Effects of Presence on Human Performance and Workload in Simulated VR-based Telerobotics

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ABSTRACT

The Sense of Presence (SoP), which is typically described as the sensation of "being there", is an influential phenomenon that can be elicited in virtual environments. It becomes particularly important in Virtual Reality (VR)-based platforms for remote work or assistance (e.g., digital twins), whereby the quality of the interactions between the human and any virtual object determine the industrial performance and well-being of the operators. While SoP is typically assumed to have a positive impact on task performance, and also to affect mental workload, systematic investigations addressing this matter in the telerobotics field, also leveraging a mixed-method approach, are missing. We here covered these aspects by analyzing the effects of SoP on users' performance and workload during simulated teleoperation of an industrial robotic arm in VR. Our participants guided the robot through a pick-and-place task via different control modalities and under different task loads. We operationalized the users' performance in terms of operation times at the pick-and-place task; the explicit workload was inferred via self-report, while the implicit workload was deduced from the users' pupil size variations. Our results demonstrate a positive effect of the SoP on task performance, suggesting higher efficiency when feeling a higher SoP. Little to no impact of the SoP on the users' workload was observed, which however is worthy of further investigation.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; • **Hardware → Emerging interfaces**.

KEYWORDS

human-robot interaction, virtual reality, industry 5.0, presence, human factors

ACM Reference Format:
Federica Nenna, Davide Zanardi, and Luciano Gamberini. 2023. Effects of Presence on Human Performance and Workload in Simulated VR-based Telerobotics. In *Proceedings of the 16th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '23), July 05–07, 2023, Corfu, Greece.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3594806.3594856

PETRA '23, July 05–07, 2023, Corfu, Greece

ACM ISBN 979-8-4007-0069-9/23/07.
https://doi.org/10.1145/3594806.3594856

1 INTRODUCTION

In all Virtual Reality (VR) environments, the sensation of "being there" is what makes VR technologies engaging and valuable methods to simulate the real world. This sensation is called Sense of Presence (SoP), and it is typically considered a basic requirement for designing compelling and engaging virtual environments [8]. According to the definition of [26], the SoP can be described as a binary experience that links perceived self-location and, in most cases, perceived action possibilities to a mediated spatial environment. The binary experience can be understood as the participant's choice to be in either the virtual environment or the physical place where the simulation takes place [23]. During this experience, mental capacities are defined by the mediated environment instead of reality. Consequently, the quality of virtual environments plays a crucial role in affecting the users' psychophysiological states and enhancing the SoP [22]. Feeling a high SoP assumes particular relevance in VR-based working contexts, in which the virtual environment becomes the actual workplace and the operators are called to interact with digitalized robots and machines from a remote site (e.g., digital twins). Those examples fall into the teleoperation or telerobotics sectors, whereby the interactions between the human and any virtual object determine the performance and well-being of the operators (e.g., [3]).

While digital manufacturing is increasingly gaining attention, using VR technology for telerobotics has become one of the most successful innovations in the new Industry 5.0. With VR, users can interact with a simulated environment in a way that closely resembles the real world, which can greatly enhance their ability to perform tasks. In addition, robot teleoperation allows users to remotely control robots, which can be especially useful in hazardous or difficult-to-reach environments [14]. In such situations, by having a well-established SoP, employees can avoid confusion and errors while performing work tasks, ultimately resulting in enhanced productivity [7].

A few studies have assessed the SoP in telerobotics contexts, and most of them report that the ability to perform physical movements or whole-body-based interactions helps increase the SoP [1, 24]. To mention a few examples, [10] observed how allowing users to physically walk in their own space and interact with a VR-teleoperated robot enhanced the operator's perceived SoP. Interestingly, [6] revealed a positive impact of SoP on performance. They provided visual aids on a work area while guiding a robotic arm in VR with the intent of improving the teleoperators' SoP and performance. They showed that an increased SoP, as well as adopting a first-person perspective, helped shorten the learning curve, allowing the operators to become proficient in the teleoperation after shorter familiarization with the system. Furthermore, the visual cues superimposed on the VR robotic simulation helped in enhancing the teleoperation performance. Despite this evidence, there are still unanswered questions regarding the impact of SoP on human performance and workload in telerobotics. To gain a better understanding of this matter, a concise overview of the current literature on the relationships among SoP, performance, and workload is provided as follows.

