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Digital Human Modeling Technology in Virtual Reality - Studying Aspects of Users' Experiences

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Abstract. Virtual Reality (VR) could be used to develop more representative Digital Human Modeling (DHM) simulations of work tasks for future Operators 4.0. Although VR allows users to experience the manikin as rather realistic in itself, there are still several aspects that need to be considered when shifting from tasks performed in the real world into a virtual one, adding cognitive and user experience (UX) aspects. Currently, there is limited research of UX in VR. The overall aim was to gain deeper insights into how users' experiences can ultimately help us to improve how VR can aid in DHM. A pilot study examined how users perceived and experienced actions performed by a humanoid hand (manikin) in VR. Users' perceived presence indicates how well they are immersed in the virtual environment, and Proactive eye gaze (PEG) was used to measure the realism of the virtual hand. The obtained findings indicate some potentially surprising outcomes and some tentative explanations for these are discussed. The lessons learned from this pilot will be used as input to a future larger study that continues to highlight how UX aspects can be useful in a DHM context.

Keywords. digital human modeling, virtual reality, UX, proactive eye gaze

1. Introduction

In this paper we address how digital human modeling (DHM) could benefit working environments for future industrial operators interacting with various kinds of enabling technologies in manufacturing. In order to achieve the goals for the industrial operators at the shop floor, DHM provides tools for analyzing physical ergonomics during the whole design and development cycle [1]. DHM tools enable interaction with manikins in the form of digital twins of human operators that provide support to DHM practitioners and users to view, foresee, investigate, plan, and evaluate work tasks and perform risk assessments while still being in the digital world [1].

The usage of Virtual Reality (VR) and digital twins allows both the DHM practitioners and the future human operators to consider and experience the envisioned work tasks and interaction before being physically manifested and situated. There are several benefits aligned with this way of working, e.g., reducing costs, enabling rapid design of work stations and tasks, and more usable DHM tools. However, this approach requires that the

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digital twin is reliable and credible in itself. Although VR allows users to experience the digital twin in a way that is in many ways realistic, there are still several user aspects that ought to be considered when we move from tasks performed in the real physical world into a simulated one. Presence, for instance, aims to address how well a user is immersed in the virtual environment; higher presence means the user feels that the environment is responding authentically (i.e. similar to the non-virtual world) to the users senses and actions [2, 3]. Subsequently, higher presence is linked to higher realism and thus gaining higher validity and credibility in evaluations [3]. A study by Faas et al. [2] found that designers who scored higher on presence and immersion oftentimes scored higher on design performances as well. The authors conclude that presence can be used as an indicator of performance and learning in design-and-build activities. Thus, presence is a method to evaluate how well users adapt to a virtual world. Presence has also been shown to increase when the user's move their body in the virtual world (e.g.[4, 5, 6, 7]).

Eye-tracking systems in VR have become more precise which has made it possible to study various aspects of eye gaze behavior in a virtual environment [8]. In this work, we are investigating proactive eye gaze (PEG) as a way to quantify presence and immersion, thus studying how realistic a VR environment could be. The phenomenon of PEG illustrates a certain kind of eye-hand coordination pattern during object manipulation and action observation, where the eye-gaze behaviors precede hand behaviors [9]. We also argue that DHM tools could be further developed by adding such cognitive aspects, because traditionally the field of ergonomics predominantly addresses the assessment of anthropometry and physical strains on the body in DHM [10, 11, 1]. We use Virtual Reality (VR) to support the development of more representative DHM simulations of work tasks and actions. Our proposed use of PEG in DHM is thus two-fold – measuring the level of realism a specific VR experience provides and offer a potential tool for measuring and/or predicting behaviors of future industrial operators. Our focus in this paper will be the former.

Our primary aim is to perform an initial investigation into how users perceive and experience actions being performed by a humanoid hand (manikin) in VR. Regarding users' perceptions, we want to investigate whether and to what extent users exhibit PEG when observing a simulated agent's hand movements. Regarding users' experiences, we want to understand how the overall user experience (UX) [12] is affected when observing the agent's hand movements in the simulated environment, because limited research of UX in VR exists [13, 14]. Deeper insights into user perception an experience in VR can ultimately help us to gain a deeper understanding of how VR can aid in DHM.

