attitude (Affective) context	17
Intent to Use context	4

Total EUI score gives an operators' cognitive flow towards an intention to use: in this example 55. This measures the cognitive flow from exogenous through endogenous context; it does not measure the human factor constructs discussed above.

Example 2 – with HF Constructs

This 44 question example uses the above core questionnaire, in addition to the 31 construct questions. This questionnaire gives not only a EUI flow score, but also separate scores for Usability, TLX Workload, SART, and TiE. This example can apply to a passive, non-computer-assisted exosystem.

Domain / Context	Question	Appendix B Question #					
Exogenous Domain			Circle the most appropriate number.				
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task <u>before</u> wearing the exosystem.	1	1	2	3	**4**	5
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2	1	**2**	3	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3	1	2	**3**	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4	1	2	3	**4**	5
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8	1	2	3	**4**	5
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9	1	2	**3**	4	5
	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	10	1	2	**3**	4	5
	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	11	1	**2**	3	4	5
	Rate how well you could concentrate on the work (High) or (Low)?	12	1	2	3	**4**	5

Domain / Context	Question	Appendix B Question #					
Task Context	Rate how complex (1) to simple (5) your task was.	13	1	**2**	3	4	5
	Rate how performing the task seems different (1) to familiar (5) to you.	14	1	2	3	**4**	5
Endogenous Domain							
Ease of Use Perception Context	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	16	1	2	3	4	**5**
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	17	1	2	3	**4**	5
	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	18	1	2	**3**	4	5
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	1	2	3	**4**	5
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	1	2	3	**4**	5
	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	20	1	2	3	**4**	5
	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	21	1	**2**	3	4	5
	When faced with a new or novel situation while doing your work task, how well did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	22	1	2	**3**	4	5
	When faced with a new or novel situation while doing your work task, how quickly did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	23	1	2	3	**4**	5

Domain / Context	Question	Appendix B Question #					
Ease of Use Perception Context	Rate how you felt your performance in doing the task, from bad (1) to good (5).	52	1	2	3	4	**5**
	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	25	1	2	3	**4**	5
	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	26	1	2	3	**4**	5
	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	27	1	2	3	**4**	5
	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	29	1	2	3	**4**	5
	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	30	1	2	3	**4**	5
	Rate how physically strenuous (1) to easy (5) your work-task was.	31	1	2	3	4	**5**
Usefulness Perception Context	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.	45	1	2	3	4	**5**
	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	46	1	2	3	4	**5**
	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	47	1	2	3	4	**5**
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	49	1	2	**3**	4	5
	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.	51	1	2	3	**4**	5

Domain / Context	Question	Appendix B Question #					
Attitude (Affective) Context	Rate how you felt your performance in doing the task, from bad (1) to good (5).	52	1	2	3	**4**	5
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	53	1	2	3	4	**5**
	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	54	1	2	3	**4**	5
	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	55	1	2	3	4	**5**
	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	56	1	2	**3**	4	5
	Rate your trust from Low (1) to High (5) of the exosystem.	57	1	2	3	**4**	5
	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	58	1	2	3	**4**	5
	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	59	1	**2**	3	4	5
	Rate how engaged in the task you felt you were, from Low (1) to High (5).	27	1	2	3	**4**	5
	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	61	1	2	3	**4**	5
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	50	1	2	3	**4**	5
Intention	Rate how little (1) to much (5) you intend to use the exosystem.	66	1	2	3	**4**	5

Example 2 – Scoring

The Context scores within the exogenous and endogenous domains should be added together, and all context scores should then also be added forming a Total EUI score. As the responses to this Likert scale questionnaire can be considered ordinal data, where the numbered responses 1 – 5 are *not* equidistant from each other, a mean average within each context should *not* be used. The Likert scale responses could differ due to individual differences, therefore using a mean score would lead to misinterpretation. Rather, the median and/or mode of scores within each context should be used. Note: in order to compare operators cognitive flow scores while using exosystems you must have the same questions in your questionnaires for both exosystems. Note: in order to compare operators cognitive flow scores while using exosystems you must have the same questions in your questionnaires for all systems. Example 2 Scores:

Factors	Total Scores
Individual context	4
Social context	9
Task context	22
Ease of Use perception context	63
Usefulness perception context	22
Attitude (Affective) context	43
Intent to Use	4

Total EUI score gives an operators' cognitive flow towards an intention to use: in this example 171. This includes the human factor constructs discussed above.

