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Comparison of teleportation and walking in virtual reality in a declarative learning task

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Introduction: Virtual reality (VR) offers new possibilities for learning in educational settings by navigating through large 3D virtual environments. When designing VR-based learning applications, developers have to decide between different locomotion techniques to navigate through VR. Since physical activity and walking have been shown to enhance learning, physical walking in VR should increase learning compared to locomotion techniques without physical activity.

Methods: In this study, we examined if learners who are able to walk freely in VR differ regarding their declarative knowledge acquisition from learners who are teleported in VR.

Results: Learning outcomes did not differ between these two conditions, neither immediately after learning in VR nor after a one-day delay. Also, participants' sense of presence in the virtual environment did not differ between the two conditions.

Discussion: These findings suggest that both teleportation and walking are suitable for declarative knowledge acquisition in VR, and that teleportation may be sufficient enough.

KEYWORDS
walking, teleportation, learning, education, physical activity, knowledge acquisition, immersion

1 Introduction

Virtual reality (VR) opens exciting new possibilities for immersive learning experiences by allowing users to navigate three-dimensional virtual worlds. These environments can range from emulating medieval cities and museums to chemical laboratories (Checa and Bustillo, 2020; Giangreco et al., 2019; Hu-Au and Okita, 2021). Moreover, these environments also allow to teach abstract content like climate change in an efficient way [e.g., Markowitz et al. (2018), Thoma et al. (2023)]. Presenting learning content in VR is a promising alternative to conventional learning materials. For instance, earlier research compared knowledge acquisition between a group of students who completed an architecture lesson using VR and a group who completed the lesson using presentation slides, videos, and pictures. The students who used VR for learning showed higher scores in a subsequent knowledge test (Wu et al., 2021). In a similar vein, Gloy et al. (2022) compared immersive VR anatomy atlases with anatomy textbooks. Results showed that students who learned in VR completed the test faster and achieved a higher proportion of correct answers. Indeed, the beneficial effects of VR on learning have been shown in multiple meta-analyses [e.g., Villena-Taranilla et al. (2022), Wu et al. (2020), Yu (2021)]. Learning often involves the acquisition of declarative knowledge which refers to an individual's knowledge about facts or ideas (Anderson, 1976; Shavelson et al., 2005). Webster (2016) compared the acquisition of declarative knowledge between a VR setting and a lecture-based setting, showing that VR enhanced the acquisition of declarative knowledge. Thus, VR is also effective for learning new declarative knowledge.

In VR, locomotion is a key element to optimally exploit the benefits of VR, leading to better immersion and improved presence (e.g., Kim and Rhiu (2021), Langbehn et al. (2018)). The methods of navigating in VR vary, with navigation relying on joysticks, teleportation, or physical walking. Each method for navigation in VR has its benefits and disadvantages. The usage of a joystick for movement has been shown to result in more motion sickness than walking and teleportation (Buttussi and Chittaro, 2019; Caputo et al., 2023; Frommel et al., 2017; Langbehn et al., 2018). However, walking in VR requires more physical effort, time to traverse a VR environment, and a larger physical area compared to movement using a joystick or teleportation (Bozgeyikli et al., 2016; Buttussi and Chittaro, 2019; Kim and Rhiu, 2021; Shewaga et al., 2017). Additional hardware like omnidirectional treadmills could resolve the problem of available physical space but they are currently still expensive. Redirected walking solves the problem of available space by adjusting participants' path as soon as they reach the end of their available physical space (e.g., Banakou and Slater (2023)). Based on users' preferences, Langbehn et al. (2018) highlighted that both teleportation and redirected walking should be favored over movement by joystick in VR. The development of current VR headsets like the Meta Quest 3 seems to align with these suggestions by offering a dynamic shift between teleportation and walking–for instance in the hub environment. Despite this, Sayyad et al. (2020) observed a preference for walking over teleportation in their study, and multiple studies also showed that physically walking through VR increases the sense of presence and spatial orientation compared to teleportation (Kim and Rhiu, 2021; Langbehn et al., 2018; Shewaga et al., 2017; Slater et al., 1995; Usoh et al., 1999). It remains unclear how walking and teleportation affect the acquisition of declarative knowledge. More research is needed to investigate which type of locomotion is best suited for declarative knowledge acquisition in VR, and this has motivated us to conduct this study.