We report findings from a small pilot study that was performed in preparation for an upcoming larger experiment. These findings are tentative and used as input to frame the broader discussion in this paper. While the findings from present pilot should not be interpreted as conclusive results, they represent important steps toward a larger study of the use of VR in DHM tools. We employ an UX approach to enhance the ability of DHM tools to generate realistic and credible simulations and evaluations of bio-mechanical and cognitive ergonomics, including the use of digital twins; thus, supporting the envisioned digital work space for Operator 4.0 [15].

2. Background

Industrie 4.0 is characterized by the recent and rapid advances in digitalization and intelligent autonomous technologies, e.g. internet of things, augmented reality, VR, and collaborative robots that are entering the manufacturing domain [16, 17]. For the manufacturing industry, the intended benefits of this revolution is expected to result in shorter development periods, individualization on demand for the customers, flexibility, decentralization and resource efficiency [16]. One consequence of this revolution is a shift in working environments throughout all aspects of the manufacturing industry towards increasingly advanced digital work spaces.

A central issue of Industrie 4.0's digital work space is the development with respect to Operator 4.0 [15]. Operator 4.0 refers to smart and skilled operators of the future, who are assisted by various kinds of intelligent automated systems that provide sustainable physical and cognitive support, allowing operators to achieve and develop a high degree of cognitive, collaborative, and innovative knowledge and skills - without compromising safety, competitiveness and productivity [15]. Two examples of proposed of Operator 4.0 types that involve augmentations of human capabilities are the Virtual Operator and the Healthy Operator. The Virtual Operator will use various kinds of VR technologies to digitally replicate a production line, work station design, assembly tasks or a manufacturing environment, enabling the operator to interact with various tools, artifacts and robots found in a factory with real-time feedback and reduced risk. Via advanced software, various tools and manual assembly tasks could be transformed into a digital twin world, in which interactive virtual simulations of assembly sequences could be used for designing and evaluating work tasks as well as for training these smart operators in complex assembly tasks. In other words, VR enacts the envisioned 'virtual factory' as an integrated simulation model [15]. The Healthy Operator will be equipped with several wearable devices and trackers that will measure aspects like exercise activity, stress, heart rate and other biometrics as well as location. The Healthy Operator will be able monitor both the physical workload and cognitive workload on specific tasks or during the work-shift, receiving alerts and warnings regarding proper workloads.

However, the future digital work space of Operator 4.0 poses several interrelated challenges, of which two are addressed below [18]. First, the need to enhance the quality of the interaction between humans and autonomous systems in general, and enabling technologies in particular. Second, changes of work roles and work practices due to more advanced forms of human-technology interaction at the shop floor will make work more demanding and flexible, and an interest in human-centered aspects has the potential to promote well-being and professional development in order to be a desired workplace.

However, the envisioned digital work space of Operator 4.0 will not materialize automatically [19, 18]. Of particular note for this paper, it requires careful design and evaluation of future enabling technologies like human-robot collaboration (HRC) systems where the interaction quality between operators and collaborative robots should be experienced positively and well suited to their purposes, being smooth, safe, trustworthy and satisfying to interact with [20, 18]. Taking a human-centered design approach [21] for the envisioned digital workplaces has an important influence to the job satisfaction, safety, and operator well being, which previous research on these topics rarely considered [19]. The fields of human factors/ergonomics, human-computer interaction (HCI), and UX have a great deal in common, although some differences exist. These approaches originate from the human-centered design perspective, having its foundation in the Standard Ergonomics of human-system interaction [21], which has become invaluable to evaluate the quality of human-system interaction in general.

UX in particular is more general than ergonomics because it considers and characterizes *"how users encompass all aspects of the interaction with a service/system or products"* [21, 12, 22]. Usability is a component of UX, but UX also encompasses additional components that go beyond the more instrumental usage of usability in ergonomics and HCI. Usability is defined as: *"the **effectiveness, efficiency** and **satisfaction** with which specified users achieve specified goals in particular environments*, in which **'effectiveness'** is defined as: *"the accuracy and completeness with which specified users can achieve specified goals in particular environments"*, **'efficiency'** is defined as *"the resources expended in relation to the accuracy and completeness of goals achieved*", and **'satisfaction'** as: *"the comfort and acceptability of the work system to its users and other people affected by its use"* [21].

