Ready for VR? Assessing VR Competence and Exploring the Role of Human Abilities and Characteristics

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ABSTRACT

The use of VR for educational purposes provides the opportunity for integrating VR applications into assessments or graded examinations. Interacting with an VR environment requires specific human abilities, thus suggesting the existence of a VR competence. With regard to the emerging field of VR-based examinations, this VR competence might influence a candidate's final grade and hence should be taken into account. In this paper, we proposed and developed a VR competence assessment application. The application features eight individual challenges that are based on generic 3D interaction techniques. In a pilot study, we measured the performance of 18 users. By identifying significant correlations between VR competence score, previous VR experience and theoretically-grounded contributing human abilities and characteristics, we provide first evidence that our VR competence assessment is effective. In addition, we provide first data that a specific VR competence exists. Our analyses further revealed that mainly spatial ability but also immersive tendency correlated with VR competence scores. These insights not only allow educators and researchers to assess and potentially equalize the VR competence level of their subjects, but also help designers to provide effective tutorials for first-time VR users.

Keywords: Virtual Reality, VR, Skill Assessment, Spatial Ability, Self-efficacy, Immersive Tendency, Technology Literacy

1 INTRODUCTION

Immersive Virtual Reality (VR) provides several benefits for learning and training of new knowledge and skills. It can increase task performance (1), cause higher learning motivation (2), allow for visualization as well as analysis of complex learning contents (3), and achieve implicit learning by providing a direct and explicit audiovisual demonstration of the application of the learning content (4, 5). VR can assist the learning of 3D geometry (6), history (7), training of medical emergency procedures (8) as well as classroom management competency (9). Besides enabling learning and training, VR could further facilitate the assessment of a learner's performance. This is particularly relevant in the field of medical education, where practical examinations are known for their high demands on personnel and resources (10). Hence, realistic and easily repeatable VR-based scenarios are increasingly used to assess medical competencies across various specialties (11).

Despite significant technological advancements, Virtual Reality (VR) fundamentally remains a mediated experience. This is primarily achieved through the use of Head-Mounted Displays (HMDs) combined with input devices such as game controllers or full-body tracking systems. VR environments offer interaction paradigms not feasible in the physical world, exemplified by features like teleportation. Furthermore, VR frequently employs feedback substitutions to compensate for absent sensory information, such as visually highlighting an object upon touch to indicate graspability (12). Consequently, even with high degrees of realism, users must navigate a certain level of abstraction to effectively utilize VR systems. This process necessitates specific human abilities, which culminate in what we term VR Competence. This competence, which can vary in its level of development among individuals, extends beyond mere operational proficiency with input/output devices. It critically involves the capacity to comprehend as well as interpret information conveyed through and the correct execution of VR-specific interaction metaphors, such as laser-pointer selection metaphors and feedback substitutions. When considering VR as an examination platform, the equitable assessment of knowledge is paramount. Therefore, minimizing individual disparities in VR competence is crucial to ensure a fair evaluation for every candidate, preventing the assessment from being unduly influenced by variations in VR interaction proficiency.

[Figure 1 about here.]

To effectively account for VR competence in assessment scenarios, it is crucial to first identify its underlying human abilities. We propose a VR system designed to challenge users with a sequence of short levels, each targeting fundamental 3D interaction techniques. Specifically, each level focuses on a distinct metaphor related to either *selection and manipulation* or *travel* interaction. By measuring individual performance across these levels, we aim to quantify a user's VR competence. VR competence is a subject's proficiency with VR input/output devices and the capacity of executing interaction metaphors as well as comprehending the information conveyed through them. Furthermore, we intend to assess various human abilities theoretically contributing to VR competence. By analyzing the correlations between these measured abilities and the performance data from our VR levels, we anticipate identifying the core human abilities that constitute VR competence.

Contribution

We developed a VR Competence Assessment environment, built around generic 3D interaction techniques, which features eight individual challenges as displayed in Figure 1. Using this system, we measured the performance of 18 participants. To establish a basic validity of our assessment method, we hypothesized that greater prior VR experience would correlate with higher VR competence. Our analysis revealed a significant positive correlation between these two measures, supporting the foundational validity of our approach. Furthermore, we investigated the relationship between user performance and several self-reported characteristics, including presence, immersive tendency, self-efficacy, technology literacy, and spatial ability. Our findings indicate that certain abilities, such as spatial ability and immersive tendency, were strongly associated with VR competence. Conversely, other factors like presence and technology literacy showed no significant correlation. While these insights await confirmation in larger cohorts, they offer immediate practical implications. Educators can leverage these findings to assess and, ideally, equalize the VR competence of candidates undergoing VR-based examinations. Additionally, these insights can guide designers in creating more effective tutorials for first-time VR users, ultimately enhancing their initial VR experience.

