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Wearable Robot Acceptance: Understanding the Impact of Trialability on User Perception

Chukwuma Nnaji, Ph.D.
Texas A&M University
College Station, Texas

Ifeanyi Okpala, Ph.D.
The University of Alabama,
Tuscaloosa, Alabama

Ibukun Awolusi, Ph.D.
The University of Texas as San Antonio
San Antonio, Texas

The use of emerging technologies such as Wearable Robots (WRs) or exoskeletons has gained considerable attention in the construction industry in recent times. WRs or exoskeletons augment workers' physical capacity when performing physically demanding tasks. While there is growing interest in exoskeletons, existing literature suggests that some workers oppose WR use on job sites. This resistance is largely driven by second-hand information gathered through multiple channels, and not based on actual use. Therefore, it is important to assess how hands-on experience (trialability) influences the end-user perception of the use of exoskeletons. To fill this gap, the researcher utilized a mixed-method approach consisting of a structured literature review, controlled experiment, and surveys (pre-post experiment surveys). Statistical analyses revealed that in most cases, trialability had a positive influence on technology acceptance constructs assessed (including "Behavioral Intention to Use"), confirming the important role of hands-on experience in exoskeleton integration research and practice.

Key Words: Exoskeleton, Wearable robots, Technology acceptance, Trialability

Introduction

The management of occupational safety and health in the construction industry faces unique challenges. These challenges result in part from the dynamic work environments of construction, the frequent use of heavy equipment, and the unavoidable worker-hazard interactions (Hallowell & Gambatese, 2009). As part of efforts to improve construction safety performance, researchers have reported that the application of safety technologies within various phases of construction projects will significantly enhance the safety and health of construction workers (Guo et al., 2017; Nnaji & Karakhan, 2020). Of these technologies, Wearable Robotics (WRs) has been gaining considerable attention in the construction industry in recent times (Antwi-Afari et al., 2021; Okpala et al. 2022a). The potential benefits of WRs for safety and productivity improvements have been covered in safety research (Kim et al., 2019; Okpala et al. 2022a; Zhu et al., 2021). Although WRs have the potential to significantly reduce work-related musculoskeletal disorders (WMSDs) and the attendant losses associated with accidents (Gonsalvez et al. 2021; Antwi-Afari et al., 2021), this reduction is only possible when workers truly perceive WRs' utility and decide to use the device during work. However, existing literature suggests that the use of wearable devices in the construction industry is relatively low (SmartMarket Report, 2021; Okpala et al., 2020). For workers to appreciate the potential utility of exoskeletons, they should take part in the decision-making process and be allowed to test these technologies before they are integrated into work operations.

According to the Innovation Diffusion Theory, the concept of trialability (i.e., trying out an innovative technology) is critical to driving the successful integration of an emerging solution (Sahn, 2006). Fundamentally, it is posited that information from end-users will provide critical information that will enable the technology to be developed and implemented in such a way that the expectations of end-users are satisfactorily met (Elprama et al., 2022). User experience is very important in examining technology acceptance (Choi et al., 2017) leading to user-centered work designs (Shore et al., 2018) and productive appraisals of the effects of the WRs being introduced to the workplace (Kermavnar et al., 2021). However, little to no studies within the construction domain have examined the impact of trialability of the acceptance of WR in the construction industry. Moreover, the concept of exoskeleton acceptance has not been investigated in depth within construction research. To objectively investigate the role of trialability in exoskeleton acceptance, it is critical to assess workers' perception towards the use of exoskeletons using a pre-and post-user evaluation approach supported by sound technology acceptance theories (Choi et al., 2017; Edirisinghe, 2019).

Understanding factors that influence individuals' use (acceptance) or rejection of a specific technology is a trending topic in marketing, information systems, construction management, and other social science domains (Tarhini et al., 2015); thus, researchers have developed theories and models to investigate, understand, predict and explain multiple variables that influence technology acceptance by workers and their respective construction organizations (Okpala et al. 2021). According to Venkatesh et al. (2003), these human behavior theories and methodologies have been satisfactorily used in the formulation of important and unique contributions to user acceptance of technology. In times past, a few of them have been conceptualized, synthesized, and tested to employ intention and/or usage as key dependent variables (in cross-sectional and between-subjects comparison). According to Tarhini et al. (2015), the key theories and models include the Theory of Reasoned Action (TRA), the Theory of Planned Behavior (TPB), the Technology Acceptance Model (TAM), and the extended TAM, the Unified Theory of Acceptance and Use of Technology (UTAUT), Innovation Resistance Theory and the Social Cognitive Theory. However, a recent study by Okpala et al. (2022b) indicates that UTAUT is the most effective model for explaining worker wearable device acceptance behavior within construction research. Given the lack of information on the role of trialability on WR acceptance, the present study aims to 1) identify factors/constructs that influence the acceptance of WR at the individual level in the construction industry, and 2) conduct a pilot study to assess the role of hands-on experience in behavior change using the constructs identified in the present study.