In the above ISO standard [21], there are two additional notes to the above characterization of UX that go as follows: Entry 1: *"Users' perceptions and responses include the users' emotions, beliefs, preferences, perceptions, comfort, behaviours, and accomplishments that occur before, during and after use"*. Entry 2: *"User experience is a consequence of brand image, presentation, functionality, system performance, interactive behavior, and assistive capabilities of a system, product or service. It also results from the user's internal and physical states resulting from prior experiences, attitudes, skills, abilities and personality; and from the context of use"*. This means that it is not possible to guarantee a certain user experience, because it is the outcome of the subjective inner state of a human user. Although, by designing a high quality interaction with the intended users and the usage context in mind it is possible to positively impact the users' experiences.

Hence, UX aspects can be aligned with a broader meaning of topics, changing from pragmatic and hedonic qualities [12], to emotional aspects of the experience when interacting with robots or other enabling technologies [23]. Pragmatic quality refers to fulfilling the so-called "do-goals" of the user, which means that the interactive system makes it possible for the user to reach the task-related goals in an effective, efficient, and satisfying way. Hence, pragmatic aspects relate to the usability component of UX [21]. Hedonic quality refers to the so-called "be-goals" of the user, which relates to psychological, subjective and emotional needs that can have a great impact on how enabling technologies are experienced [22]. A central activity in UX is to extract, identify, and characterize UX goals [19, 12]. UX goals are high-level objectives, which should be driven by the representative use of an envisioned interactive system. The UX goals should identify what is important to the users, stated in terms of anticipated user experience of an interaction design. The UX goals are expressed as desired effects, for example the interactive artifact's ease-of-use, perceived safety, quality-of-use, acceptance, immersion, trust, or emotional arousal [12]. It should be emphasized that the major focus of study in UX is not the user's behavior as a response of a certain condition, as commonly done in experimental psychology. Instead, the focus is on several aspects of the users' experiences of interacting with the robot or any kind of enabling technologies in a particular context to achieve a certain task/goal or fulfill a need, which is a significant difference.

The kinds of enabling technologies required for Industrie 4.0 and Operator 4.0 are not yet fully realized, and there is a need to include an understanding of Operator 4.0

early in the analysis and design phases. One way to achieve this is through visualization software early in a design process in order to optimize the design of a product. With regards to DHM software, it can be argued that along with a focus on realistic digital simulations of the physical human bodies, user context and cognition should also be considered to be important aspects of DHM [10, 11]. In the specific case of HRC development, DHM could be used to support and assess both physical and cognitive aspects of the future digital workplaces which include HRC systems. The proposed UX perspective may improve insights provided by DHM software regarding work performance, ergonomics, cognitive and physical fatigue, trust and expectations, and potential errors [24], which are aligned with several UX perspectives. This could substantially improve the effectiveness of DHM tools which focus almost exclusively on bio-mechanical constraints. Currently, most DHM tools simulate tasks and actions for a specified work situation given a set of physical and bio-mechanical constraints, without consideration of the emergence of cognitive constraints such as cognitive goals and intentions [10]. For example, insights from embodied cognitive science have revealed that cognition is the emergent result of complex systems of agent-environment interaction where perception, bio-mechanics, environment, and action mutually constrain one another [25].

However, prior work has shown that using VR technology itself may result in negative user experience, and ultimately may produce results that do not match real-world behaviors. As pointed out by Papadimitriou [13], UX in VR both “includes the aspects of the experience and is influenced by them simultaneously.” The author argues that the increased popularity of VR has resulted in efforts to design and evaluate which aspects and characteristics influence a positive user experience in VR environments, although limited research has been conducted so far.

While rapid development of VR systems as a part of Industrie 4.0 has occurred in recent years, it is important to be aware of the ways in which VR experiences do not completely match reality, just as it is important to understand how digital or physical models of tasks, workstations or products may not match actual implementations. Hence, the user’s performance and experience must be interpreted and understood in relation to the specific VR conditions and digital context. Commonly identified potential problems, now and then, with VR include head-mounted display weight or fit, limited motion tracking and/or control, system latency, lack of visual realism, limited haptic and/or non-visual feedback, nausea, and lack of presence [24, 26, 13, 27]. The latter concept – presence is commonly defined as the feeling of "being there" in a virtual environment [3]. Presence is closely linked to the concept of immersion and as there is no consensus on the definitions between these concepts, we will take the stance that presence is achieved by way of immersion [3]. The level of presence in a VR environment has been shown to correlate with how much interaction and movement is being expressed by the user[4, 5].