1.1 Sense of presence and Performance

The literature on the relations between the SoP and the users' performance shows mixed results. [20] modulated the SoP by using various degrees of simulation vividness during a VR-based pick-and-place task. The findings revealed that the level of vividness, and subsequently, the level of SoP, did not affect users' performance. However, the SoP was significantly correlated with heart rate. The authors thus argued that some physiological measures could be used as an accurate indicator of SoP in virtual environments. In [7], participants were engaged in a wheel-changing task in low-immersive VR, during which relevant multi-sensory information (visual, audio, tactile) was provided to represent cues that are not typically available in conventional simulations. The results showed that the more multi-sensory feedback was added during the task, the more participants performed the task faster and reported an increased SoP. Different studies also observed a direct relation between the SoP and the efficiency of learning processes. For instance, according to [2], a high SoP can increase the learning process in virtual environments. Interestingly, [11] report how the difference in learning performance between immersive VR conditions and traditional 2D environments is more dependent on the SoP rather than the use of VR itself. On the other hand, other researchers have found a decrease in learning performance as SoP increases [16]. The author suggested that, as compared to conventional media, cutting-edge high-immersion VR can increase processing demands and cognitive workload leading to a decrease in knowledge acquisition.

1.2 Sense of presence and Workload

While several studies have pointed out the benefits of highly immersive VR, others warn about the intense cognitive load that such technologies might elicit on users. In the gaming and cinema sectors, there are examples that demonstrate an increase in cognitive load when the level of immersion - and thus SoP - is enhanced [5, 19]. Similar effects can be found in other research areas as well. [15] assessed the impact of different sensory elements, such as viewpoint, auditory cue type, and visual information, on SoP, workload, and performance during a virtual simulated basketball game. The results showed that, while there was no relation between SoP and performance, the SoP positively correlated with the self-reported mental workload at the NASA-TLX questionnaire. In this case, using multiple sensory channels in a virtual environment probably increased the SoP, but at the cost of a higher mental workload. In [9], participants executed a driving simulation task under dual-task in a virtual environment and investigated the relative effects on the SoP. The study found that neither driving nor dual tasks had any adverse or beneficial impact on the SoP. Nonetheless, there is also evidence of the positive effects of SoP on workload. For instance, during soldier training conducted in VR, the SoP strongly and negatively correlated with the frustration dimension of the NASA-TLX questionnaire [13]. The authors hypothesized that, in these cases, a higher level of SoP directed attention away from self-thoughts about their own performance, lowering the sense of frustration during the task execution. Conversely, those who experienced a lower level of SoP may have focused more on their performance, resulting in a greater experience of frustration. Overall, the relation between SoP and workload is still to be clarified, particularly in the telerobotics field, where such relation might have even greater implications for the operators acting in VR.

2 OUR STUDY

Based on the literature, the impact of the SoP on workload and performance is still unclear. First, the domain of the studies unfolded above are varied, and only a few studies focus on the telerobotics domain [6, 20]. Furthermore, most of the studies deducted the workload levels from self-report scales [9, 13], which we consider as *explicit workload*, as it is explicitly felt and reported by the participant. Oppositely, to the best of our knowledge, there is no study investigating the relation between SoP and the levels of *implicit workload*, as inferred from physiological parameters that are not under the direct control of the user. In this view, [20] found a relation between SoP and heart rate, suggesting that the level of SoP might affect implicit physiological parameters; however, this question remains hypothetical. By covering these aspects, we here explored the relations between SoP, performance, and workload in participants driving an industrial robotic arm simulation through a pick-and-place task in VR. Specifically, we leveraged the operation times at the pick-and-place task as a performance measure, the pupil size variations throughout the task execution as an index of implicit workload, and the responses at the NASA-TLX questionnaire [12] as an index of the explicit workload.