2 THEORETICAL BACKGROUND

In recent years, numerous VR applications have been developed for training of technical and non-technical skills and partially integrated into medical curricula – ranging from brain death diagnostics (13) and skin cancer screenings (14) to virtual autopsies (15) and the training of medical emergencies (16). These immersive simulations offer realistic environments and allow learners to practice complex tasks that are difficult to replicate in traditional settings. Recent meta-analyses suggest that VR-based training may be at least as effective, if not superior, to traditional methods (17, 18). Importantly, in some areas, more immersive VR trainings appear to be less conducive to learning than those with lower levels of immersion (17) – possibly due to increased cognitive load caused by the complexity of hardware and software controls (19). Beyond training, VR is also being increasingly used in clinical assessments for undergraduate (11) and graduate (20) medical learners, offering potential benefits in standardization, objectivity, and automation, despite current challenges regarding software maturity and implementation costs. In a recently conducted VR-based OSCE examination (21), higher discrimination indices were observed compared to a content-equivalent physical examination. This may indicate that, in addition to medical performance, a latent construct such as VR competence may have influenced the assessment. To ensure fair exam conditions and avoid favoring participants with prior VR experience, the construct of VR competence should be further explored and considered in exam planning.

2.1 Challenges of Interacting with VR Environments

Immersion is defined as "*the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant*" (22). Immersion further encompasses the possible user actions within a given system (23) like grabbing and manipulating virtual objects. Compared to interacting with a virtual learning environment on a computer screen using mouse and keyboard, the egocentric visualization of and direct interaction with the virtual environment using VR not only leads to a high level of presence (24) but also facilitates the learning process for learners coming from less technologically advanced regions of the world (25). Presence describes the subjective acceptance of the virtual environment as one's location (23) and hence indicates the realness of the virtual experience (26).

On a concrete level, interaction with an immersive virtual environment is realized by implementing 3D interaction techniques. 3D interaction techniques can belong to the overarching categories of selection, manipulation, navigation, and system control (12). These well-researched techniques can be found in every 3D environment, independent of the display technology used. If no direct real-world mapping like real walking (27) for navigation is possible, the interaction techniques can be implemented with metaphors (12). An interaction metaphor represents an easily understandable substitute for a complex real world action like grasping for moving objects of any shape and weight. The design of these metaphors is influenced by both human factors, e.g., visual representation, ergonomics, cognitive load, and system factors, e.g., limitations of input devices or tracking space (12).

Selection and Manipulation

Selection and manipulation tasks involve first selecting and then modifying objects in virtual environments. Effective manipulation is important for many VR tasks, requiring the design of interfaces that enhance user performance and comfort (28, 12). Tasks are characterized by factors like object size, user distance or the user's physical state (12).

Navigation

Navigation in VR combines travel and wayfinding. In detail, travel is the locomotion component, which involves moving from one place to another, and wayfinding the cognitive component that involves route planning (12). Effective navigation is crucial for usability, especially since virtual travel often supports other primary tasks like object interaction (12). Travel can be further categorized into exploration, search, and maneuvering, each with unique requirements (12). Wayfinding supports these tasks through cognitive aids like spatial understanding and mental maps (29, 12).

System Control

System control enables users to manage interactions within 3D environments, such as issuing commands and modifying system states. Unlike discrete control tasks like navigation, system control tasks often specify what should be done, leaving the system to define the details of how it is executed (12). Interactions for system control are often realized with interaction metaphors belonging to the category of *selection and manipulation* and also can include symbolic input, i.e., the input of characters and numbers. Thus, system control provides no additional level of abstracted interactions and will not be further considered in our investigation of a VR competence.

The realization of *selection and manipulation* as well as *navigation* interaction techniques depends on specific factors. While *selection and manipulation* commonly is distinguished in range and representation (12), *travel* includes the factors of range as well as destination, motion type, trigger, and representation (30). Hence, the individual realizations cause different levels of abstraction users need to overcome to successfully use a VR system. When aiming at the investigation of a general VR competence, these different levels of abstraction need to be respected.

