Human Factors and Wearable Technologies, Vol. 141, 2024, 94–104
https://doi.org/10.54941/ahfe1005058

Occupational Exoskeletons as Symbionts: Defining Operator-Exoskeleton Interactions

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ABSTRACT

The fourth industrial revolution heralds the emergence of the Operator 4.0, characterized by the augmentation of physical, sensory or cognitive capabilities of workers. This transformation involves a shift from artificial and human agents working together toward a radical coupling of those two entities. The concept of symbiosis has been introduced to characterize these new *human cyber-physical systems*. Occupational exoskeletons contribute to the development of the "*super strength-operato*r" aspect of Operator 4.0. Currently, attempts to implement exoskeletons in the workplace are accelerating, raising questions about their acceptance by operators. However, to comprehensively grasp the challenges associated with the use of exoskeletons, it is essential to broaden the comprehension of operator-exoskeleton interactions beyond acceptance. An initial step towards achieving this understanding involves clarifying the terminology used to describe interactions between humans and exoskeletons. By positioning exoskeletons as potential symbionts and drawing insights from the ergonomics literature on symbiosis, this article aims to define the human-exoskeleton symbiosis.

Keywords: Human-technology symbiosis, Occupational exoskeletons, Interactions, Acceptance

INTRODUCTION

Occupational exoskeletons are wearable devices designed to "*enhance the power of a person*" (de Looze et al., 2016, p. 671). By locally reducing the muscular effort required by a physical task, these devices form a set of promising means to address the prevalence of musculoskeletal disorders (MSDs) (Theurel & Desbrosses, 2019). Currently, integration attempts within companies are increasing, and a recent report estimated that the number of occupational exoskeletons will be multiplied by 20 by 2030, for a European market reaching 4 billion euros (Exskallerate, 2023). Therefore, the understanding of operator-exoskeleton interactions, and more specifically the reasons and consequences of their long-term use by operators, represents a critical challenge for companies.

The question of interactions between humans and technology is a key element in ergonomics and numerous authors have put forward taxonomies in

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order to define them. To do so, two criteria are generally used: the distance separating the human and the machine and the distribution of roles between these two entities. For example, interactions with robots are generally subdivided as co-existence, collaboration and cooperation following these two paradigms (Schmidtler et al., 2015).

The recent emergence of Human Cyber-Physical Systems, to enhance the physical, sensory or cognitive capacities of operators using wearable technologies involves an alliance regarding the action between humans and technology. In other words, wearable technologies are "merging" with human action (Bengler et al., 2012). Consequently, the lines between automatic and manual are blurred, thus making the use of classifications based on the distribution of roles between humans and machines complex with regards to defining the interactions between humans and technology.

This observation is at the origin of a renewed interest in the concept of symbiosis in ergonomics (Gerber et al., 2020; Romero et al., 2016) which would allow for a description that is more adapted to these new types of interaction induced by H-CPS. Initially used in biology to designate a close association between two distinct species (a symbiont and its host), Licklider (1960) was the first to use the analogy of symbiosis in human-technology relationships, by predicting the close future union between humans and computers. While the symbiosis has been conceptualised with respect to diverse technologies (e.g., Artificial Intelligence (AI) as discussed by Sultana & Nemati, 2021; and Physically Coupled Human-Machine Systems, as explored by Inga et al., 2023), this concept has not yet specifically been addressed regarding occupational exoskeletons. Yet, in the case of occupational exoskeletons, considering the human as a host benefiting from the pairing with the technological "exoskeleton" symbiont seems intuitive; these devices are, after all, literally designed to be "external" "skeletons", aiming to assist the user's movement.

Currently, operator-exoskeleton interactions are frequently addressed through the study of their acceptance, namely psychological mechanisms which lead to using or rejecting these devices. Yet, consideration of the concept of symbiosis in the case of occupational exoskeletons would allow for a better understanding of interactions between the operator and the exoskeleton. By positioning the occupational exoskeleton as a symbiont, the aim of this article is to broaden the understanding regarding the emergence conditions and challenges linked to their *acceptance*. To do so, the first part will present the interest of making an analogy between the symbiosis in biology and the operator-exoskeleton symbiosis; and the second part will position the operator-exoskeleton symbiosis as a temporal construction. Then, the experience during the pairing with the exoskeleton will be envisaged through the prism of embodiment and acceptance concepts.