Example 2 – Scoring the Constructs

Here are the individual breakouts from the human factor constructs:

Usability Construct:

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Effectiveness	46	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	5	Usefulness Perception
Efficiency	47	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	4	Usefulness Perception
Engagingness	27	Rate how engaged in the task you felt you were, from Low (1) to High (5).	4	Attitude (Affective) Context
Error Tolerance	18	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	3	Ease of Use Perception
	19	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	4	Ease of Use Perception
Ease of Learning	20	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	4	Ease of Use Perception
	21	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	2	Ease of Use Perception

This gives a Usability score of 26

NASA TLX Workload Construct:
:

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Mental Demand	27	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	4	Ease of Use Context
Physical Demand	31	Rate how physically strenuous (1) to easy (5) your work-task was.	5	Ease of Use Context
TEMPORAL DEMAND	59	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	2	Attitude (Affective) Context
PERFORMANCE	52	Rate how you felt your performance in doing the task, from bad (1) to good (5).	4	Attitude (Affective) Context
EFFORT	19	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	4	Ease of Use Perception
FRUSTRATION LEVEL	55	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	5	Attitude (Affective) Context

This gives a TLX Workload score of 24.

SART (Situational Awareness Rating Technique) Construct:

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Instability of situation	10	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	3	Task Context
Variability of Situation	11	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	2	Task Context
Complexity of Situation	13	Rate how complex (1) to simple (5) your task was.	2	Task Context
Arousal (eagerness)	54	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	4	Attitude (Affective) Context
Spare mental Capacity	26	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	4	Ease of Use Perception
Concentration	25	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	4	Ease of Use Perception
Division of Attention	12	Rate how well you could concentrate on the work (High) or (Low)?	4	Task Context
Information Quantity	22	When faced with a new or novel situation while doing your work task, <u>how well did you understand</u> what to do to solve the problem? Rate the amount from low (1) to high (5).	3	Ease of Use Perception
Information Quality	23	When faced with a new or novel situation while doing your work task, how <u>quickly</u> did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	4	Ease of Use Perception
Familiarity	14	Rate how performing the task seems different (1) to familiar (5) to you.	4	Task Context

This gives a SART score of 34

Trust in Exosystems (TiE)

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Trust - Reliability / Competence	29	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	4	Ease of Use Perception
Trust - Reliability / Competence	51	Rate how not confident (1) to confident (5) you are or being able to complete future work tasks after you've used the exosystem.	4	Attitude (Affective) Context
Trust - Reliability / Competence	61	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	4	Attitude (Affective) Context
Trust - Understanding/ Predictability	58	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	4	Attitude (Affective) Context
Trust - Understanding/ Predictability (changing modes)	30	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	4	Ease of Use Perception
Trust - Familiarity	14	Rate how performing the task seems different (1) to familiar (5) to you.	4	Task Context
Trust – Trust in Exosystems	56	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	3	Attitude (Affective) Context
Trust – Trust in Exosystems	57	Rate your trust from Low (1) to High (5) of the exosystem.	4	Attitude (Affective) Context

This gives a TiE score of 31.

Example 3

The following is a 58 query example questionnaire developed from the 69 question EUI question alternatives. This questionnaire gives not only a EUI flow score, as well as scores for Usability, TLX Workload, SART, and TiE, but also scores to questions that are pertinent to the study/experimental situation/context that also address issues discussed in the human factors and exosystem-specific literature.