Background

Wearable Robots in Construction

Wearable robots, exoskeletons, exosuits, or super suits are a category of robotics and automation that comprises a system that produces a force or motion which augments the action of the wearer with increased strength and endurance during an activity (Fleischer & Hommel, 2008). The core benefit of a wearable robotic system is the enhanced ability of the construction worker to lift loads and engage in other manual handling activities with a lessened impact on body parts, such as their shoulders and lower backs (Zhu et al., 2021). This benefit is made possible by a combination of actuators, electrical systems, or/and hydraulics overlain by soft membranes or other suitable material in direct contact with the worker's skin (Kim et al., 2019). There are two broad classes of exoskeletons, namely active and passive exoskeletons. Active exoskeletons are those exosuits that use actuators in the form of electric motors, hydraulics, and pneumatics to provide support; while passive exoskeletons only use mechanical actuators like dampers and springs to store and release elastic energy as the worker engages in the movement of their body parts (Antwi-Afari et al., 2021). According to Exoskeleton Report (2022), examples of active exoskeletons are Iron Hand [upper body (wrist) type for grasping] and ATOUN Model Y (upper body type for bending and lifting). Passive exoskeletons include Ekso Vest (upper body type for elevated arm, static arm, and repeated arm motions), SuitX MAX (full body type for bending, lifting, squatting, elevated arms, and prolonged standing), and FLx ErgoSkeleton (upper body for pick and carry tasks).

Within the construction sector, studies on exoskeleton use have largely centered on experimental trials to demonstrate the efficacy in reducing physical demand on muscles associated with various body parts (Antwi-Afari et al., 2021, Gonsalves et al., 2021, Jain et al., 2021). Although Okpala et al. (2022a) deduced, through a survey of 51 construction and project managers, that wearable robotics could prevent between 30 and 40 % of injury incidents associated with critical WMSD risk factors, and can prevent construction-related WMSDs associated with all human body parts, there continues to be skepticism regarding their actual use on job sites (De Looze et al., 2016). Little to no research has focused on understanding the acceptance of exoskeletons before and after workers are exposed to the technology.

Role of User Experience in Technology Acceptance

When investigating technology acceptance, researchers have posited that the experience of the user (construction worker) is considered a technology-inherent determinant for raising technology acceptance (Mlekus et al., 2020; Vaziri et al., 2016). This supports the concept of trialability which connotes that the technology application functionality, after use, can influence how the worker's intention to adopt the device. In construction management and safety research, the exploration of predictive and explanatory theories/models have yielded results with a variety of degree of influences between independent and dependent variables (Choi et al., 2017; Lee et al., 2015; Okpala et al., 2022; Tarhini et al., 2015). In explaining or predicting technology acceptance in the construction domain, there is a lack of studies that experimentally assess the role of user experience. Just like in Rogers' diffusion theory of innovations (Sahn, 2006), Trialability (hands-on experience) could be critical to understanding how construction researchers should evaluate workers' behavior and attempt to influence adoption (Lee et al., 2011). In relating this position to the current research, it has been posited that trialability (when individuals use the exoskeleton for a task) can improve their views toward accepting the technology (Hayes et al., 2015). It is expected that information gotten from users before and after utilizing the exoskeletons will provide useful insights that support successful implementation within the construction domain.

Unified theory of acceptance and use of technology

The unified theory of acceptance and use of technology (UTAUT) is a more recent and comprehensive theory that has received significant attention in multiple research fields. As depicted in Figure 1, Lai (2017) explained that four constructs predict workers' behavioral intention to accept and use technology. The constructs are designated as (1) performance expectancy, (2) effort expectancy, (3) social influence, and (3) facilitating conditions.

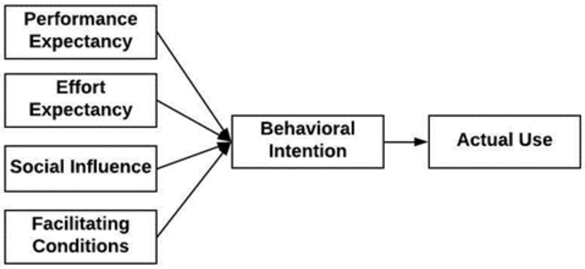

Figure 1. Unified Theory of Acceptance and Use of Technology (UTAUT)

According to Venkatesh et al. (2003), constructs such as perceived usefulness, extrinsic motivation, relative advantage, and outcome expectations form the performance expectancy in the UTAUT model while effort expectancy captures the notions of perceived ease of use and complexity. Herein, the facilitating conditions also correlate with the intention to use a technology, considering that they include factors highly reputed to make the action easy (Lee et al. 2011). Examples can be voluntariness of use, perceived behavioral control, and device wearability (Taherdoost 2018). These constructs could be used to assess workers' exoskeleton acceptance and provide a robust framework for assessing the impact of trialability on workers' acceptance. Table 1 summarizes questions (Items) used to assess each construct and relevant literature that supports each construct.