Embodied cognition theories suggest that the acquisition of knowledge is linked to the sensory experience of one's body and its movements, highlighting the significance of physical engagement and real-world context in learning (Barsalou, 1999). Indeed, the body is involved in a wide array of cognitive functions, including language comprehension (Glenberg and Kaschak, 2002), numerical understanding (Link et al., 2013), or metaphorical understanding (Wilson and Gibbs, 2007). However, some educational contents merely rely on the acquisition of purely declarative knowledge with limited potential for embodied alignment. Nevertheless, embodiment also enables the potential of physical activation, which has been shown to enhance academic performance and achievements (Rasberry et al., 2011; Wretman, 2017; Zabriskie and Heath, 2019). Moreover, physical activation through movement breaks during classes has been shown to increase students' attention (Daly-Smith et al., 2018; Lynch et al., 2022). These studies suggest that physical activities in the learning process may be crucial. Notably, the amount of physical activation is possibly more intense in these studies compared to walking. However, studies in the educational context also showed the positive effects of walking on learning (Biber and Heidorn, 2021; Weight et al., 2021). The walking classroom is a didactic approach in which students listen to education podcasts while walking. This approach has been shown to increase students' long-term retention, as well as their self-perceived learning efficacy, happiness, and energy (Biber and Heidorn, 2021; Erwin et al., 2021; Weight et al., 2021). The walking classroom also enhances students' alertness and information processing (Erwin et al., 2021; Weight et al., 2021) which might facilitate the acquisition of declarative knowledge. While findings from the walking classroom approach show the cognitive benefits of physical activity, it is an open question to what extent the same mechanisms also apply to walking in VR environments.

Previous research has shown that walking in VR has a positive effect – for example regarding presence and motion sickness (Ibánez et al., 2016; Saredakis et al., 2020). However, further research is needed to investigate the effect of physically walking in VR on learning – especially regarding the acquisition of declarative knowledge. This aspect is particularly important for designers of future educational applications in VR, as they are faced with the important decision of whether to include physical walking or teleportation in VR. The enhanced learning and cognitive functioning during the walking classroom suggest that walking in VR enhances declarative knowledge acquisition. However, the walking classroom shows that continuous walking during knowledge acquisition enhances learning. In VR applications, however, walking is rather used to move between points of interest at which declarative knowledge can be acquired. The short physical activity of walking between points of interest might also enhance cognitive functioning and thereby enhance learning. Riecke et al. (2010) have shown enhanced performance in a navigation task when participants navigated through VR by physical walking instead of using joysticks. Earlier studies could not corroborate these findings (Moreno and Mayer, 2002), but VR headsets have dramatically improved in usability and movement possibilities over the last decade. Recent research by Queiroz et al. (2023) found that movement in VR reduces the amount of learning compared to sitting in VR. Contrary, Johnson-Glenberg et al. (2021) showed enhanced learning due to movement, albeit their study varied movement only in regard of hand movements. Consequently, there has not been any conclusive evidence if walking and teleportation in VR might affect the outcome of declarative knowledge acquisition differently.

In this study, we examined if learners who are able to walk in VR differ regarding their declarative knowledge acquisition from learners who are teleported in VR. Recent meta-analyses have shown that VR enhances learning (Wu et al., 2020; Yu, 2021), and these effects were also observed for the acquisition of declarative knowledge (Webster, 2016). However, these studies did not compare whether the type of movement in VR affects knowledge acquisition. Previous research on embodied cognition suggests that physical activity is beneficial for learning [e.g., Rasberry et al. (2011), Weight

FIGURE 1
The first room of the VR museum which shows all eight planets labeled with their respective names.

et al. (2021), Wretman (2017), Zabriskie and Heath (2019)]. Therefore, we expected that in VR the outcomes of declarative knowledge acquisition of walking learners are better than those of teleported learners. To investigate whether the knowledge acquired in VR is still available on the following day, we compared immediate and delayed recall.

2 Methods

2.1 Participants

Seventy-five students participated in a laboratory experiment in exchange for course credit. A power analysis performed with G*Power (Faul et al., 2007) produced a minimum sample size of 60 participants (effect size of 0.2 for a between-within interaction with a power of .85, a p-value of .05, measurements and groups of 2, and correlations among the repeated measurements of .5). The exclusion criteria included wearing a pacemaker, hearing implants or hearing aids, susceptibility to migraine, epilepsy, as well as neurological or psychiatric disease. Eleven participants were excluded due to technical issues during the experiment. The final sample consisted of 64 participants. 44 participants were female (68.75%), and 20 participants were male (31.25%). Participants' age ranged from 18–29 years (M = 22.3 years, SD = 2.0 years). None of the participants were enrolled in a curriculum that relates to the learning content of the experiment (i.e., astronomy). All participants gave their written informed consent and could withdraw from the study at any time. The study protocol was reviewed and approved by the ethics committee of the faculty of human sciences of the authors' institution.