Domain / Context	Question	Appendix A Question #					
Exogenous Domain			Circle the most appropriate number.				
Individual Context	Rate how unsure (1) to self-confident (5) you felt in completing your task <u>before</u> wearing the exosystem.	1	1	2	3	④	5
Social Context	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your age.	2	1	②	3	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of your gender.	3	1	2	③	4	5
	Rate your feeling of anxiety (1) to no anxiety (5) of using an exosystem because of what your co-workers might think.	4	1	2	3	④	5
	Does your organization offer the choice of using or not using the exosystem to complete your work? No (1) to Yes (5)	5	1	2	3	4	⑤
	Rate if others should not (1) to should (5) use exosystems.	7	1	2	3	④	5
Task Context	Rate the non-compatibility/compatibility of the exosystem with the systems/equipment that you're going to be using it with (vehicles, controls, clothing, load carriage, PPE, tools)	8	1	2	3	④	5
	Rate the non-compatibility (1) to compatibility (5) of the exosystem to fit into or through confined spaces (ex. narrow openings/hatches, vehicle aisles, etc.)	9	1	2	③	4	5
	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	10	1	2	③	4	5

Domain / Context	Question	Appendix A Question #					
Task Context	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	11	1	**2**	3	4	5
	Rate how well you could concentrate on the work (High) or (Low)?	12	1	2	3	**4**	5
	Rate how complex (1) to simple (5) your task was.	13	1	**2**	3	4	5
	Rate how performing the task seems different (1) to familiar (5) to you.	14	1	2	3	**4**	5

Endogenous Domain							
Ease of Use Perception	Rate how hard (1) to easy (5) you felt your task was by using the exosystem.	16	1	2	3	4	**5**
	Rate how badly (1) to well (5) the exosystem fit you, after adjustment.	17	1	2	3	**4**	5
	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	18	1	2	**3**	4	5
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	1	2	3	**4**	5
	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	19	1	2	3	**4**	5
	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	20	1	2	3	**4**	5
	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	21	1	**2**	3	4	5
	When faced with a new or novel situation while doing your work task, how well did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	22	1	2	**3**	4	5

Domain / Context	Question	Appendix A Question #					
Ease of Use Perception	When faced with a new or novel situation while doing your work task, how quickly did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	23	1	2	3	**4**	5
	Rate how you felt your performance in doing the task, from bad (1) to good (5).	51 52	1	2	3	4	**5**
	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	25	1	2	3	**4**	5
	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	26	1	2	3	**4**	5
	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	27	1	2	3	**4**	5
	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	29	1	2	3	**4**	5
	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	30	1	2	3	**4**	5
	Rate how physically strenuous (1) to easy (5) your work-task was.	31	1	2	3	4	**5**
	Rate your imbalance (1) to balance (5) while wearing the exosystem.	33	1	2	3	4	**5**
	Rate how overheated (1) to cool (5) wearing the exosystem made you feel.	36	1	**2**	3	4	5
	Rate the difficulty (1) to ease (5) of the initial set-up/adjusting of the exosystem	37	1	2	**3**	4	5
	Rate slowly (1) to quickly (5) you can move while wearing the exosystem in your work environment.	42	1	**2**	3	4	5