Presence by immersive VR systems has been studied since the conception of VR (for a fuller review on presence in VR see [3, 28, 3]). As early as 1998, Slater et al. [4] saw how participants initially viewed the VR environment as a screen with low presence, but once the users realized that they could move around in VR, they experienced a higher presence as if they were “stepping through” the screen. In that study participants were asked to bend down and to rotate their heads in order to make them aware of their body in relation to the environment. The study concluded that increased body movements increase the presence in VR. Presence has continued to be of interest in the field of VR. More recently, Lee et al. [5] showed that presence was assessed higher when participants could interact more within the VR environment by being more embodied, i.e. using their own legs to walk around in the environment in contrast to using a gamepad control method or hand-based walking control interface for walking.

While the specifics of embodied theories of cognition can at first seem overwhelming in a DHM context, there are specific hypotheses which should be relatively easy to apply. In this paper we specifically focus on the idea that cognition is for action and anticipation of action. PEG is a way to quantify how realistic a VR environment may be. PEG is observed both in nonsocial settings, where eye-gaze precedes one's own actions and in social settings where eye-gaze precedes the actions of a co-actor. Moreover, PEG is considered to be an important mechanism for producing the kind of smooth and intuitive human-robot interaction [29] that is the basis for successful HRC in Industrie 4.0. While PEG phenomena are relatively well established in tightly constrained research contexts, the extent to which PEG occurs in naturalistic and repetitive conditions similar to manufacturing and assembly contexts is not yet well explored. In order to better understand PEG in these contexts and provide relevant insights for DHM of these phenomena, we investigated PEG in a VR environment.

3. Method: Pilot study

VR can be useful in a DHM context to test worker environments virtually before building the physical instantiation. With this in mind, we present a pilot study investigating PEG in virtual environments in order to understand how well PEG behaviors in VR environments match the PEG behaviors in physical environments. We want to stress that the study presented here is a pilot and is only a indicative of our future larger experiment. In this within-subject pilot study, participants observed a virtual humanoid hand that performed several kinds of reaching and grasping tasks (Fig. 1). This movement is inspired by a pick and place action, where an actor is, as the name suggests, picking up and placing an object. In this case, the participants observed an object being picked up and placed rather than performing the action themselves.

Procedure After the participants (N=5) signed a consent form, they were instructed to step into the VR room where they would sit in front of a table and observe an object moving in front of them. They were asked to simply observe the scene until the experiment ended. After the instructions, the participants put on the HTC Vive Pro Eye. The session started by calibrating the participant's eye gaze, followed by starting the experiment. Before the experiment began, the participant was re-centered in the virtual environment to ensure that all participants had the same initial view point of the stimulus objects. In the experiment, a cylindrical object moved either by itself (self-propelled condition), or was moved by a virtual hand (humanoid hand condition), 20 times each with a counterbalanced starting order. Both conditions were driven by the same prerecorded biological motion profiles. The experiment took about 10 minutes in total.

Material The virtual environment was developed in Unity3D 2018 LTS and is illustrated from the participant's point of view in figure 1. The virtual environment was displayed on an HTC Vive Pro Eye with a display frequency of 90 Hz. Position and rotation of the headset were tracked at 90 Hz and eye-tracking was recorded at 120 Hz. Eye tracking data was provided via the HTC SRanipal v1.1.0.1 SDK. SRanipal provides processed eye values relative to the headset with a delay from eye record to provided data due to

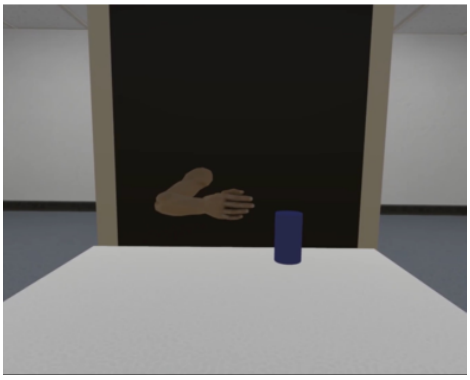

Figure 1. The field of view for the participants in VR with the humanoid hand condition. The humanoid hand reaches out from the black box and moves the object.