2.2 Early Approaches to VR Competence Assessment

Research on assessing VR user competences is limited, but notable exceptions include the Virtual Environment Performance Assessment Battery (VEPAB) by Lampton et al. (31) and the Nottingham Assessment of Interaction in Virtual Environments (NAÏVE) by Griffiths et al. (32).

Lampton et al. (31) developed VEPAB to measure human performance in VR environments, particularly for military training. It assessed basic tasks like vision, locomotion, tracking, object manipulation, and reaction time to establish a baseline for VR performance. Through studies, they found that VEPAB could reliably measure VR performance, with significant improvements of participants over time (31). Additionally, VEPAB was sensitive to differences in input devices.

Griffiths et al. (32) developed NAÏVE to differentiate participant performance across various VR tasks, focusing on navigation, object interaction and the combination of both. Their goal was on the one hand to screen VR competence levels of study participants to assure about equal levels. On the other hand, they aimed to assess VR competence for training purposes, for example to ensure a minimum skill level to profit from VR training. The tasks were integrated into a seamless experience, and the tool successfully classified participants into performance categories (32).

While VEPAB and NAÏVE differed in their approaches – VEPAB uses isolated tasks and NAÏVE integrates tasks into a longer experience – both tools included essential navigation and object manipulation tasks. However, some aspects of VEPAB, like vision and tracking tests, are outdated today. As VR technology has advanced significantly, there is a need for updated tools that reflect current research and technological possibilities. Hence, this work additionally aims to develop and evaluate a modern application to assess VR competence in line with today's standards.

2.3 Personal Characteristics and VR Competence

Understanding how personal abilities and characteristics influence VR competence is important for later improving user performance by training these abilities and characteristics. Research already identified certain human abilities, factors, and skills that influence user performance in VR applications. Hence, we briefly inspect the connection between VR performance, human abilities, and characteristics such as spatial ability, self-efficacy, immersive tendency, technology literacy, presence, and what is known about their impact on VR performance.

Spatial Ability

Spatial ability is all about effectively using spatial information and is crucial in fields like science, technology, engineering, and mathematics (STEM). In everyday life, it is, e.g., important for orienting oneself in the environment (33). Studies show that higher spatial ability leads to faster and more accurate 3D object manipulation (34), and moderates performance with using 3D user interfaces when the interaction metaphor has a higher level of abstraction (35), while lower spatial abilities can put users at a disadvantage in VR environments (36).

Self-Efficacy

Self-efficacy is the belief in one's ability to use their skills to achieve desired goals (37). While already discussed extensively in its influences on computer usage (38, 39, 40, 41, 42, 43), more recent studies also demonstrate similar effects with VR. Additionally, higher self-efficacy was found to enhance perceived ease of use (44, 43), intention to use a VR system (44, 43), and learning outcomes (45).

Immersive Tendency

Immersive tendency is one's ability to experience presence in VR (46) and to become more involved with virtual experiences (47, 48). It is believed to influence how users focus on tasks and process information within virtual environments (48). Although empirical evidence for its effect on learning and performance is mixed (49, 50, 51), immersive tendency remains an important aspect of VR interactions and thus may influence overall performance.

Technology Literacy

Technology literacy, in the context of this work, is defined as "*the ability of a person to use, manage, assess, and understand technology*" (52). Since the use of a technology is per definition part of technology literacy, it could be very relevant to a VR competence. Previous research has shown that technology literacy enhances performance in educational contexts (53, 54), but direct links to VR are sparse. Yet, higher technology literacy likely aids VR interaction, making it a relevant factor for this study.

Presence

Presence is an application- and technology-dependent experience and refers to the feeling of being in a virtual environment rather than the physical one (46). It has a weak but consistent positive correlation with performance in VR (55, 46), particularly in tasks involving spatial perception and procedural skills (1, 56, 57).

2.4 Research Gap

Taken together, all these factors can influence a user's performance in completing tasks in a VR environment. However, according to our best knowledge, it is yet unclear to what extent each factor contributes to a user's VR competence and, even more importantly, what factors form a VR competence. To close this research gap, we conducted a study assessing the individual personal characteristics and correlating them to our participants' performance in correctly executing VR interaction techniques. That way, we cannot only determine the VR competence of a user but also use the competence as a human factor in assessments of a user's overall performance, e.g., in an exam setting.