3 METHODS

3.1 Participants

Our sample was composed of 18 participants (9 females). The age mean was 26.33, the SD was 2.02. All of them voluntarily took part in the experiment without monetary compensation, after signing informed consent. They all reported having normal or corrected-to-normal visual acuity only via contact lenses, normal color vision, and no current or past neurological or psychiatric problems. The experimental protocol was approved by the local ethics committee, and the study was conducted following the principles of the Declaration of Helsinki.

3.2 Technical set-up

Each participant was equipped with an HTC Vive Pro Eye headset, which is endowed with an integrated eye-tracking system. The virtual environment (see Figure 1) was programmed in Unity (version 2019.4.18f1). The VR headset was connected to an MSI GT63 Titan

8RF laptop, where data were automatically saved at the end of each task.

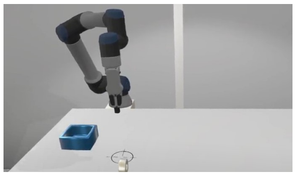

Figure 1: An overview of the virtual environment from the participant's point of view

3.3 Experimental procedure and tasks

The methods adopted for this experiment are thoroughly explained in [18]. Thus, we provide only a brief explanation of the experimental task and procedure; for more detailed information, see [18]. After completing questionnaires about demographics and individual expertise, all participants underwent a training session to familiarize with the tasks. The experimental session then consisted of 5 tasks presented in a random order, namely an arithmetic task and a pick-and-place task executed via controller buttons (button-based control system) and physical actions (action-based control system), and under low (single-task) and high mental demands (dual-task, simultaneously with the arithmetic task). After each task, participants completed the NASA-TLX questionnaire [12] for measuring workload, while right after the last task, they completed the MEC-SPQ questionnaire for measuring the sense of presence [25]. For the latter, they were asked to rate their sense of presence in relation to the whole VR experience.

3.4 Measures and statistical analysis

Specifically for this investigation, we focused on the participants' responses at the MEC-SPQ [25] that indicated their sense of presence. The absolute presence values ranged from 1 (min) to 5 (max) on a Likert scale in each questionnaire dimension. After scaling the scores to fit a 0-1 scale, three groups were created: participants with a presence score ranging from 0 to 0.33 formed the *Low* presence group (n = 5), those ranging from 0.34 and 0.66 formed the *Medium* presence group (n = 6), and those higher than 0.67 formed the *High* presence group (n = 7).

We then leveraged the operation times as a performance measure (i.e., the time needed for completing the pick and the place actions). Furthermore, we analyzed the pupil size variations throughout the pick-and-place task as an index of implicit workload [17, 18], and the responses at the NASA-TLX questionnaire [12] as an index of the explicit workload. The eye-tracking data were processed as described in [18]. As the SoP referred to the whole VR experience, which included 5 tasks, we here averaged the operation times, pupil size variations and NASA-TLX score over the five tasks as well.

For analyzing the data, we used Generalized Linear Models (GLMs) from *lme4* package [4] in Rstudio [21]. For each measure, the appropriate model was chosen after fitting the data through the function *descdist()* of the package *fitdistrplus*. The model analyzing the operation times included the factors Presence Level (i.e., Low, Medium, High) and Task Phase (i.e., Pick, Place). The analysis of the pupil size variations was conducted over the factors Presence Level, Task Phase and Window (from 1 to 6), to observe possible differences in pupil size variations throughout the task execution. Finally, the analysis of the NASA-TLX was conducted on the factors Presence Level and Item (i.e., Mental demand, Temporal Demand, Physical demand, Performance, Effort, Frustration).