The Need for a Continuation of Symbiotic Analogy

Human-technology symbiosis is generally presented as enabling the increase of human performance (Gerber et al., 2020). If we continue the analogy with the biological symbiosis, it is important to consider all types of repercussions of the symbiotic interaction on the human agent, as stated by Flemisch and Baltzer (2022, p. 3) : "*We should keep our eyes open regarding human machine symbiotic relationships which could develop harmful for the human partner*". Indeed, in the biosphere, symbiosis refers to a set of interactions between two species which may be beneficial, without effect, or harmful for one or both partners. In the case of interactions whereby one of the partners benefits at the expense of the other, the symbiosis is qualified as "*parasitism*". If there is no effect on either of the partners, the symbiosis is said to be "*neutralism*". Finally, if both species benefit from the interaction, the term "*mutualism*" is used.

At first, it may be complex to imagine how the exoskeleton could benefit from, at the expense of or simultaneously, the pairing with the human agent. For the continuation of the analogy, let's consider that, as an object without any degree of autonomy, always requiring a human host to come into operation; the exoskeleton *exists* to be worn. In this perspective, the exoskeleton is a symbiont "benefiting" from coupling with the human agent every time it is worn, regardless of the repercussions on the human agent. Thus, the continuation of the analogy with the symbiosis given by Flemisch and Baltzer (2022) becomes obvious in the case of occupational exoskeletons. Indeed, numerous undesired effects of occupational exoskeletons on the operator have been reported (for a review, see Kranenborg et al., 2023). They refer to these undesired effects as side-effects define as "*any unintended effect that occurs as a consequence of exoskeleton use*". These side effects can be psychological (e.g. frustration), psycho-physiological (e.g. discomfort), task-related (e.g. performance) or biomechanical/physiological (e.g. muscle activity). If a great number of these side-effects are perceived or are perceived intensely, and simultaneously, no compensatory benefit is felt during the use, the exoskeleton symbiont could be likened to a parasite benefiting from the pairing at the user's expense. In this configuration, and by resuming the extension of the analogy with the symbiosis provided by Flemisch and Baltzer (2022), the operator-exoskeleton symbiosis falls under a "*parasitism*"-type interaction. However, the operator-exoskeleton "parasitic symbiosis" is not frozen in this state. Jakobsen et al. (2023) and Moyon et al. (2019), showed that a prolonged period of use (called *familiarization*) of the exoskeleton could enhance the benefits on the human agent. Thus, over time, the operator would be capable of changing the nature of the interaction. This change would rely on the human's capacity to get used to the side effects, through adaptation or habituation. This therefore leads us to envisage the operator-exoskeleton symbiosis as a temporal construction.

The Operator-Exoskeleton Symbiosis: A Temporal Construction

Adelé and Brangier (2013) suggested, under the term technosymbiosis, to consider symbiosis as the construction of a human-technology relationship over time rather than a fixed interaction mode, determined by the characteristics of the technology and the interactions with it. The modification of the nature of the interaction thanks to adjustment capacities to deal with the side-effects, is also observed in the case of exoskeletons. Thus, in an ecological context of use, Kim et al. (2021) revealed that the modification of the perceptual-motor system induced by the exoskeleton's assistance sometimes leads to the operators consciously adapting their operating methods. Stirling et al. (2020) underline that an increased cognitive load may be felt during the first moments of the interaction, then fade over time. Similarly, the discomfort perceived during the first moments of interaction may, after repeated interactions, evolve towards more positive perceptions (as suggested by El Husaini et al., 2023).

Beyond the operator's adjustments to the side effects, the familiarization period may also be a period during which the operator commits to a series of explorations and implements proactive research strategies to optimise the effects of the exoskeleton's assistance, depending on their needs. Indeed, certain authors have, for example, identified the different ways in which the operators use the exoskeleton, whether it be depending on activities (de Vries et al., 2022; Smets, 2019) or in the intensity of use (Hensel & Keil, 2019).