3 SYSTEM DESIGN

The proposed VR application needs to challenge users with the execution of commonly used interaction metaphors varying in degree of abstraction and measure their performance to assess their potential VR competence. The measured performance subsequently can be correlated with the individual characteristics of each user to also identify the human abilities that contribute to the VR competence the most. Hence, the VR application shall 1) provide a sequence of challenges, of which each targets one interaction metaphor, and 2) measure a user performance in the execution of the interactions. We developed the application with "Unity" version 2022.3.23f1 using an "Oculus Quest 2" HMD with its game controllers. Several additional packages were utilized to aid the development. First, the "XR Interaction Toolkit" version 2.5.2 and the "Oculus XR Plugin" version 4.2.0. Next, several packages from "Tilia" were used: "Tilia CameraRigs TrackedAlias Unity" (v2.5.2), "Tilia CameraRigs XRPluginFramework Unity" (v2.1.11), "Tilia Indicators ObjectPointers Unity" (v2.2.10), "Tilia Input UnityInputSystem" (v2.4.8) and "Tilia Interactions Interactables Unity" (v2.16.6).

In total, our application consists of eight levels, each with a dedicated tutorial prior to the actual level. The tutorial guides the user through the task with detailed instructions, allowing them to try the interaction three times at their own speed, before advancing to the assessment level. Once in the assessment level, a timer of *one minute* is started upon clicking the start button. During this time, the user is asked to complete as many repetitions of the respective interaction as possible. As the level progresses, the difficulty increases, e.g., due to smaller target objects. To avoid a ceiling effect and to derive VR competence thresholds at a later stage, we made the decision to scale the levels in a way that it is impossible to complete them within one minute. We asked two colleagues with a very high gaming and VR experience to tackle the levels for initially balancing them. The application automatically logs the number of completed successful repetitions and calculates the percentage of completed executions with the unattainable maximum score of the level. The VR competence score results out of averaging the percentages of all levels. In the end, the logged data is saved as a .csv file for follow-up analyses.

3.1 Levels for Navigation

[Figure 2 about here.]

Travel is a supporting interaction to enable users to perform their primary task and rarely the user's predominant goal of an application (12). This especially might be the case when intending to use a VR application for graded exams. Hence, we made the decision to only add a teleportation travel technique level to our application. Teleportation causes the least level of cybersickness in comparison to other artificial travel techniques (58). Also, the current gold standard for realizing navigation is a combination of providing teleportation for travel over a greater distance and using real walking for navigating within close range. While teleportation causes a certain level of abstraction, real walking remains a natural locomotion technique.

When navigating through a virtual environment using artificial travel techniques like teleportation, users might experience a greater challenge to develop a spatial understanding for the layout of the virtual environment (58). Therefore, we decided to further include an assessment for wayfinding skills.

As a result of this, our VR competence assessment application tests navigation in two separate levels, one for travel and one for wayfinding. The level for travel assesses the user's teleportation skills. Randomly generated teleport platforms decrease in size and increase in distance as the user progresses. Also, the platforms randomly vary in their vertical position, thus challenging a user to either position the teleportation target on a higher or lower position. A curved ray is used to teleport between platforms, with feedback provided through visual cues and sound. Figure 2 depicts the teleportation task.

The wayfinding level tests the user's orientation based on the approach described by Weißker et al. (58). The user is placed in a city environment where they must navigate a path and estimate their starting point after taking two turns as displayed in Figure 1 first lower image. The city layout is randomly chosen out of ten previously generated maps. Using teleportation to travel, the users are asked to travel to a specific position and subsequently to point to their starting position with a ray. The scoring is based on the accuracy of their estimate in degrees, thus being the only level with a scoring not based on the number of completed executions.

3.2 Level for Selection

We test the user's ability to correctly select targets with three levels. Two levels challenge the user to correctly select targets at different distances. The third level requires the user to find and select a specific cube in a pile of other cubes.

The cube selection level challenges the user to identify and grab a target red cube from a pile of blue distractor cubes, giving appropriate feedback. The task becomes progressively harder as the red and blue cubes shrink in size. The task is displayed in Figure 1 third upper image.