2.2 Experimental design

A 2 × 2-mixed-factor design was conducted with locomotion type (walking vs. teleportation) in VR and measurement time (immediately after vs. 24 h after learning) as independent variables. Participants were randomly assigned to the walking or teleportation condition and explored a VR environment exhibiting the solar system. The main dependent variable was the acquired knowledge about the solar system measured with a quiz described below. Additionally, participants' experience in the virtual environment (e.g., presence, motion sickness) was assessed by means of the questionnaires also described below.

2.3 Material

2.3.1 Virtual environment

A 3D virtual environment was developed using Unreal Engine, version 4.27 (Epic Games, 2019). This virtual environment was modelled as a museum. The museum consisted of six rooms which were connected by an elevator. Each room measured 4.94 × 3.87 m and the elevator 1.88 × 1.16 m. The museum showed an exhibition of the solar system. The first room showed a model of the solar system with all eight planets labeled with their respective names (see Figure 1). In the subsequent four rooms, each room presented two planets of the planetary solar system which were placed in opposite corners (see Figure 2). The distance between the points where the participants had to study the planet spanned 3 m. Overall, the expected pathway in each room consisted of approximately 9 m for each room. The presentation of these planets aligned with the order of the planets in the solar system. For each planet, four facts were presented alongside the miniature (e.g., "orbital period around the Sun: 84 years", "ice giant", "3rd largest planet", or "named after Greek god" for Uranus; see Figure 3 for an example). The final room showed all planets in order of the solar system (see Figure 4). The virtual environment was displayed using a wireless, motion-tracked head-mounted display (HTC Vive Pro 2; 2,448 × 2,448 pixels per eye) and a desktop PC (using a NVIDIA GeForce GTX 1080 graphics card and an Intel Core i7 processor).

2.3.2 Measurement of learning outcomes

A quiz consisting of 14 open-ended questions was created to evaluate participants' declarative knowledge of the planetary solar

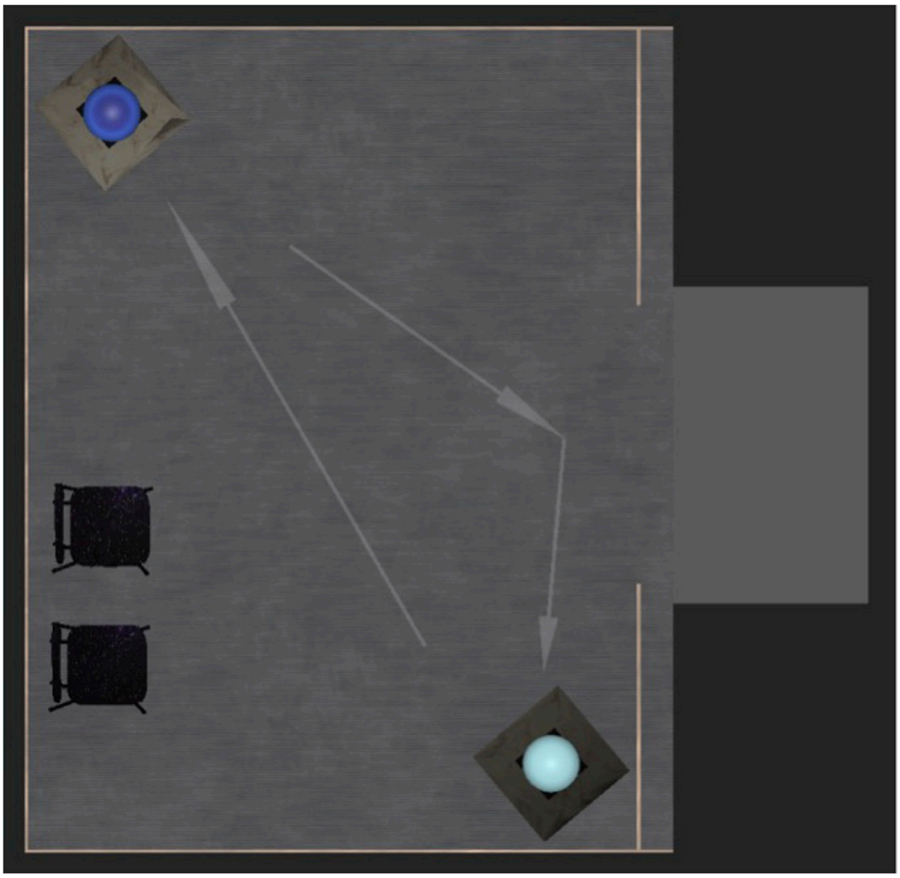

FIGURE 2
An example room from the bird's perspective. Two planets are depicted in the top left and bottom right corner. In the whole-body movement condition, arrows sequentially emerge on the floor, guiding participants step by step to their destinations.

system after exploration of the virtual environment. Table 1 shows each question and the percentage of correct answers given by participants across all conditions. The quiz was conducted using Qualtrics (https://www.qualtrics.com).