4 RESULTS

4.1 Performance (operation times)

A significant effect of Presence (X^2 = 12.78, p < 0.01) and of Task Phase (X^2 = 224.8, p < 0.0001) emerged when analyzing the operation times (X^2 = 12.75, p < 0.01). Furthermore, their interaction also reached the significance level (X^2 = 12.44, p < 0.01). Post hoc tests of interest revealed significant differences between the Low presence and the High presence groups both in the Pick (p<.05) and Place phases (p<.001) and between the Low presence and the Medium presence groups only in the Place phase (p<.05). Descriptive statistics are reported in Table 1 and results are resumed in Figure 2.

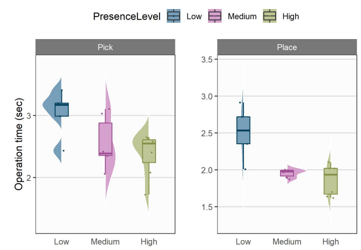

Figure 2: Operation times (sec) in the pick-and-place task divided by Presence Level

4.2 Implicit workload (pupil size variation)

The model analyzing the effects of Presence on the Pupil size variations did not yield a significant main effect of Presence (X^2 = 5.24, p = .07). However, the full interaction between Presence, Task Phase and Window was significant (X^2 = 79.48, p < 0.0001). For this investigation, we were particularly interested in analyzing the post hoc contrasts between the different Presence levels within each Task Phase and Window. Such post hocs revealed that the pupil size variations did not differ between the Presence levels in any of the Task phases or Windows (all p > .05), except for the last Window (i.e., six) of the Place phase, where the pupil size variation of those who were part of the Medium presence group was significantly higher compared to the Low presence group (Figure 3).

4.3 Explicit workload (NASA-TLX questionnaire)

When analyzing the effects of Presence on the NASA-TLX questionnaire score (Figure 4), only the factor Item reached the significance threshold (X^2 = 33.15, p < .0001), while the factor Presence (X^2 = 4.26, p = .11) and its interaction with Item (X^2 = 14.09, p = .16) were not significant.

Table 1: Descriptive statistics for all measures divided by Presence levels

			Presence Levels: Low *mean (SD)*	Presence Levels: Medium *mean (SD)*	Presence Levels: High *mean (SD)*
Operation times (sec)	*Pick*		3.05 (2.28)	2.56 (1.88)	2.37 (1.67)
	Place		2.51 (1.55)	1.95 (1.05)	1.86 (1.02)
Pupil size variation (mm)	*Pick*	*wnd 1*	0.001 (0.07)	0.002 (0.05)	0.0007 (0.06)
		wnd 2	0.009 (0.12)	0.022 (0.09)	-0.002 (0.11)
		wnd 3	0.001 (0.17)	0.032 (0.13)	-0.01 (0.15)
		wnd 4	-0.018 (0.19)	0.027 (0.15)	-0.02 (0.16)
		wnd 5	-0.045 (0.20)	0.016 (0.15)	-0.04 (0.17)
		wnd 6	-0.070 (0.23)	0.002 (0.16)	-0.06 (0.19)
	Place	*wnd 1*	0.001 (0.06)	0.003 (0.05)	-0.0003 (0.05)
		wnd 2	0.012 (0.11)	0.028 (0.08)	0.0009 (0.09)
		wnd 3	0.007 (0.16)	0.043 (0.12)	0.002 (0.14)
		wnd 4	-0.005 (0.18)	0.051 (0.14)	0.002 (0.15)
		wnd 5	-0.022 (0.20)	0.053 (0.15)	0.006 (0.16)
		wnd 6	-0.036 (0.23)	0.053 (0.17)	0.017 (0.17)
NASA-TLX questionnaire (1-20)	*Mental Demand*		11.2 (6.83)	8.5 (6.59)	8.57 (6.78)
	Temporal Demand		8.45 (4.05)	6.46 (4.49)	3.79 (0.71)
	Physical Demand		10.7 (5.54)	8.42 (5.62)	11.4 (6.39)
	Performance		9.05 (5.65)	8.17 (6.57)	8.96 (7.53)
	Effort		12.1 (3.93)	9.71 (6.02)	11.0 (6.47)
	Frustration		7.5 (6.03)	5.33 (4.35)	6.5 (6.15)