In short, the familiarization period allows the operator to both optimize the assistance effects (desired effects), as well as to get used to the non-desired effects (side effects). This double process constitutes an appropriation of the exoskeleton symbiont, enabling the operator to progressively exploit the device's full potential (Saga & Zmud, 1994, use the term *extended use* to describe this state). In such a case, the symbiotic interaction may evolve towards "*mutualism*" level.

However, in the case of on-going interactions in the long-term, Flemisch and Blatzer (2022) argue that mutualist symbiotic relationships may cover harmful aspects through prolonged coupling. This is the case, for example, of the 'nomophobia' (No Mobile Phone Phobia) phenomenon described as the fear that results from separation with one's smartphone (King et al., 2014) or the functional dependence that may set in regarding prolonged interactions with technologies, described in literature with regards to the long-term user experience (Karapanos et al., 2009). To illustrate these phenomena, Flemisch and Blatzer (2022) used the analogy of the *centaur* and the *horse-rider* to address "irreversible symbiosis" and "reversible symbiosis".

With regard to exoskeletons, the lack of long-term studies or studies amongst experimented users is often raised (Baldassarre et al., 2022). Nevertheless, the symbiotic perspective allows us to envisage similar phenomena in long-term coupling between the operator and the exoskeleton. Mutualism-type symbiosis could therefore be irreversible in a situation whereby the operator would no longer consider working without the exoskeleton.

The Operator-Exoskeleton Symbiosis: An Experiential Perspective

In their exploration of the human-technology symbiosis as a multivariate concept, Inga et al. (2023) argue that the symbiotic interaction leads to a modification of the human experience. In the case of occupational exoskeletons, the modification of this experience is closely linked to the subjective experience of the physical limits of one's own body, as well as the distinction between oneself and other objects, often referred to as *embodiment* (Longo et al., 2008).

Embodiment: A Consequence of Symbiotic Construction

Numerous studies have documented how interaction with objects can redefine the boundaries of the "self". In this case, the embodiment of the object has been defined as "*the sense that emerges when the properties of the object are processed as if they belonged to the biological body of the individual*" (Kilteni et al., 2012, p. 375). In the case of human-exoskeleton interactions, little research has been done on the embodiment phenomenon (Hybart & Ferris, 2022). Yet, as an inclusion experience of the technology in a specific conception of self, it is undoubtedly the most capable of characterising the operator-exoskeleton symbiosis.

Certain works make the link between the embodiment of objects and "*readiness-to-hand*" and "*present-at-hand*" concepts from Heidegger's work (Bennett et al., 2022; Bird, 2011). Heidegger provides the example of the hammer to illustrate these concepts: when we use a hammer to drive a nail, the hammer becomes "*ready-to-hand*", meaning naturally integrated in our gesture. The focus is not on the hammer itself, but rather on the aim of driving the nail. It is a "*readiness-to-hand*" experience whereby the tool becomes an extension of the intention. On the contrary, if the hammer breaks, our attention moves towards the hammer as a faulty object. At this moment, the hammer becomes "*present-at-hand*", and our perception focuses on its technical details rather than on its use.

In the context of exoskeletons, this distinction between *present-at-hand* and *ready-to-hand* could express the symbiotic transition between *parasitism* and *mutualism*. At the start of the symbiotic development, due to the novelty and the side effects, exoskeleton symbionts may be perceived as separate objects from the body, requiring focus on the object and its effects (*present-at-hand*). Then, by way of use, the exoskeleton may be felt to merge with the body and the user's action, thus enhancing the attention given to the task (*ready-to-hand*).

By transposing the literature review on the embodiment of analogue technologies to exoskeletons (i.e. prosthetic devices) conducted by Segil et al. (2022), the attainment of a *readiness-to-hand* state with respect to occupational exoskeletons would be enhanced by.