2.3.3 Questionnaires

The sense of presence was measured using an adapted German version of the presence scale (Kim and Biocca, 1997). Participants rated the nine items using a 7-point Likert scale. The items were reformulated by changing "broadcast" and "television" to "experience in virtual reality". Additionally, the pictorial presence self-assessment-manikins (PP-SAM; Weibel et al., 2015) was used to measure sub-dimensions of presence using pictorial manikins. This questionnaire consists of six items, each measuring a different aspect of presence (self-location, possible actions, attention allocation, spatial situation model, higher cognitive involvement, and suspension of disbelief). The virtual reality sickness questionnaire (VRSQ; Kim et al., 2018) was used to measure potential symptoms of motion sickness. This questionnaire contains 9 symptoms for which participants indicate the experienced intensity using a 4-point Likert scale (0 = not at all, 1 = slightly, 2 = moderately, and 3 = very). The VRSQ covers two subdomains of symptoms (oculomotor and disorientation), which can be summed to a total score of symptoms ranging from 0%–100%. Additionally, participants were asked to indicate the amount of prior VR experience by choosing between "not at all", "little" or "many", as well as describing their prior knowledge about the presented topic using an open-ended question.

2.4 Procedure

Participants were randomly assigned to the walking or teleportation condition with each condition comprising 32 participants. Participants were informed that the study investigates the potential of VR for declarative learning and that they should remember the displayed information in VR. Participants explored the virtual environment either by physically walking or teleportation. In both conditions, the order of the rooms was kept the same. Participants started by standing in the elevator. When the elevator opened, participants could step into the first room. In the first room, they were instructed to study the model of the solar system and become acclimated to the virtual environment. Subsequently, they had to return into the elevator. After stepping back into the elevator, the doors closed before opening again on the next floor, where they began to explore the next room. This was the first room in which two planets were presented. Each participant followed the same path which was signaled by arrows on the floor. Whenever the participants would stand in front of a planet, the corresponding information would appear. After 30 s, the information disappeared,

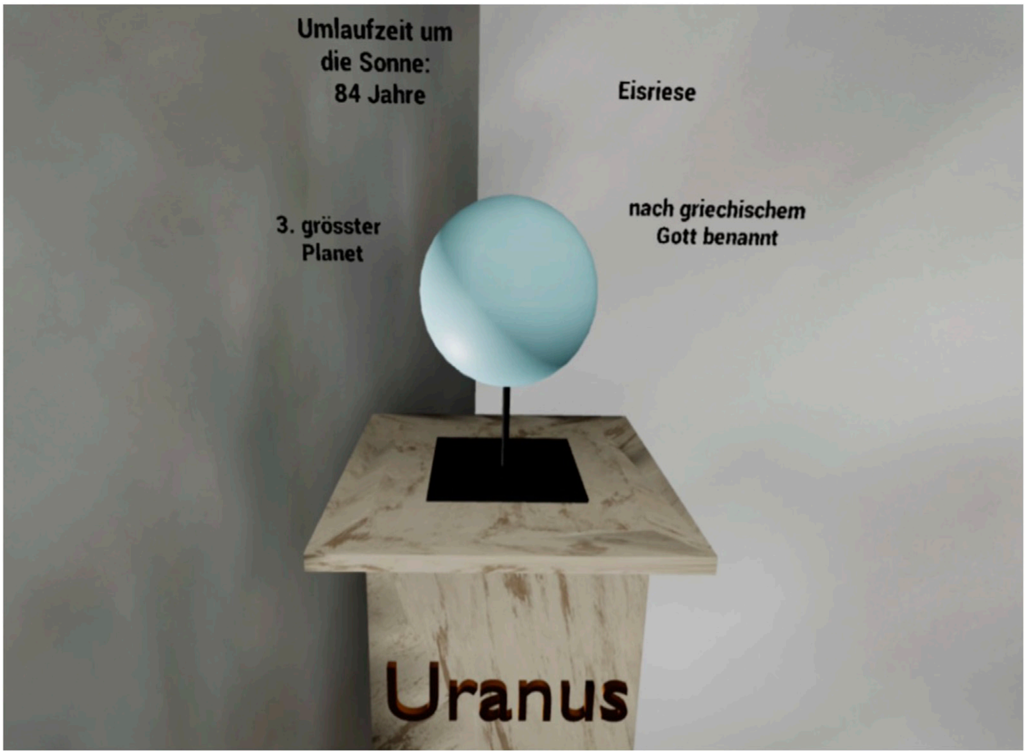

FIGURE 3
An example room of the virtual museum showing Uranus and the corresponding information about the planet.