In the raycast level, the user uses a virtual ray to aim at square buttons that randomly appear at a certain distance in the environment. After confirming the selections by pressing the trigger on the controller, auditory feedback is played and a new button appears. As the task progresses, the buttons decrease in size, increasing the difficulty and requiring greater precision for aiming. Figure 1 third lower image depicts the task.

The touch level is similar to the raycast one, with the difference that the buttons need to be touched directly with the virtual controller. Hence, this level tests selection at close range as displayed in Figure 1 fourth lower image. The task requires precision as new, over time smaller, buttons spawn at random locations after each successful touch.

3.3 Levels for Object Manipulation

[Figure 3 about here.]

[Figure 4 about here.]

Object manipulation is tested with two levels, the first one combining rotation and repositioning. It requires the user to grab a cube and shove it in a tube-like box, as depicted in Figure 3 and Figure 1 fourth upper image. With each cube placed into the box, the box rotates randomly and shrinks slightly, forcing the user to adjust the cubes' rotation and position more accurately.

In the scaling level, the user is tasked with scaling a cube to match a size between two reference cubes. The larger reference cube designates the upper size limit, the smaller reference cube represents the lower size limit. The user grabs the interactable cube with both hands and pulls them apart to scale it, with the cube's color changing to green when the correct size is achieved. Figure 4 and Figure 1 second lower image depict the scaling interaction. The difficulty increases as the size difference between the reference cubes gradually shrinks, requiring the user to be more precise with their scaling.

3.4 Level for Hardware Handling

Since most VR applications are controlled with respective game controllers, we also added a hardware handling level to assess a user's skill to press the correct buttons. This button press level displays one extra pair of the game controller's 3D model and highlights specific buttons to be pressed as displayed in Figure 1 first upper image. Over time, the number of buttons to be pressed at the same time increase to make the task more complex. Users receive continuous visual feedback (green for correct button presses, red for incorrect) in conjunction with auditory feedback upon task completion.

4 METHODOLOGY

We conducted a user study to investigate whether 1) a specific VR competence can be measured with our VR application, and 2) the VR competence depends on specific human abilities and characteristics. In our study, the VR competence assessment application challenged the participants with the levels in the following order as displayed in Figure 1: Button press, teleportation, selection and grabbing, rotation, orientation, scale, raycast, and touch.

Based on our theoretical considerations in section 2 and the design of our system described in section 3, the following hypotheses were generated.

Under the assumption that greater experience with VR systems correlates with enhanced VR competence, we assessed participants' prior VR exposure. This assessment included quantifying both their total hours of VR usage and the cumulative number of individual VR experiences. We hypothesized a higher VR competence score for users with a higher VR experience.

H_1: *There is a positive correlation between a person's VR experience in hours and their overall score on the VR competence assessment application.*

H_2: *There is a positive correlation between a person's number of VR uses and their overall score on the VR competence assessment application.*

We further assessed individual abilities and characteristics to investigate their role with respect to a subject's VR competence. As we did not find a clear trend for immersive tendency in our analysis of previous research in section 2, H_5 is formulated as a bidirectional relationship. The hypotheses are as follows:

H_3: *There is a positive correlation between a person's spatial ability and their overall score on the VR competence assessment application.*

H_4: *There is a positive correlation between a person's VR self-efficacy and their overall score on the VR competence assessment application.*

H_5: *There is a relationship between a person's immersive tendency and their overall score on the VR competence assessment application.*

H_6: *There is a positive correlation between a person's presence in the virtual environment and their overall score on the VR competence assessment application.*

H_7: *There is a positive correlation between a person's technology literacy and their overall score on the VR competence assessment application.*

4.1 Measures

Besides automatically logging the performance of the participants during runtime of our VR competence assessment application, we administered several questionnaires to assess the participants' individual abilities and characteristics. Also, we asked for some demographic data.

Spatial Ability

To measure spatial ability, the 20-item Mental Rotation test from Vandenberg and Kuse (59) was used, in the redrawn version from Peters et al. (60). In the test, participants are presented a 3D object made of cubes. Subsequently, they must select the identical, but rotated object from four options. The two incorrect options include either the mirrored version of the target object or completely different objects. An answer is scored as correct if both figures are recognized correctly, therefore a maximum score of 20 was possible. For instructing this task, the approach by Peters et al. (60) was used. As it was important that the instructions and examples of this test are understood correctly, they were translated to German.