1) The development of a sense of agency. The agency describes the feeling according to which the movements are chosen, initiated or controlled by the user (Haggard, 2017). In this way, the agency converges with the notion of mastery of technology, which is important in symbiotic conceptualisations (Adelé & Brangier, 2013; Inga et al., 2023). In the case of occupational exoskeletons, the feeling of movement control is essential as the operator's expertise is at stake. If it is potentially disrupted by the exoskeleton, it must be able to be found through the development of mastery and control of the technology.
2) The development of a sense of ownership. The experience of ownership involves perceiving a tool as being a part of oneself.

From a perceptual-motor point of view, this experience is linked to the unified processing of external sensory information (said to be exteroceptive, for example visual or tactile) coming from the interaction with the object with sensory information, or coming from the user's body (said to be interoceptive or proprioceptive, if we refer to the perception of the body's position in space) (Segil et al., 2022). The repetition of interactions with the object favours the unification of the processing of these different sensory inputs, and thus enhances the *sense of ownership*.

On a psychological level, this feeling can also fall within the framework of the "extended self" theory put forward by Belk (1988), which explores the way in which material belongings are involved in the construction (and enable the extension) of the "feeling of self". According to the author, this "perceived ownership" is accomplished through the control and mastery of the possessed object (this therefore places the *sense of agency* as a prerequisite for the emergence of a *sense of ownership*).

3) Integration into the user's body representations: Body representations consist of perceptions of our physical envelope (de Vignemont, 2010) and are generally divided into body schema, peripersonal space, and body image.

- Body schema (BS) is a mental representation of the body oriented to action (Cardinali et al., 2012). The interaction with tools has been identified as modifying the body schema. Canzoneri et al. (2013), for example, showed that after the use of a slender pole, subjects perceived their arm to be narrower and longer compared to before use. In the same way, the occupational exoskeleton could perturb the representation of the body for action, potentially even in the moments following its use.
- Peripersonal space (PPS) is described as "*the representation of the portion of space immediately surrounding the body, where in general interactions between the individual and the environment happen*" (Galli et al., 2015, p. 1). Biggio et al. (2017) showed that the long-term experience of interaction with an object (in the specific case of a tennis racket) led to an enlarged PPS. Galli et al. (2015) observed a similar phenomenon in the case of wheelchair use. As exoskeletons are worn by the user, and generally have a significant volume, the hypothesis according to which, through usage, the exoskeleton remodels the representation of the PPS is feasible.
- Body image (BI) involves the perceptions and attitudes of people regarding their body and their appearance (Burychka et al., 2021). Contrary to the PPS and the BS, the BI is not a representation of the body oriented to motor action, it refers to the emotional relationship that we have with our body and its social dimension. In this respect, the BI could refer to the emotional dimension described in the conceptualisation of comfort of wearable technologies by Knight and Baber (2005). Or it could also refers to the social aspects highlighted in the literature on the acceptance of occupational exoskeletons (Elprama et al., 2022).

Certain authors highlight that the integration of the object in corporal representations condition their command (Arbib et al., 2009), while others argue the idea that the repeated use enables the emergence of this phenomenon (Weser & Proffitt, 2021). In any event, it is highly likely that these three corporal representations may be modified (not necessarily at the same time and with the same intensity) by the use of occupational exoskeletons.

The operator-exoskeleton mutualist symbiosis therefore involves a journey TOWARD MASTERING the exoskeleton (*sense of agency*) which is permitted by - or which may allow, depending on the view - its integration into bodily representations (BS, PPS and BI). This process leads to the development of a vision of the exoskeleton as being a part of oneself (*sense of ownership*).

However, so that this journey can be made, the operator must continue their use of the exoskeleton over time. This problem raises the question of *acceptance*.

Acceptance: A Prerequisite for Symbiotic Construction

Acceptance represents a broad spectrum of literature on the decision-making process behind technology-usage behaviours. The most-used models, regardless of the technology, are Davies' Technology Acceptance Model (TAM) (1989), as well as Venkatesh et al.'s Unified Theory of Acceptance and Use of Technology (UTAUT) (2003). The aim of these models is mainly the identification of determinants which explain the intention of using or rejecting a device. In the case of occupational exoskeletons, the studies conducted on acceptance aimed to identify these determinants (see Elprama et al., 2022 for a summary). They generally take the form of evaluations regarding the use of exoskeletons through the prism of these determinants and at a given moment in time. Few authors have written about what leads to operators continuing their usage of exoskeletons over time (Baldassarre et al., 2022). Yet, in the scientific literature relating to other technologies, there are already models which are interested in this question of continuity of use. These models show that the determinants regarding the first use differ from those explaining later usages and their continuation. Thus, satisfaction is raised as being a major determinant regarding continued use (Bhattacherjee, 2001). Further in time, usage behaviours are explained by the force of habit, rather than by decision-making processes (Limayem et al., 2007).