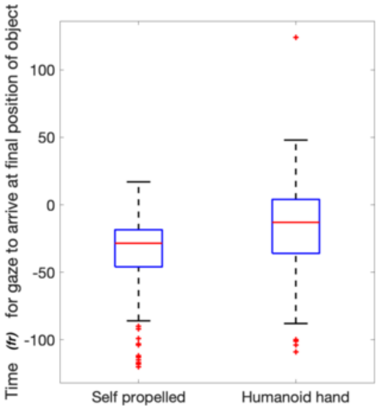

Figure 2. The box plot to the right illustrates the amount of time (fr) between the arrival of the gaze and the object at its final position.

processing of approximately 16.6 ms. As a result, given Unity's 90 Hz frame rate for the HTC Vive, eye tracking values have an expected latency of up to 33.2 ms. Focus objects were calculated in real-time based on the current position and orientation of the headset and an average gaze vector provided by the SRanipal SDK. The stimulus motions were driven by prerecorded data of a single individual engaged in an object pick and transport task, inspired by a pick and place action. The positions and orientations of both the individual's hand and the transport object were recorded at 90 Hz using two HTC Vive Trackers (2018). For playback, position and orientation were used for the transport object. However, due to technical challenges, only position was used to drive the stimulus hand. The stimulus arm was a part of the First Person Generic Arms Pack (BlocBros Studio) Unity asset package and arm kinematics were driven by the FinalIK (RootMotion) Unity asset package. The collected data included gaze location on a plane relative to the stimulus objects as well as comments gathered from the participants afterwards.

4. Findings

A within-subject analysis of repeated measure (ANOVA) was conducted to compare the two conditions for the time (in frames) between the arrival of the gaze and the object at its final position. The analysis indicated that the onset activation of PEG was significantly earlier in the self-propelled condition ($F(1,4) = 25.12$, $P < 0.01$) than in the humanoid hand condition. This is illustrated in figure 2: a strong negative value implies strong PEG and a positive value means that the first gaze onto the object came after the object was placed in its final position. Interestingly, these findings suggest the opposite of previous results on PEG from e.g., Flanagan and Johansson [9] and Falck-Ytter et al. [30]. However, we are aware that any interpretation of the findings is tentative, given the sample size and novelty of the particular VR implementation in this context.

5. Discussion

The analysis of the collected data from the pilot study suggests some potentially surprising findings; PEG was elicited later when a humanoid hand was present rather than when no hand was present. We provide some tentative explanations for the initial findings. Although VR can enact a strong sense of presence, it involves numerous modifications, simplifications, and omissions of real world features and thus, should not be uncritically considered to be relevantly similar to real world stimuli. It is therefore possible that there is a difference between PEG in the real world and in VR. This relates to both the VR environment as a whole and the specific profile of the hand condition. For example, previous studies have suggested that a more natural hand interaction in VR, with complex hand grasp- and rotation options, resulted in a higher sense of presence. In contrast, a less natural hand interaction, with one default grasp option and one rotation option, resulted in participants scoring lower on presence in VR [7]. A similar phenomenon may be occurring here such that the virtual hand in VR was experienced differently than a movement is done by a real human hand. Perhaps the issue lies in how this hand is interpreted: not a real hand but one closely similar to it. This could result in a visual disturbance or discomfort (e.g. uncanny valley) when viewing this virtual hand.

Turning to the UX perspective, one participant reported that the head-mounted display was experienced as narrowing the field of vision, causing some degree of vertigo, and the feeling of wearing cyclops. There was also some difficulty to get the head-mounted display to fit comfortably as indicated by some of the participants. Experiences of vertigo and possible limited presence are related to being situated in a virtual environment by the users and head mounted display discomfort are related to experienced comfort and satisfaction of the VR equipment.