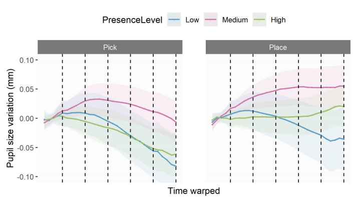

Figure 3: Pupil size variation (mm) in the pick-and-place task divided by Presence Level

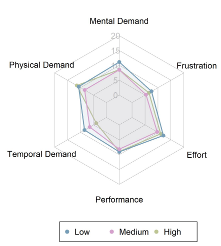

Figure 4: NASA-TLX score (1-20) expressed after the pick-and-place task divided by Presence Level

5 DISCUSSION AND CONCLUSIONS

In this experiment [18], participants guided a VR-based simulation of an industrial robotic arm through a pick-and-place task via different control modalities (i.e., button-based and action-based) and under different mental loads (i.e., single-task, dual-task). Thereafter, they expressed their self-perceived SoP with respect to the virtual simulative environment. For this contribution, we thus clustered participants based on their self-reported SoP and explored whether different levels of SoP (i.e., low, medium, high) could affect performance, implicit and explicit workload. Specifically, we leveraged participants' operation times as a performance measure, their pupil size variations as an index of their implicit workload (which is not controlled directly by the participant), and the scores they self-reported at the NASA-TLX questionnaire expressed after each task as a measure of their explicit workload.

Our results evidenced how the level of presence and immersion within the virtual environment significantly affected users' **performance**, but not their implicit or their explicit workloads. Particularly, those participants who reported a low SoP were significantly slower in completing both the pick and the place task phases than those who self-reported a high SoP. This result is in line with literature [6] and evidences the importance of feeling present at the remote location in telerobotics environments, as it can significantly affect the efficiency of the teleoperations. Indeed, the more a teleoperator feels present in the virtual environment, the more he/she will perform efficiently.

Differently, we also observed how different levels of SoP led to similar workloads levels. Indeed, there was no significant influence of the Presence levels on the implicit (i.e., pupil size variations) not on the explicit workload (i.e., NASA-TLX questionnaire). We only observed a tendency for a higher self-reported **temporal demand** and **mental demand** in those participants who experienced a lower SoP, compared to those who experienced a medium and also a high SoP. Such effects, despite not reaching the significance threshold, would align with the previous interpretation of [13], who hypothesized how, for lower levels of SoP, participants might focus more on their actual performance in VR (in this case also on the related temporal demand) thus increasing the mental burden during the task execution. In our case, the more a user feels present in the virtual environment - so the higher the felt involvement and immersion - the less he/she felt mentally overloaded, also overlooking the task's pressing rhythm. This result is even more interesting when considering that those participants who self-reported higher presence were also those who performed faster at the pick-and-place task. Therefore, despite their actual task pace being more rapid than the low Presence group, they tended to feel less temporal demand than that group, also feeling less mental burden. In this view, it is possible that feeling completely immersed and engaged in the task, and in the virtual environment, flattened the temporal perception of the task rhythm and the related feeling of mental demand, while also allowing a faster task execution. However, these interpretations are not supported by the statistical tests and are thus just based on the descriptive trend of our data (see Table 1).

When looking at the presence effects on the **implicit workload**, instead, our results showed that the pupil size did not vary significantly between the different presence groups. Only at the very end of the place action, those who reported a medium presence level showed a higher pupil size compared to those of the low presence group. While this effect was present only in the last window of the place phase, there seems to be a general tendency for higher pupil size variations in the medium presence group compared to the low and high presence groups, which instead showed similar trends (see Figure 3). Literature unfolding pupil size variations relative to different levels of SoP in VR is scarce. Future research might delve into this question, as some relations between pupil size variations and SoP seem to exist.