Thus, we suggest considering acceptance as the necessary strength, emerging from the operator, to continue the operator-exoskeleton symbiotic construction towards an automatic behaviour.

Our symbiotic conceptualisation suggests that during the first interactions, symbiosis is mostly "*parasitism*". This can be explained due to the side-effects perceived by the operator and their impact on their expertise. For some users, it is possible that the side-effects perceived during the first interactions are under-valued (and/or the benefits are over-valued) due to a novelty effect (Sung et al., 2010). This leads to an ephemeral feeling of satisfaction. In this case, like a speculative bubble, satisfaction is artificially high, and it is likely that this will lead to a disillusion, followed by a rejection of the exoskeleton. The "*parasitism*" interaction mode must not be automatically associated with a lack acceptance, even though it strongly increases the probability of rejection. Indeed, in order to progress towards a "*mutualism*" mode, the operator must decisively commit to an appropriation process. This relies on a high level of motivation, involving the belief that the exoskeleton can protect against the development of MSDs (coupled with the desire to protect oneself) and requires a social and organisational context which promotes the continuation of use. When the symbiotic coupling moves towards a "mutualism" mode, the probability of rejection decreases; due to the optimisation of benefits resulting from the ownership and the development of usage habits, involving a certain automation of behaviour.

CONCLUSION

Human-technology symbiosis is a concept which enables a change in interaction modes with new technologies to be expressed, but which also allows us to report on the ever closer connection that we have with these technologies. Using works which conceptualise the human-technology symbiosis, we suggest considering occupational exoskeletons as symbionts. Our conceptualisation of the operator-exoskeleton symbiosis is based on the notion of time and describes the way in which the exoskeleton symbiont is coupled out of favour or in favour with the operator, following an appropriation process. This symbiotic construction is permitted by the commitment to use, expressed by the degree of acceptance. Simultaneously, a genuine *oneness* formed by the user's biological body and the technological "exoskeleton" agent may be experimented; this is the embodiment phenomenon. This perspective paves the way to an understanding of operator-exoskeleton interactions beyond *acceptance* as currently addressed in the literature. Future studies could, for example, aim to explore the embodiment phenomenon of occupational exoskeletons in operators through the difference components described. As the temporal dimension is at the heart of our proposition, conducting longitudinal studies or studies which address long-term users of occupational exoskeletons would enable the documentation of appropriation processes of these devices, by, for example, highlighting a transition between the "*parasitism*" and "*mutualism*" stages in the operator-exoskeleton relationship.

REFERENCES

Adelé, S., & Brangier, E. (2013). Evolutions in the human technology relationship: rejection, acceptance and technosymbiosis. IADIS *International Journal on* www/Internet, *11* (3), 46–60.

Arbib, M. A., Bonaiuto, J. B., Jacobs, S., & Frey, S. H. (2009). Tool use and the distalization of the end-effector. *Psychological Research PRPF*, *73*, 441–462.

Baldassarre, A., Lulli, L. G., Cavallo, F., Fiorini, L., Mariniello, A., Mucci, N., & Arcangeli, G. (2022). Industrial exoskeletons from bench to field: Human-machine interface and user experience in occupational settings and tasks. *Frontiers in Public Health*, *10*, 1039680.

Belk, R. W. (1988). Possessions and the extended self. *Journal of consumer research*, *15*(2), 139–168.

Bengler, K., Zimmermann, M., Bortot, D., Kienle, M., & Damböck, D. (2012). Interaction Principles for Cooperative Human-Machine Systems. *It-Information Technology*, *54*(4), 157–164.