Table 1
Constructs and Items for UTAUT

Constructs	Items	References
Performance Expectancy (PE)	• Using Exoskeletons increases my productivity. • I think Exoskeletons help improve the quality of work. • Using Exoskeletons enhances my overall performance.	Rahman et al. (2017), Venkatesh et al. (2003)
Effort Expectancy (EE)	• Exoskeletons are very easy to operate. • Exoskeletons are easy to fit and adjust. • It is easy to learn how to use exoskeletons.	Rahman et al. (2017), Venkatesh et al., (2003), Zhang and Ng (2013)
Social Influence (SI)	• Using exoskeletons could make me look weak. • I have such an image that exoskeletons are difficult to use. • Exoskeletons are only useful for people who need help to finish a task.	Gledson, 2021; Kaur et al. (2020); Joachim et al., 2018
Facilitating Condition/ wearability (FC)	• The fit and overall comfort of exoskeletons are important for me. • I am reluctant to use exoskeletons that feel uncomfortable. • I am interested in using exoskeletons regardless of how I feel.	Bogue (2018); Sarac et al. (2019)
Behavioral Intention to Use (BI)	• I intend to use exoskeletons to perform drilling or similar tasks if given the opportunity. • I plan to continue using exoskeletons in the future. • All things considered, I will keep using exoskeletons as long as I have access to it.	Tarhini et al., (2015), Yousafzai et al. (2010), Choi et al. (2017)

Based on existing research, the research team hypothesizes that hands-on experience will significantly improve participants' perception of exoskeleton use.

Table 2
Research Hypotheses

ID	**Hypothesis**
H1 (PE)	Hands-on experience will significantly improve participants' perception of exoskeleton's perceived effectiveness.
H2 (PEU)	Hands-on experience will significantly improve participants' perception of exoskeleton's perceived ease of use.
H3 (SI)	Hands-on experience will significantly reduce participants' perception of the negative impression associated with the use of exoskeletons.
H4 (FC)	Hands-on experience using exoskeletons will significantly increase participants' perception of their wearability.
H3 (BI)	Hands-on experience will significantly increase participants' intention to use exoskeletons.

Research Methods

The present study implemented a three-phase research framework to achieve the research goal. This consists of the structured literature review and survey design; expert review of the survey questionnaire; and controlled experimentation. The literature review consisted of academic research articles pertinent to construction technology applications, and WRs in construction. This extensive search solely depended on generic platforms such as Web of Science, Scopus, and Google Scholar (Okpala et al., 2020). The literature review led to the identification of important technology acceptance models and theories. Following the selection of the applicable theories/models (UTAUT), the author developed a survey questionnaire using data from Table 1. The questionnaire was designed using a 5-point Likert scale which varied from 1= Strongly Disagree to 5= Strongly Agree. Three domain experts with an average of 10 years of experience in construction management and technology implementation reviewed the questionnaire items, thereby assessing the variables concerning WRs acceptance. Next, the research team utilized a within-subject simulation experiment to expose participants to exoskeletons. Twenty-five were recruited to participate in multiple simulated drilling tasks using exoskeletons over three sessions. These sessions typically lasted between 30 minutes to an hour, depending on the type of task and the number of rest participants needed. Each session was separated by at least 48 hours. Participants were asked to complete a questionnaire on acceptance before the first session and a few days after completing the last session.

A non-parametric repeated measure t-test was used to analyze responses received from participants since the data violated the equal variance and normality assumptions needed for parametric analysis. The Wilcoxon signed-rank test, which is an equivalent of the paired sample t-test, was used in the present study given that a pair of repeated measurements are assessed. The null hypotheses for these tests are presented in Table 1.