With this study, we have started to untangle some mechanisms that link SoP, performance and workload in the telerobotics sector. While these results inspire future investigations, we acknowledge the following **limitations**. First, we did not manipulate the levels of presence directly. Oppositely, we performed a data-driven clustering of participants according to their self-expressed SoP, which led to three groups, each composed of 5, 6, and 7 participants respectively. Furthermore, while our participants' responses to the MEC-SPQ questionnaire covered the whole scale, ranging from 1 to 5, the variance of those responses was not that large, and the averaged responses tent to the higher pole of the scale (i.e., mean = 3.79; SD = 1.11). Therefore, we can say that our results originate from a virtual environment that elicits a relatively high SoP. For a more precise evaluation of the SoP and its effects on teleoperators' performance and workloads, future research might manipulate specific features of the virtual environment that are known to significantly affect SoP (e.g., the virtual environment vividness like in [20]) and systematically assess their impact on users' behavioral and cognitive mechanisms on a larger sample. Furthermore, our first attempt of understanding the relations between pupil size variation and SoP might be worthy of further exploration.

Overall, we shed first light on the practical impact of the SoP on operators driving a VR-based simulation of an industrial robot. While there is a clear positive effect of the SoP on the teleoperation performance, the SoP seems to have little to no impact on the users' workload, both when measuring it explicitly (i.e., via self-reports) and implicitly (i.e., by interpreting the users' pupil size variations). This work contributes to quite poor and contradictory literature on telepresence, task performance, and users' workload, highlighting the need for further research that clarifies the relations between these factors in the telerobotics area, and particularly with workload.

ACKNOWLEDGMENTS

We thank Davide Gobbo for his support on the virtual environment programming. This study was carried out within the scope of the project "use-inspired basic research", for which the Department of General Psychology of the University of Padova has been recognized as "Dipartimento di eccellenza" by the Italian Ministry of University and Research. The project was partially supported by the European Commission under Grant (ID: 826266; Co-Adapt project).

REFERENCES

[1] Jonggil Ahn, Euijai Ahn, and Gerard J Kim. 2015. Robot mediated tele-presence through body motion based control. In *2015 IEEE International Conference on Systems, Man, and Cybernetics*. IEEE, 463–468.
[2] Wadee Alhalabi. 2016. Virtual reality systems enhance students' achievements in engineering education. *Behaviour & Information Technology* 35, 11 (2016), 919–925.
[3] Luis Almeida, Paulo Menezes, and Jorge Dias. 2017. Improving robot teleoperation experience via immersive interfaces. In *2017 4th Experiment@ International Conference (exp. at'17)*. IEEE, 87–92.
[4] Douglas M Bates. 2010. lme4: Mixed-effects modeling with R.
[5] Priska Breves and Holger Schramm. 2019. Good for the feelings, bad for the memory: The impact of 3D versus 2D movies on persuasion knowledge and brand placement effectiveness. *International Journal of Advertising* 38, 8 (2019), 1264–1285.
[6] Filippo Brizzi, Lorenzo Peppoloni, Alessandro Graziano, Erika Di Stefano, Carlo Alberto Avizzano, and Emanuele Ruffaldi. 2017. Effects of augmented reality on the performance of teleoperated industrial assembly tasks in a robotic embodiment. *IEEE Transactions on Human-Machine Systems* 48, 2 (2017), 197–206.
[7] Natalia Cooper, Ferdinando Milella, Carlo Pinto, Iain Cant, Mark White, and Georg Meyer. 2018. The effects of substitute multisensory feedback on task performance and the sense of presence in a virtual reality environment. *PloS one* 13, 2 (2018), e0191846.
[8] James J Cummings and Jeremy N Bailenson. 2016. How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media psychology* 19, 2 (2016), 272–309.
[9] Christophe Deniaud, Daniel Mestre, Vincent Honnet, and Benoit Jeanne. 2014. The concept of" presence" used as a measure for ecological validity in driving simulators. In *Proceedings of the 2014 European Conference on Cognitive Ergonomics*. 1–4.
[10] Wei Gai, Huiyu Li, Yanshuai Zhao, Maiwang Shi, Wenfei Wang, Yunchuan Sun, and Chenglei Yang. 2020. A New Navigation Method for VR-based Telerobotic System via Supervisor's Real Walking in a Limited Physical Space. In *2020 International Wireless Communications and Mobile Computing (IWCMC)*. IEEE, 494–498.
[11] Simone Grassini, Karin Laumann, and Martin Rasmussen Skogstad. 2020. The use of virtual reality alone does not promote training performance (but sense of presence does). *Frontiers in psychology* 11 (2020), 1743.
[12] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.
[13] Stephanie J Lackey, JN Salcedo, James L Szalma, and Peter A Hancock. 2016. The stress and workload of virtual reality training: the effects of presence, immersion and flow. *Ergonomics* 59, 8 (2016), 1060–1072.
[14] Hongyi Liu and Lihui Wang. 2020. Remote human–robot collaboration: A cyber–physical system application for hazard manufacturing environment. *Journal of manufacturing systems* 54 (2020), 24–34.
[15] Ruiqi Ma and David B Kaber. 2006. Presence, workload and performance effects of synthetic environment design factors. *International Journal of Human-Computer Studies* 64, 6 (2006), 541–552.
[16] Guido Makransky, Thomas S Terkildsen, and Richard E Mayer. 2019. Adding immersive virtual reality to a science lab simulation causes more presence but