FIGURE 4
The last room of the VR museum which shows all eight planets in the order of the solar system.

signaling to the participant to move on. This pattern was repeated across all rooms. In the walking condition, the participants could physically walk along the signaled path to the second planet in the room. In the teleportation condition, participants remained in a standing position and did not move in real life. Teleportation occurred automatically so that participants were not required to use a controller. This was done to reduce both motor activity and interference due to the use of the controllers. Furthermore, this allowed us to align the time needed for teleportation with the expected time for walking through the VR environment.

Right after the VR learning experience, participants were asked to complete the declarative knowledge quiz. Subsequently, presence, motion sickness, and the PP-SAM were assessed, and participants were asked about their prior knowledge and VR experience. On the

TABLE 1 Questions of the quiz for evaluating participants' declarative knowledge immediately after and 24 h after learning in VR. For each condition, the frequency of correct answers is displayed with the percentage of correct answers for the respective condition in brackets.

Question	Immediate		24 h later	
	Walking	Teleportation	Walking	Teleportation
Write down the order of the planets in the solar system (from closest to farthest from the Sun).	17 (53.12%)	18 (56.25%)	20 (62.50%)	20 (62.50%)
The ___ is the only planet that has no moons.	26 (81.25%)	29 (90.62%)	23 (71.88%)	29 (90.62%)
The ___ is called the morning or evening star.	26 (81.25%)	25 (78.12%)	26 (81.25%)	28 (87.50%)
The origin of the water on the ___ is not yet completely clear.	32 (100.00%)	32 (100.00%)	31 (96.88%)	32 (100.00%)
Salt deposits are found on the ___.	26 (81.25%)	27 (84.38%)	30 (93.75%)	26 (81.25%)
The ___ is the most massive planet.	28 (87.50%)	28 (87.50%)	26 (81.25%)	28 (87.50%)
The ___ is the only planet named after a Greek God.	28 (87.50%)	25 (78.12%)	28 (87.50%)	24 (75.00%)
The ___ is the only planet that is not visible to the naked eye.	28 (87.50%)	27 (84.38%)	27 (84.38%)	25 (78.12%)
Arrange the planets in order of size (from smallest to largest).	5 (15.62%)	6 (18.75%)	6 (18.75%)	6 (18.75%)
Arrange the planets by their orbital periods around the Sun (order from shortest to longest).	16 (50.00%)	16 (50.00%)	15 (46.88%)	15 (46.88%)
____ belong to the Earth-like planets.	19 (59.38%)	22 (68.75%)	21 (65.62%)	23 (71.88%)
____ belong to the ice planets.	23 (71.88%)	25 (78.12%)	27 (84.38%)	28 (87.50%)
____ belong to the gas planets.	23 (71.88%)	26 (81.25%)	27 (84.38%)	27 (84.38%)

next day, participants returned to the lab and answered the knowledge quiz again. Participants were not told about a second knowledge test in advance. Instead, they were told that they would visit a different virtual world on the second day. This was done to prevent participants from learning more about the presented topics between the two sessions.

2.5 Data analysis

Responses to the quiz questions were checked manually with one point per correct answer. Misspelled answers (e.g., "Markury" instead of "Mercury") were also counted as correct. Data analysis was performed using R Studio (Posit Team, 2023) and R (R Core Team, 2023). To assess the acquisition of knowledge, a mixed ANOVA was conducted with the movement condition (walking vs. teleportation) as between-subject factor and the measurement time (immediately vs. 24 h after the VR experience) as within-subject factor. Independent sample t-tests were conducted to compare the effects of the movement condition on presence and motion sickness. If the assumptions for an independent sample t-test were violated, Kruskal–Wallis tests were used instead. Given the absence of significant differences between the movement conditions, additional equivalence tests were performed for participants' knowledge, presence, and motion sickness using jamovi (The jamovi project, 2024).

3 Results

3.1 Knowledge

Participants could score up to 14 points in the knowledge quiz. Their scores in the quiz ranged from 1 to 13 (M = 9.54, SD = 2.54).

TABLE 2 Means and standard deviation (in brackets) of the scores in the quiz for each condition immediately and 24 h after learning in VR.