Domain / Context	Question	Appendix A Question #					
Ease of Use Perception	Rate jerky (1) to smooth (5) you can move while wearing the exosystem.	43	1	2	3	**4**	5
	Rate the restraint (1) to freedom of movement (5) in doing your task while wearing the exosystem (i.e., can you sit on ground/chair, kneel, lay down, climb stairs, etc.)	32	1	2	3	**4**	5
	Rate the clumsiness (1) to agility (5) you felt from the exosystem.	34	1	2	**3**	4	5
	Rate how inaccurate (1) to accurate (5) you felt with the exosystem in the completion of your work/task.	35	1	2	3	4	**5**
Usefulness Perception Context	Rate the following statement: I find exosystems not useful (1) to useful (5) in my job.	45	1	2	3	4	**5**
	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	46	1	2	3	4	**5**
	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	47	1	2	3	**4**	5
	Rate how flexible the exosystem was in helping you doing your work. (ex. Could it help you in performing different subtasks in your work? Did it stay out of your way when you needed it to?)	49	1	2	**3**	4	5
Attitude (Affective) Context	Rate how unsure (1) to self-confident (5) you felt after wearing the exosystem.	51	1	2	3	**4**	5
	Rate how you felt your performance was in doing the task, from bad (1) to good (5).	52	1	2	3	**4**	5
	Rate your overall dissatisfaction (1) to satisfaction (5) with the exosystem	53	1	2	3	4	**5**
	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	54	1	2	3	**4**	5
	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	55	1	2	3	4	**5**

Domain / Context	Question	Appendix A Question #					
Attitude (Affective) Context	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	56	1	2	(3)	4	5
	Rate your trust from Low (1) to High (5) of the exosystem.	57	1	2	3	(4)	5
	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	58	1	2	3	(4)	5
	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	59	1	(2)	3	4	5
	Rate how engaged in the task you felt you were, from Low (1) to High (5).	27	1	2	3	(4)	5
	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	61	1	2	3	(4)	5
	Rate how little (1) to how much (5) the exosystem extended your limits? (i.e. I could do less/more repetitions, I had less/better quality to my work, etc.)	63	1	2	3	(4)	5
	Rate how little (1) to how much (5) you felt like the exosystem was a part of your own body.	50	1	2	3	(4)	5
Intention to Use	Rate how little (1) to much (5) you intend to use the exosystem.	66	1	2	3	(4)	5
	Rate the statement: "I would not use (1) to use (5) the exosystem for my task if it were available to me."	67	1	2	3	4	(5)
	Rate how worse off (1) to how well (5) the exosystem met your needs?	68	1	2	3	(4)	5
	Rate your overall experience, bad (1) to good (5) wearing the exosystem.	69	1	2	3	4	(5)

Example 3 - Scores

The Context scores within the exogenous and endogenous domains should be added together, and all context scores should then also be added forming a Total EUI score. As the responses to this Likert scale questionnaire can be considered ordinal data, where the numbered responses 1 – 5 are *not* equidistant from each other, a mean average within each context should *not* be used. The Likert scale responses could differ due to individual differences, therefore using a mean score would lead to misinterpretation. Rather, the median and/or mode of scores within each context should be used. Note: in order to compare operators cognitive flow scores while using exosystems you must have the same questions in your questionnaires for both exosystems. Example 3 Scores:

Factors	Total Scores
Individual context	4
Social context	18
Task context	22
Ease of Use perceptions:	91
Usefulness perception	17
Attitude (Affective)	51
Intent to Use	18

Total EUI score gives an operators' cognitive flow towards an intention to use: in this example <u>221</u>. This includes the human factor constructs discussed above.

Example 3 – Scoring the Constructs

Here are the breakouts from the human factor constructs:

Usability Construct:

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Effectiveness	46	Rate how effective you felt you were using the exosystem, from Low (1) to High (5).	5	Usefulness Perception
Efficiency	47	Rate how efficient you felt you were in completing the task using the exosystem, from Low (1) to High (5).	4	Usefulness Perception
Engagingness	27	Rate how engaged in the task you felt you were, from Low (1) to High (5).	4	Attitude (Affective) Context
Error Tolerance	18	If the exosystem did not fit you well (for example, straps too tight/loose /chafing), rate if you were unable (1) to how well (5) you could continue with your work.	3	Ease of Use Perception
	19	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	4	Ease of Use Perception
Ease of Learning	20	Rate how easy to learn you felt the exosystem was, from Low (1) to High (5).	4	Ease of Use Perception
	21	Rate how long you felt it took to learn how to use the exosystem, from Low (1) to High (5).	2	Ease of Use Perception

This gives a Usability score of 26.