Although we cannot say with confidence that the VR setting is the reason for the current direction of these findings, we believe it is important to not discount the possibility that some aspects of the virtual presentation and the task of the participant had an impact on the current findings. However, it is not totally clear whether this impact is the outcome of how the users perceived and experienced the virtual humanoid's hand movements, not manipulated the object themselves, or the fact of being situated in a virtual world, or a combination of all. It is obvious that the virtual hand and its movements and the VR environment are not isomorphic to reality, i.e, they are not a one-to-one match, and therefore some relevant dimensions may be missing or inadequately represented and realized in our study (see Kolbeinsson et al. [31] for a discussion on fidelity, representativeness, and immersion in simulations). A UX evaluation of these aspects may provide more systematic insights into their impact on user behavior and experience.

VR has been increasingly popular in recent years, and has contributed to making development cycles shorter, safer, and more flexible. It has also been a popular tool for many industries to train their workers in a variety of workplace domains, e.g. safety, onboarding, and running scenarios [3]. It is important to understand the users' experience of VR and specifically how the VR equipment and being situated in the VR environment potentially can influence how users understand, enact and act in the artificial world. By employing a more systematic UX approach, a deeper understanding could be gained how new technology and new modes of interacting with technology, not only results of some after aspects of the users' visual and cognitive behaviors [32], but also how VR supports users to achieve their aims and goals.

In parallel to the present work, we have conducted a study of eye gaze behavior in a pick and place task performed in VR [33]. Participants were asked to move around in a VR environment and pick up objects from a table and place them in a bin. In contrast to the findings of the present work, Billing et al. [33] conclude that the eye gaze behavior of participants executing the pick and place task in VR has many similarities to that of a pick and place action performed in real life. One important difference between these studies was that Billing et al. [33] investigated a task that participants executed themselves, while in the present work we investigated a setting where participants were observers. As discussed in the introduction, presence increases with greater interaction with a virtual environment [4, 5, 6]. As such, it is likely that the level of presence experienced by participants is higher when executing a task [33], compared to the observer condition used in the present work. This could be interpreted as an indication that the level of presence may directly influence the results of evaluations performed in VR, and to what extent these results are transferable to tasks performed in real life. We believe presence should therefore be addressed through UX evaluation in our future study and could aid other VR studies in order to understand both the user experience and how the user experience affects results.

For our future study, we intend to build on our pilot with a larger sample size and to systematically evaluate the UX perspective. The design will change in three ways. First, to avoid participants getting more information in the hand condition, the reaching for the object will be removed and only the transport of the object will be included. As a hand is not visible in the self-propelled condition, there is no reach and grasp action here compared to the hand condition. This inconsistency might also give enough time for the participants to observe incongruences, such as the lack of preshape of the hand and hand rotation. Second, the end position of the object will be marked on the table as this visual information could elicit faster PEG. This is commonly used in PEG studies and is therefore reasonable to add in order to compare our results to similar studies. Lastly, the conditions will be expanded with both one more hand profiles and one more movement profile. For the hand profiles, we will explore a third condition: a robot hand which has been previously shown to elicit PEG in a real world human-robot interaction [29]. Furthermore, besides the biological motion that was included in our pilot, we intend to add a mechanical motion stimuli. Research on point light displays has indicated that biological motion, as opposed to visual cues, elicit PEG [34].

Regarding UX evaluation in VR, it has been argued that traditionally established evaluation approaches may not fit or are irrelevant, because of the unique ways that users can interact with the content and do tasks via VR technologies. Papadimitriou [13] points out that the increased popularity of VR has resulted in efforts to design and evaluate which aspects and characteristics influence a positive user experience in VR environments, although limited research has been conducted so far. Indeed, Stanney et al. [35] have developed a taxonomy of criteria and heuristics called the Multi-criteria Assessment of Usability for Virtual Environments (MAUVE), with the aim to systematically focus on usability and UX aspects when designing and evaluating VR environments. The MAUVE taxonomy includes the following criteria: 1) wayfinding, 2) navigation, 3) object selection and manipulation, 4) visual output, 5) auditory output, 6) haptic output, 7) simulator-sickness, 8) engagement, 9) presence, and 10) immersion. A tentative way of systematically evaluating users' perceptions, expectations and experiences of the hand simulations in VR may be to use a modified version of the MAUVE taxonomy, focusing on the comfort, presence, and representativeness aspects of the experience, where both quantitative and qualitative data will be collected. Furthermore, we also want to evaluate the dimensions of the users' perceptions and experiences of being situated in the VR environment as well as their experiences of virtual hands with different profiles and grasping movements. Another significant modification to the above work of UX evaluation in VR is that we will include pragmatic and hedonic UX goals for these aspects and dimensions, because this fundamental aspect of conducting proper UX evaluation is lacking in the works by Papadimitriou [13] and Stanney et al. [35].