Bennett, D., Roudaut, A., & Metatla, O. (2022, April). Multifractal Mice: Operationalising Dimensions of Readiness-to-hand via a Feature of Hand Movement. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (pp. 1–18).

Bhattacherjee, A. (2001). Understanding information systems continuance: An expectation-confirmation model. *MIS quarterly*, *25*(3), 351–370.

Biggio, M., Bisio, A., Avanzino, L., Ruggeri, P., & Bove, M. (2017). This racket is not mine: The influence of the tool-use on peripersonal space. *Neuropsychologia*, *103*, 54–58.

Bird, J. (2011). The phenomenal challenge of designing transparent technologies. *Interactions*, *18*(6), 20–23.

Burychka, D., Miragall, M., & Baños, R. M. (2021). Towards a comprehensive understanding of body image: Integrating positive body image, embodiment and self-compassion. *Psychologica Belgica*, *61*(1), 248.

Canzoneri, E., Ubaldi, S., Rastelli, V., Finisguerra, A., Bassolino, M., & Serino, A. (2013). Tool-use reshapes the boundaries of body and peripersonal space representations. *Experimental brain research*, *228*, 25–42.

Cardinali, L., Jacobs, S., Brozzoli, C., Frassinetti, F., Roy, A. C., & Farnè, A. (2012). Grab an object with a tool and change your body: Tool-use-dependent changes of body representation for action. *Experimental Brain Research*, *218*, 259–271.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340.

El Husaini, M., Maberry, A., & Martin, A. E. (2023). Validation of a modified visual analogue scale to measure user-perceived comfort of a lower-limb exoskeleton. *Scientific reports*, *13*(1), 1–10.

Elprama, S. A., Vanderborght, B., & Jacobs, A. (2022). An industrial exoskeleton user acceptance framework based on a literature review of empirical studies. *Applied Ergonomics*, *100*, 103615.

Exoskeletons: Future exoskeleton technology application by 2030. (2023, May). Exskallerate. https://northsearegion.eu/media/24407/exskallerate_foresight-1.pdf

Flemisch, F., & Baltzer, M. C. A. (2022). Are Rider-Horse or Centaurs intelligent Human Systems Integration? First Sketch of reversible and non-reversible human technology/machine/AI Symbiosis. *Intelligent Human Systems Integration (IHSI 2022) Integrating People and Intelligent Systems*.

Galli, G., Noel, J. P., Canzoneri, E., Blanke, O., & Serino, A. (2015). The wheelchair as a full-body tool extending the peripersonal space. *Frontiers in psychology*, *6*, 639.

Gerber, A., Derckx, P., Döppner, D. A., & Schoder, D. (2020). Conceptualization of the human-machine symbiosis–A literature review. In *Proceedings of the 53rd Hawaii International Conference on System Sciences*.

Haggard, P. (2017). Sense of agency in the human brain. *Nature Reviews Neuroscience*, *18*(4), 196–207.

Hensel, R., & Keil, M. (2019). Subjective evaluation of a passive industrial exoskeleton for lower-back support: A field study in the automotive sector. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*(3–4), 213–221.

Hybart, R. L., & Ferris, D. P. (2022). Embodiment for Robotic Lower-Limb Exoskeletons: A Narrative Review. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*.

Inga, J., Ruess, M., Robens, J. H., Nelius, T., Rothfuß, S., Kille, S.,... & Kiesel, A. (2023). Human-machine symbiosis: A multivariate perspective for physically coupled human-machine systems. *International Journal of Human-Computer Studies*, *170*, 102926.

Jakobsen, L. S., de Zee, M., Samani, A., Desbrosses, K., & Madeleine, P. (2023). Biomechanical changes, acceptance, and usability of a passive shoulder exoskeleton in manual material handling. A field study. *Applied Ergonomics*, *113*, 104104.

Karapanos, E., Zimmerman, J., Forlizzi, J., & Martens, J. B. (2009). User experience over time: an initial framework. In *Proceedings of the SIGCHI conference on human factors in computing systems*, 729–738.

Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments*, *21*(4), 373–387.