NASA TLX Workload:

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Mental Demand	27	Rate how engaged in your work you felt using the exosystem, from Low (1) to High (5).	4	Ease of Use Context
Physical Demand	31	Rate how physically strenuous (1) to easy (5) your work-task was.	5	Ease of Use Context
TEMPORAL DEMAND	59	Rate the time pressure you felt in performing your task either from yourself or others, from none (1) to a lot (5)	2	Attitude (Affective) Context
PERFORMANCE	52	Rate how you felt your performance in doing the task, from bad (1) to good (5).	4	Attitude (Affective) Context
EFFORT	19	How badly (1) to well (5) did the system support you when you needed it during your work task? Did your task take a lot of effort to accomplish?	4	Ease of Use Perception
FRUSTRATION LEVEL	55	Rate the frustration level you felt during the performance of the task, from High (1) to Low (5).	5	Attitude (Affective) Context

This gives a Workload score of 24.

SART (Situational Awareness Rating Technique):

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Instability of situation	10	Rate if the situation during your work-task is unstable and likely to change suddenly (1) or is it stable and straightforward (5)?	3	Task Context
Variability of Situation	11	Rate the fewer (1) or greater (5) number of variables that are changing during your work (average).	2	Task Context
Complexity of Situation	13	Rate how complex (1) to simple (5) your task was.	2	Task Context
Arousal (eagerness)	54	Rate how you felt not eager (1) to eager (5) you felt to perform your task.	4	Attitude (Affective) Context
Spare mental Capacity	26	Rate how little (1) or how much (5) much extra attention and focus you have to spare during the work (for example, do you feel you have a lot of extra attention to attend to new variables or subtasks?)	4	Ease of Use Perception
Concentration	25	Rate how you much you can concentrate and focus on your work, from Low (1) to High (5)?	4	Ease of Use Perception
Division of Attention	12	Rate how well you could concentrate on the work (High) or (Low)?	4	Task Context
Information Quantity	22	When faced with a new or novel situation while doing your work task, how well did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	3	Ease of Use Perception
Information Quality	23	When faced with a new or novel situation while doing your work task, how quickly did you understand what to do to solve the problem? Rate the amount from low (1) to high (5).	4	Ease of Use Perception
Familiarity	14	Rate how performing the task seems different (1) to familiar (5) to you.	4	Task Context

This gives a SART score of 34.

TiE (Trust in Exosystems):

HF Sub-construct	Question #	Question	Score	EUI Context/Perception
Trust - Reliability / Competence	29	Rate how much (1) to how little (5) you felt the exosystem might make sporadic errors.	4	Ease of Use Perception
Trust - Reliability / Competence	51	Rate how not confident (1) to confident (5) you are or being able to complete future work tasks after you've used the exosystem.	4	Attitude (Affective) Context
Trust - Reliability / Competence	61	Rate how you feel about the reliability of exosystem, from unreliable (1) to reliable (5).	4	Attitude (Affective) Context
Trust - Understanding/ Predictability	58	Rate how unpredictable (1) to predictable (5) the exosystems actions were during your tasks.	4	Attitude (Affective) Context
Trust - Understanding/ Predictability (changing modes)	30	Rate your distrust (1) to trust (5) of the exosystem to be able to transition to different subtasks you while doing your work (for example, from kneeling to standing, or from tightening a screw to scraping).	4	Ease of Use Perception
Trust - Familiarity	14	Rate how performing the task seems different (1) to familiar (5) to you.	4	Task Context
Trust – Trust in Exosystems	56	Rate how unsafe (1) to safe (5) you would feel getting back up if you fell while wearing the exosystem.	3	Attitude (Affective) Context
Trust – Trust in Exosystems	57	Rate your trust from Low (1) to High (5) of the exosystem.	4	Attitude (Affective) Context

This gives a TiE score of 31.