Furthermore, Stephanidis et al. [14] have recently identified seven grand challenges for HCI, where some main research issues are addressed that consider living and interacting in technology augmented environments. In particular, they highlight the need to develop proper UX evaluation in VR environments towards the assessment of VR attributes beyond subjective assessments only, the need to design VR environments that achieve realistic user experience, and finally to support social interaction in the VR environment. We hope to contribute to some of these identified issues in our upcoming work of using the digital twin approach when continuing our work on studying UX aspects of digital human modeling technology.

6. Conclusion

The initial intent with the work presented in this paper was to present the obtained results from the larger study, including the experiment and the proposed UX evaluation, but due to the unforeseen covid-19 situation across the globe, it became impossible to perform. Our pilot study can therefore be seen as lessons learned.

To conclude, as we move towards Industrie 4.0, research in DHM is advancing rapidly in order to accommodate future workers in the digital work space. Not only is it necessary to consider changes in physical environments and actions, but it is also important to consider how these changes are interconnected with some aspects of human cognition. In this context, the use of VR in DHM tools enables ergonomics and other specialists involved in the design of future workstations for Operator 4.0, to simulate and evaluate the worker environment of the digital work space of the factories of the future virtually before building the physical instantiations. This way of working may be more cost efficient and faster than the traditional way of working as well as increasing the well-being of the operators. We therefore suggest that a more diverse use of methods and taking a UX approach in DHM will benefit the field as a whole, and the future Operators 4.0 in the envisioned digital work space will benefit even more.

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References

[1] Raschke U, Cort C. Siemens Jack. In Scataglini, Paul (Eds.). DHM and Posturography. Academic Press; 2019.

[2] Faas D, Bao Q, Frey D, Yang M. The influence of immersion and presence in early stage engineering designing and building. Artificial Intelligence for Engineering Design, Analysis and Manufacturing. 2014;28(2):139–151.

[3] Skarbez R, Brooks F Jr, Whitton M. A survey of presence and related concepts. ACM Computing Surveys (CSUR). 2017;50(6):1–39.

[4] Slater M, McCarthy J, Maringelli F. The influence of body movement on subjective presence in virtual environments. Human Factors. 1998;40(3):469–477.

[5] Lee J, Kim M, Kim J. A study on immersion and VR sickness in walking interaction for immersive virtual reality applications. Symmetry. 2017;9(5):78.

[6] Hameed A, Perkis A. Affects of Perceived-Actions within Virtual Environments on User Behavior on the Outside. In: 2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX); 2020. p. 1–6.

[7] Rosén J. The importance of natural hand interaction in virtual reality [master thesis]. Lund University; 2017.

[8] Clay V, König P, König S. Eye tracking in virtual reality. Journal of Eye Movement Research. 2019 4;12(1).

[9] Flanagan J, Johansson R. Action plans used in action observation. Nature. 2003;424(6950):769–771.

[10] Billing E, Hanson L, Lamb M, Högberg D. Digital Human Modelling in Action. In: SweCog 2019, the 15th SweCog conference, Umeå, Sweden, November 7-8, 2019. University of Skövde; 2019. p. 25–28.

[11] Thorvald P, Högberg D, Case K. Applying cognitive science to digital human modelling for user centred design. International Journal of Human Factors Modelling and Simulation. 2012;3(1):90–106.

[12] Hartson H, Pyla P. The UX Book: Process and guidelines for ensuring a quality user experience. Elsevier; 2012.

[13] Papadimitriou D. User experience evaluation in virtual reality [master thesis]. Tampere University; 2019.

[14] Stephanidis C, Salvendy G, Antona M, Chen JY, Dong J, Duffy VG, et al. Seven HCI grand challenges. International Journal of Human–Computer Interaction. 2019;35(14):1229–1269.

[15] Romero D, Bernus P, Noran O, Stahre J, Fast-Berglund Å. The operator 4.0: human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. In: IFIP international conference on advances in production management systems. Springer; 2016. p. 677–686.