Results and Discussion

Out of the 25 participants, 18 (10 males, 8 female) healthy engineering students with no reported musculoskeletal issues or other related health that affects their ability to stand, walk, bend, and lift performed lab-simulated drilling tasks. Demographic statistics of participants as represented in mean were: age = 22 years; weight = 173 lbs.; and height = 5 feet and 8 inches. Table 3 shows the participants' ratings in response (median value) to the constructs influencing innovation acceptance and resistance before and after completing the drilling experiments using exoskeletons. The user perception of the participants on constructs that affect the acceptance of exoskeletons generally improved after they completed the experiments. However, some constructs remained the same which implies that using the exoskeletons to complete a task did not change their perception. Table 3 contains the results of the descriptive and inferential statistical analyses.

Table 3
Results of Descriptive and Inferential Statistical Analyses

Constructs	**Before Experiment**		**After Experiment**		**P-value**
	Median	**SD**	**Median**	**SD**	
Performance Expectancy (PE)	3.83	0.85	3.830	0.96	0.880
Perceived Effort Expectancy (PEE)	3.33	0.73	4.000	0.69	0.100
Social Influence (SI)	3.58	0.62	2.17	0.72	**0.000**
Facilitating Condition/Wearability (FC)	2.33	0.8	4.000	0.68	**0.000**
Behavioral Intention (BI)	3.67	0.81	4.000	0.71	0.600

H1: Performance expectancy (PE): Participants' perception of exoskeleton effectiveness did not change because of the experiment (median = 3.83, P-value = 0.88). This finding implies that using the exoskeletons to complete simulation tasks did not improve their perception of its effectiveness. It is important to note that the rating was above 3.0 which suggests that participants were positive about the technology's effectiveness.

H2: Perceived Effort Expectancy (PEE): After completing the tasks, the participants indicated an increase in the degree to which they believe that using the device will be free of effort (before = 3.33, after = 4.00, P-value = 0.10). Though this finding is not significant (P-value = 0.10), it illustrates the perceived non-complexity in handling the exoskeleton as opined by Choi et al. (2017).

H3: Social Influence (SI): As consistent with existing studies, the participants' SI reduced significantly after the experiment (before= 3.58, after = 2.17, P-value = 0.00) illustrating that using the technology demystified their perception towards potential social or image-related posed by the introduction of exoskeletons (Zhu et al., 2021). This result clearly shows that while end-users may have some concerns based on preconceived notions, timely exposure to exoskeletons will play a major role in revealing the true value of these technologies. Therefore, construction practitioners should consider implementing strategies that encourage the use of these technologies by workers in different work scenarios to improve their perceived behavioral control.

H4: Facilitating Conditions/Wearability (FC): The end-user perception of FC significantly improved (before = 2.33, after = 4.00, P-value = 0.00) after the experiment thus illustrating that the fit and overall comfort of the device is sufficient. This implies that while the participants had some concerns about wearability and fit prior to the experiments, these concerns reduced significantly after the experiment. It is important to note that the researchers worked closely with the participant to ensure proper fit before and during the experiments. The current design and information provided by the manufacturers were adequate and point to the need to ensure that safety managers and supervisors pay close attention to human-robot fit.

H5: Behavioral Intention (BI): The BI rating increased (before = 3.67, after = 4.00) after using the exoskeleton for the drilling task. Although the increase is not significant (P-value = 0.60), trialability could still play a role in increasing an end-users interest in using exoskeletons. It is important to note that the baseline BI was relatively high for the group evaluated in this study (Median score of 3.67 on a 5-point scale), thereby reducing the possibility of a significant difference post-hands-on experience. It is expected that hands-on experience will have a greater impact on participants with lower baseline BI, such as construction trade workers. This position is consistent with existing literature (Choi et al., 2017; Lee et al., 2015) and further demonstrates the effect of trialability on the perception of the participants.

Conclusion

Few studies have highlighted the benefits and barriers of using exoskeletons in the construction industry. Although these studies posit that WRs have a huge potential to reduce injuries, existing literature suggests that the use of WRs in the construction industry is relatively low. This has prompted a shift in orientation to focus on uncovering factors that influence individuals' use (acceptance) or rejection of the exoskeleton technology. More importantly, limited studies have evaluated the role of hands-on experience using objective and quantitative procedures. To fill this gap, the researcher utilized a mixed-method approach consisting of a structured literature review, a controlled experiment, and surveys (before and after the experiment). The study identified factors/constructs that influence the acceptance of WR at the individual level in the construction industry and assessed the role of hands-on experience on end-user acceptance behavior. Descriptive and inferential statistical analyses revealed that Trialability has a significant positive influence in 40% of the constructs assessed and a positive, but not significant impact on 40% of the constructs (including "Behavioral Intention to Use"). Therefore, the research team confirms that Trialability is an important component in exoskeleton integration research and practice. Given the results from the present pilot study, future studies should investigate the role of Trialability on trade workers' intention to use exoskeletons. The impact of age and experience should be assessed as well.

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