Measurement	Walking	Teleportation
Immediately after VR	9.28 (2.81)	9.56 (2.66)
24 h after VR	9.59 (2.39)	9.72 (2.39)

Table 2 shows the mean values for each condition. Participants' scores did not differ, $F(1, 62) = 0.12$, $p = .734$, $\eta_p^2 < .01$, between the walking (M = 9.44, SD = 2.59) and the teleportation condition (M = 9.64, SD = 2.51). Moreover, participants' scores immediately after learning in VR (M = 9.42, SD = 2.72) did not differ, $F(1, 62) = 0.95$, $p = .333$, $\eta_p^2 = .02$, from their scores after 24 h (M = 9.66, SD = 2.37). There was no interaction between experimental condition and time, $F(1, 62) = 0.11$, $p = .746$, $\eta_p^2 < .01$.

Most participants reported having no prior knowledge about the learning content presented in VR and no or only little prior experience using VR. The findings regarding the learning outcomes reported above remain the same when only looking at participants stating no prior knowledge. Similarly, the findings remain the same if the sample is split according to participants' previous experience with VR. The sample characteristics for both groups are shown in Table 3.

3.2 Sense of presence

Scores in the presence questionnaire ranged from 2.5 to 6. Presence scores did not differ, $t(61.83) = 0.49$, $p = .627$, $d = 0.12$, between the walking (M = 4.42, SD = 0.72) and the teleportation condition (M = 4.34, SD = 0.68). Participants did also not differ in any of the dimensions measured by the PP-SAM (see Table 4).

TABLE 3 Information about the sample for each condition.

Variable	Walking	Teleportation
N	32	32
Age	M = 22.03, SD = 1.69	M = 22.5, SD = 2.37
Gender	21 women, 11 men	23 women, 9 men
Amount of participants reporting prior knowledge	20 participants without prior knowledge, 12 participants with prior knowledge	21 participants without prior knowledge, 9 participants with prior knowledge, 2 participants who did not answer the question about prior knowledge
Prior Experiences with VR	14 participants with no prior VR experience, 16 participants with little prior experience, 2 participants with much VR experience	6 participants with no prior VR experience, 25 participants with little prior experience, 1 participant with much VR experience

TABLE 4 Means, standard deviations, and inference statistics for scores in the PP-SAM.

Dimension	Walking		Teleportation		Shapiro-wilk		Kruskal–wallis		
	M	SD	M	SD	W	p	$\chi2$ (1)	p	η^2
Attention allocation	1.63	0.87	1.66	0.83	0.74	<0.001	0.07	0.788	0.01
Spatial situation model	4.06	0.76	4.00	0.72	0.82	<0.001	0.36	0.549	0.01
Self-location	4.03	0.93	4.03	0.86	0.82	<0.001	0.02	0.879	0.02
Possible actions	2.84	1.11	2.56	0.88	0.91	0.001	0.83	0.362	<0.01
Cognitive involvement	3.88	1.01	4.09	1.03	0.83	<0.001	1.04	0.308	<0.01
Suspension of disbelief	2.97	1.03	2.97	1.06	0.89	<0.001	0.04	0.839	0.02

3.3 Motion sickness

The motion sickness scores measured with the VRSQ ranged from 33.3 to 75.8. Shapiro-Wilk test (W = 0.87, p < .001) showed that the data were not normally distributed, and therefore, we used a Kruskal–Wallis test. There was no difference, $\chi^2(1)$ = 1.7, p = .192, η^2 = .01, in motion sickness between the walking condition (M = 42.71, SD = 8.82) and the teleportation condition (M = 46.20, SD = 10.17). The scores in the oculomotor subscale of the VRSQ ranged from 33.3 to 91.6, and the data did not follow a normal distribution (W = 0.87, p < .001). The walking condition (M = 44.79, SD = 11.74) did not differ regarding the scores in the oculomotor subscale from the teleportation condition (M = 49.48, SD = 13.71), $\chi^2(1)$ = 2.22, p = .136, η^2 = .02. The scores in the disorientation subscale of the VRSQ ranged from 33.33 to 60, and the data did not follow a normal distribution (W = 0.86, p < .001). Again, the walking condition (M = 40.62, SD = 7.45) did not differ, $\chi^2(1)$ = 1.28, p = .258, η^2 < .00, from the teleportation condition (M = 42.92, SD = 8.28). The distribution of the scores in the VRSQ is shown in Figure 5.

3.4 Equivalence testing

Neither the equivalence test on participants' declarative knowledge outcomes (t(61.83) = −1.00, p = .162, equivalence bounds ±0.4) nor the equivalence test on the VRSQ overall score (t(60.78) = −1.634, p = .054, equivalence bounds ±0.4) reached significance. For presence, the equivalence test reached significance (t(61.83) = −1.79, p = .040, equivalence bounds ±0.4). This suggests that walking results in the same amount of presence as teleportation.