less learning. *Learning and instruction* 60 (2019), 225–236.
[17] Federica Nenna, Valeria Orso, Davide Zanardi, and Luciano Gamberini. 2022. The virtualization of human–robot interactions: a user-centric workload assessment. *Virtual Reality* (2022), 1–19.
[18] Federica Nenna, Davide Zanardi, and Luciano Gamberini. 2022. Human-centric telerobotics: investigating users' performance and workload via VR-based eye-tracking measures. *arXiv preprint arXiv:2212.07345* (2022).
[19] Johanna Roettl and Ralf Terlutter. 2018. The same video game in 2D, 3D or virtual reality–How does technology impact game evaluation and brand placements? *PloS one* 13, 7 (2018), e0200724.
[20] Tyler Rose and Karen B Chen*. 2018. Effect of levels of immersion on performance and presence in virtual occupational tasks. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 62. SAGE Publications Sage CA: Los Angeles, CA, 2079–2083.
[21] Team RStudio et al. 2020. RStudio: integrated development for R. *Rstudio Team, PBC, Boston, MA URL http://www. rstudio. com* (2020).
[22] Jean-Christophe Servotte, Manon Goosse, Suzanne Hetzell Campbell, Nadia Dardenne, Bruno Pilote, Ivan L Simoneau, Michèle Guillaume, Isabelle Bragard, and Alexandre Ghuysen. 2020. Virtual reality experience: Immersion, sense of presence, and cybersickness. *Clinical Simulation in Nursing* 38 (2020), 35–43.
[23] Mel Slater. 2002. Presence and the sixth sense. *Presence* 11, 4 (2002), 435–439.
[24] Mel Slater, Anthony Steed, John McCarthy, and Francesco Maringelli. 1998. The influence of body movement on subjective presence in virtual environments. *Human factors* 40, 3 (1998), 469–477.
[25] Peter Vorderer, Werner Wirth, Feliz Ribeiro Gouveia, Frank Biocca, Timo Saari, Lutz Jäncke, Saskia Böcking, Holger Schramm, Andre Gysbers, Tilo Hartmann, et al. 2004. Mec spatial presence questionnaire. *Retrieved Sept* 18, 2004 (2004), 2015.
[26] Werner Wirth, Tilo Hartmann, Saskia Böcking, Peter Vorderer, Christoph Klimmt, Holger Schramm, Timo Saari, Jari Laarni, Niklas Ravaja, Feliz Ribeiro Gouveia, et al. 2007. A process model of the formation of spatial presence experiences. *Media psychology* 9, 3 (2007), 493–525.