Kim, S., Nussbaum, M. A., Smets, M., & Ranganathan, S. (2021). Effects of an arm-support exoskeleton on perceived work intensity and musculoskeletal discomfort: An 18-month field study in automotive assembly. *American Journal of Industrial Medicine*, *64*(11), 905–914.

King, A. L. S., Valença, A. M., Silva, A. C., Sancassiani, F., Machado, S., & Nardi, A. E. (2014). "Nomophobia": Impact of cell phone use interfering with symptoms and emotions of individuals with panic disorder compared with a control group. *Clinical practice and epidemiology in mental health: CP & EMH*, *10*, 28.

Knight, J. F., & Baber, C. (2005). A tool to assess the comfort of wearable computers. *Human factors*, *47*(1), 77–91.

Kranenborg, S. E., Greve, C., Reneman, M. F., & Roossien, C. C. (2023). Side-effects and adverse events of a shoulder-and back-support exoskeleton in workers: A systematic review. *Applied Ergonomics*, *111*, 104042.

Licklider, J. C. (1960). Man-computer symbiosis. *IRE transactions on human factors in electronics*, (1), 4–11.

Limayem, M., Hirt, S. G., & Cheung, C. M. (2007). How habit limits the predictive power of intention: The case of information systems continuance. *MIS quarterly*, 705–737.

Longo, M. R., Schüür, F., Kammers, M. P., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, *107*(3), 978–998.

de Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., & O'sullivan, L. W. (2016). Exoskeletons for industrial application and their potential effects on physical work load. *Ergonomics*, *59*(5), 671–681.

Moyon, A., Petiot, J. F., & Poirson, E. (2019, October). Investigating the effects of passive exoskeletons and familiarization protocols on arms-elevated tasks. In *Human Factors and Ergonomics Society Europe Chapter 2019 Annual Conference*.

Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, Å. (2016). The operator 4.0: Human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. In *Advances in Production Management Systems. Initiatives for a Sustainable World.* Springer International Publishing. *Iguassu Falls, Brazil,* (677–686).

Saga, V. L., & Zmud, R. W. (1994). The nature and determinants of IT acceptance, routinization, and infusion. In *Proceedings of the IFIP TC8 working conference on diffusion, transfer and implementation of information technology* , 67–86.

Schmidtler, J., Knott, V., Hölzel, C., & Bengler, K. (2015). Human centered assistance applications for the working environment of the future. *Occupational Ergonomics*, *12*(3), 83–95.

Segil, J. L., Roldan, L. M., & Graczyk, E. L. (2022). Measuring embodiment: A review of methods for prosthetic devices. *Frontiers in Neurorobotics*, *16*, 902162.

Smets, M. (2019). A field evaluation of arm-support exoskeletons for overhead work applications in automotive assembly. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*(3–4), 192–198.

Stirling, L., Kelty-Stephen, D., Fineman, R., Jones, M. L., Daniel Park, B. K., Reed, M. P., & Choi, H. J. (2020). Static, dynamic, and cognitive fit of exosystems for the human operator. *Human factors*, *62*(3), 424–440.

Sultana, T., & Nemati, H. R. (2021). Impact of Explainable AI and Task Complexity on Human-Machine Symbiosis. In *AMCIS*.

Sung, J., Grinter, R. E., & Christensen, H. I. (2010). Domestic robot ecology: An initial framework to unpack long-term acceptance of robots at home. *International Journal of Social Robotics*, *2*, 417–429.

Theurel, J., & Desbrosses, K. (2019). Occupational exoskeletons: Overview of their benefits and limitations in preventing work-related musculoskeletal disorders. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*(3–4), 264–280.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425–478.

de Vignemont, F. (2010). Body schema and body image—Pros and cons. *Neuropsychologia*, *48*(3), 669–680.

de Vries, A. W., Baltrusch, S. J., & de Looze, M. P. (2023). Field study on the use and acceptance of an arm support exoskeleton in plastering. *Ergonomics*, *66*(10), 1622–1632.

Weser, V. U., & Proffitt, D. R. (2021). Expertise in tool use promotes tool embodiment. *Topics in cognitive science*, *13*(4), 597–609.