4 Discussion

We examined if learners enabled to walk in VR differed regarding their declarative knowledge acquisition from learners that were teleported in VR. We found no evidence for an advantage of walking when compared to teleportation. However, a *post hoc* power analysis revealed that the power for the comparisons of the between-subjects factor was low. Thus, further studies will be needed to replicate the absence of differences in declarative knowledge acquisition between walking and teleportation. Moreover, we did not find any differences in motion sickness or presence between the two experimental conditions. Hence, our findings do not confirm previous findings showing enhanced learning due to physical walking or an increased sense of presence when walking in VR (Slater et al., 1995; Weight et al., 2021; Zabriskie and Heath, 2019).

Our study focused on the planetary solar system, and we assessed different types of declarative knowledge such as lexical

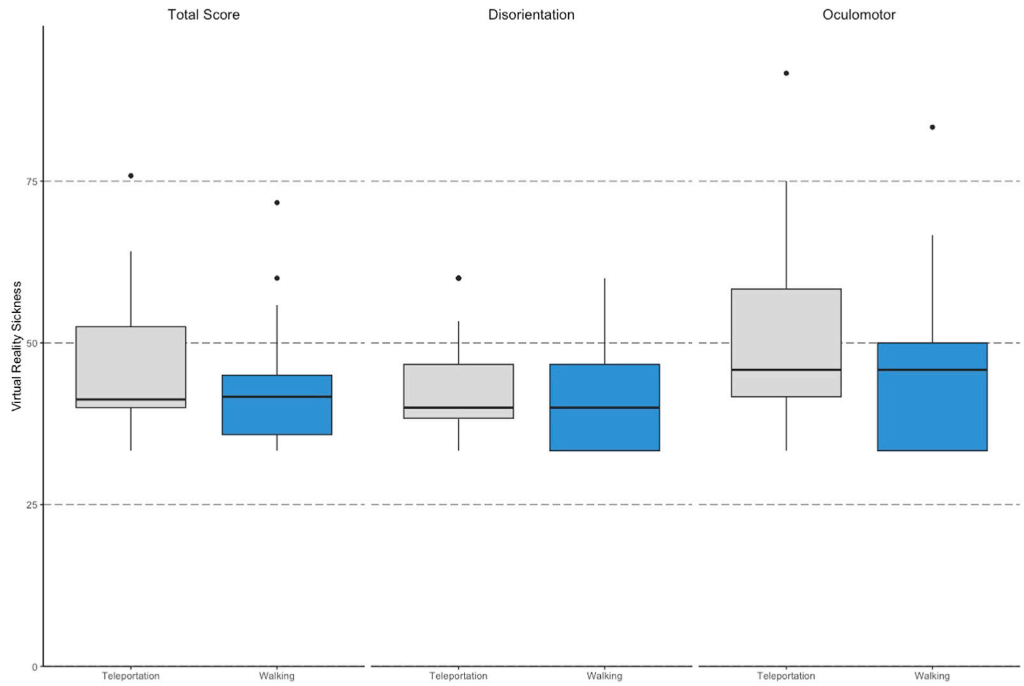

FIGURE 5
Scores in the virtual reality sickness questionnaire, both for the overall scores and the two subdimensions (disorientation and oculomotor).

knowledge (e.g., planet names), relational knowledge (e.g., the order of planets in relation to each other), and conceptual knowledge (e.g., identifying all gas planets). Hence, it is possible that walking in VR can affect the learning of other types of knowledge, especially that of procedural knowledge. This may be hypothesized to occur when walking movements in a learning task are meaningfully related to the process of knowledge acquisition (Skulmowski and Rey, 2018), for instance by being aligned with each other. VR allows for the creation of educational settings that align with body movements, and developers of VR applications should consider the advantages of VR during development (Bailenson, 2018).

Previous studies found evidence for the beneficial effect of walking classrooms on learning [e.g., Weight et al. (2021)]. Our study did not detect any noticeable improvement in learning attributed to walking in VR. This contradicts studies observing cognitive benefits after walking or physical activity (Erwin et al., 2021; Johnson-Glenberg et al., 2021; Oppezzo and Schwartz, 2014; Rasberry et al., 2011; Wretman, 2017; Zabriskie and Heath, 2019), but aligns with earlier studies finding no enhanced learning due to body movement in VR (Moreno and Mayer, 2002; Queiroz et al., 2023). One explanation might be that participants in the teleportation condition – despite not moving – remained in a standing position during the VR experience. Previous studies have shown that a standing position enhances both executive functions and working memory when compared to sitting (Mehta et al., 2016). These beneficial effects of standing could also improve the acquisition of declarative knowledge. However, there is no evidence for standing in a classroom setting having an advantage regarding learning outcomes (Chim et al., 2021). Therefore, it is unlikely that the standing position is responsible for the absence of differences in our experiment.