[16] Lasi H, Fettke P, Kemper H, Feld T, Hoffmann M. Industry 4.0. Business & information systems engineering. 2014;6(4):239–242.

[17] Kagermann H, Helbig J, Hellinger A, Wahlster W. Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group. Forschungsunion; 2013.

[18] Kaasinen E, Schmalfuß F, Özturk C, Aromaa S, Boubekeur M, Heilala J, et al. Empowering and engaging industrial workers with Operator 4.0 solutions. Computers & Industrial Engineering. 2020;139:105678.

[19] Kaasinen E, Roto V, Hakulinen J, Heimonen T, Jokinen J, Karvonen H, et al. Defining user experience goals to guide the design of industrial systems. Behaviour & Information Technology. 2015;34(10):976–991.

[20] Alenljung B, Lindblom J, Andreasson R, Ziemke T. User experience in social human-robot interaction. In: Rapid Automation: Concepts, Methodologies, Tools, and Applications. IGI Global; 2019. p. 1468–1490.

[21] ISO 9241-210: 2019. Ergonomics of human system interaction-Part 210: Human-centred design for interactive systems (formerly known as 13407). Geneva, CH: International Standardization Organization (ISO). Switzerland; 2019.

[22] Hassenzahl M. The Thing and I (Summer of'17 Remix). In: Funology 2. Springer; 2018. p. 17–31.

[23] Lindblom J, Alenljung B, Billing E. Evaluating the User Experience of Human–Robot Interaction. In: Jost C. et al. (eds) Human-Robot Interaction. Springer Series on Bio- and Neurosystems. vol. 12. Springer, Cham; 2020.

[24] Leskovskỳ R, Kučera E, Haffner O, Matišák J, Rosinová D, Stark E. A Contribution to Workplace Ergonomics Evaluation Using Multimedia Tools and Virtual Reality. In: 2019 Federated Conference on Computer Science and Information Systems (FedCSIS). IEEE; 2019. p. 317–326.

[25] Gazzaniga M, Ivry R, Mangun G. Cognitive Neuroscience: The Biology of the Mind. 4th ed. W. W. Norton & Company; 2014.

[26] Nichols S. Physical ergonomics of virtual environment use. Applied Ergonomics. 1999;30(1):79–90.

[27] Wilson J. Virtual environments and ergonomics: needs and opportunities. Ergonomics. 1997;40(10):1057–1077.

[28] Mütterlein J. The three pillars of virtual reality? Investigating the roles of immersion, presence, and interactivity. In: Proceedings of the 51st Hawaii International Conference on System Sciences; 2018. p. 1407–1415.

[29] Sciutti A, Bisio A, Nori F, Metta G, Fadiga L, Sandini G. Anticipatory gaze in human-robot interactions;. Gaze in HRI from modeling to communication" workshop at the 7th ACM/IEEE international conference on human-robot interaction, Boston, Massachusetts, USA. 2012.

[30] Falck-Ytter T, Gredebäck G, von Hofsten C. Infants predict other people's action goals. Nature Neuroscience. 2006 jul;9(7):878–879.

[31] Kolbeinsson A, Thorvald P, Lindblom J. Coordinating the interruption of assembly workers in manufacturing. Applied ergonomics. 2017;58:361–371.

[32] Szpak A, Michalski SC, Saredakis D, Chen CS, Loetscher T. Beyond Feeling Sick: The Visual and Cognitive Aftereffects of Virtual Reality. IEEE Access. 2019;7:130883–130892.

[33] Billing E, Bampouni E, Lamb M. Automatic Selection of Viewpoint for Digital Human Modelling;. To appear in Advances in Transdisciplinary Engineering (ATDE). ISSN 2352-7528, IOS Press. 2020.

[34] Elsner C, Falck-Ytter T, Gredebäck G. Humans Anticipate the Goal of other People's Point-Light Actions. Frontiers in psychology. 2012;3:120.

[35] Stanney M K, Mollaghasemi M, Reeves L, Breaux R, Graeber A D. Usability engineering of virtual environments (VEs): identifying multiple criteria that drive effective VE system design. International Journal of Human-Computer Studies. 2003;58(4):447–481.