Teleportation has been shown to result in spatial disorientation compared to walking in VR (Cherep et al., 2020; Cherep et al., 2023). Thus, teleportation in VR could result in cognitive costs, whereby these costs can be reduced by the usage of rotational self-motion cues guiding marks, mini-maps, trails, or heatmaps (Kelly et al., 2020; Kraus et al., 2020; Lim et al., 2020). In our study, we used automatic teleportation to avoid inferences due to the usability and unfamiliarity of the teleportation system or hand movements. This could have affected the spatial orientation of our sample in the teleportation condition. However, spatial disorientation in the teleportation condition would probably have resulted in differences between the two conditions regarding the scores in the knowledge quiz, motion sickness, or presence. Instead, the usage of rather small museum rooms might have helped participants in the teleportation condition to keep spatial orientation despite being teleported automatically.

Our results remain unaffected by the hardware utilized for teleportation, as participants were teleported automatically without the use of controllers. Different controllers are used in VR, ranging from those featuring joysticks to others incorporating touchpads (Novacek and Jirina, 2020). This stands in contrast to the evolution of controller prototypes seen in console or PC gaming over decades, where standardized designs have emerged (Maggiorini et al., 2019). For VR, however, controllers show more variation in design, thus resulting in larger differences in usability between different hardware models. Consequently, the method of teleportation in VR using controllers may differ from automatic teleportation and thereby influence learning outcomes (Maraj et al., 2019). Thus, forthcoming studies comparing walking to teleportation should consider the use of controllers for teleportation.

No beneficial effects of walking in VR have been demonstrated in this study. It is by all means possible that there are positive effects of walking in VR which were not revealed in this study. For instance, walking has been shown to have a positive impact on health, including reduced risk for development of chronic diseases, reduced depressive symptoms, and better quality of life (Hanson and Jones, 2015; Lee and Buchner, 2008; Varma et al., 2014). Additionally, previous studies also highlight the beneficial effects of walking in other cognitive areas beyond mere acquisition of knowledge. Oppezzo and Schwartz (2014) observed enhanced creativity both during and after walking which also enhanced the formation of new and more qualitative analogies. As such, even if walking in VR does not enhance the acquisition of the displayed content, it can potentially increase the quality of the respective classroom lesson. Furthermore, the current study exclusively compared the effect of physical walking for knowledge acquisition in VR with teleportation in VR. Other types of physical activity like cycling or running involve a higher level of physical activity than walking (Zabriskie and Heath, 2019). The current findings are limited to walking and further research is needed to investigate how different types of physical activity in VR could affect the acquisition of declarative knowledge.

Finally, it is important to note that it was not the goal of our study to investigate if VR can enhance learning in general. Instead, it aimed at comparing specifically the effects of walking and teleportation in VR on declarative learning outcomes. Since this comparison represented the focus of the current study, we refrained from a pre-test to assess participants' prior knowledge, which represents a limitation of the present study. A considerable body of research has shown that VR has a medium-large effect on learning outcomes (Villena-Taranilla et al., 2022; Wu et al., 2020; Yu, 2021), for instance for learning anatomy or landscape architecture (Gloy et al., 2022; Wu et al., 2021). Furthermore, immersive VR applications result in more pronounced learning benefits (Villena-Taranilla et al., 2022). Given the growing significance of VR, which is driven by more affordable headsets and wider usage scenarios, the number of educational applications for VR is likely to increase. Research needs to align with this trend, exploring how these applications should be designed to optimize learning in a VR environment.

In summary, our study could not support that walking in VR is beneficial for the acquisition of declarative knowledge compared to teleportation in VR. This does not question the benefits of VR for learning in general. Instead, our findings provide important information for the development of VR-based learning apps. Developers of such learning apps will need to consider whether their app should enable users to walk. In educational contexts, our findings suggest that teleportation can keep up with walking when declarative knowledge has been acquired. In these cases, teleportation in VR represents a promising avenue within future, immersive VR learning environments.

Data availability statement

The datasets for this study is publicly accessible in the open science framework (OSF): doi.org/10.17605/OSF.IO/EC32M.

Ethics statement

The studies involving humans were approved by Ethics committee of the faculty of human sciences of University of Bern. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MR: Conceptualization, Formal Analysis, Funding acquisition, Project administration, Visualization, Writing–original draft. RS: Methodology, Software, Writing–review and editing. SA: Investigation, Methodology, Software, Writing–review and editing. FM: Conceptualization, Funding acquisition, Supervision, Writing–review and editing. MD: Conceptualization, Funding acquisition, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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