Self-Efficacy

Self-efficacy was recorded with a modified version of the technology self-efficacy questionnaire (61), where "computer" was rewritten to "VR". It was presented in the original language, English. On a scale of one to five, participants rate how strongly they agree with statements regarding their experience with VR. Low scores stand for low agreement with the statements.

Immersive Tendency

Immersive tendency was measured with the corresponding questionnaire by Witmer and Singer (46). The Immersive Tendency Questionnaire (ITQ) assesses a participant's immersive tendency, their current alertness as well as fitness, and their ability to focus. It was administered in its original version in English.

Presence

We adapted the single-item Mid Immersion Presence Questionnaire (MIPQ) (62, 63) to assess the experienced presence of our participants. The MIPQ consists of the orally presented question "To which extend do you feel present in the virtual environment, as if you were really there?". Participants rate their current presence on a scale from 0 to 10. Higher scores indicate higher presence. We, however, administered the question after the end of the VR exposure as part of the post-questionnaire.

Technology Literacy

Technology literacy was recorded with the fitting subscale from the technology affinity questionnaire by Karrer et al. (64). Participants were asked to rate their agreement with statements about their attitudes and skills regarding electronic devices. It was rated on a scale of one to five, with low scores indicating low agreement. This questionnaire was shown in its original language, German.

Cybersickness

We measured cybersickness before and after the exposition to VR using the Simulator Sickness Questionnaire (SSQ) (65) to rule out the often problematic zero-baseline assumption (66). This is to ensure that the application does not trigger extensive simulator sickness that risks the well-being of the user and influences the VR competence score. The SSQ scales range from 0 to 3. The total score was calculated as described by Kennedy et al. (65), where low scores indicate low sickness. The German translation of the items stems from Hösch (67).

Usability

The usability of the application was assessed post immersion with the System Usability Scale (SUS) (68) (German version by Rummel (69)) to ensure that possible usability issues do not confound the VR competence score. For this purpose, participants rated their agreement with statements about the application from one to five. It was scored as described by Brooke (68) with the best score possible being 100.

Demography

Participants were asked about their gender, age, nationality, education level, and current main occupation to better understand our sample. In order to ensure that participants experience the VR environment as intended, we also surveyed dexterity, possible visual and hearing impairments, as well as color blindness and language proficiency for English and German. Lastly, we asked participants about their technology usage to explore possible patterns in relation to our study measures. Those included VR experience in hours of use and number of expositions, video game play time per day, as well as internet, mobile phone and PC usage per day.

4.2 Apparatus

The study was conducted in a small lab where two workstations were placed, offering a final tracking space of about 3 by 4 meters. Lighting was controlled at all times with blinds to avoid issues with the tracking. The HMD used in the study was an Oculus Quest 2 with the accompanying controllers, no additional trackers were used. The HMD was connected with the PC via cable, utilizing the Meta Quest Link application version 68.0.0.515.361. The PC ran on Windows 10 Enterprise and had an Intel i9-13900K processor with the NVIDIA GeForce RTX 4080 graphics card and 64 Gigabyte RAM available. Just like in development, the VR competence assessment application ran on Unity 2022.3.23f1. The inter-pupillary distance of the HMD was set to the advised preset 2, which corresponds to 63 mm, suitable for most users.

4.3 Study Procedure and Piloting

After welcoming the participant, they were seated at a desk to complete the digital pre-questionnaire. It provided details on the study, like its duration as well as measured factors, and required informed consent. Participants were then given safety instructions for VR use, followed by an assessment of their spatial abilities and a pre-VR SSQ. As noted in subsection 4.1, questionnaires were administered in either German or English, depending on which version was available.

Next, participants received a verbal explanation of the VR application's purpose and structure, including a short explanation of the controllers. They then stood in a designated area, adjusted the HMD, and started the VR tasks described in section 3.

Upon completing the VR levels, participants returned to the PC used for the survey to complete further questionnaires, including the SSQ, one-item presence questionnaire, SUS, ITQ, self-efficacy and technology literacy assessments. Finally, demographic data were collected, and participants were asked to confirm the conscientiousness of their responses before being thanked for their participation.

This study procedure and the application itself were tested with three separate pilot studies. Through this feedback, structure, and clarity of the questionnaire were improved. Additionally, instructions for the VR levels and small bugs in the application were fixed beforehand.

4.4 Participants

The study was conducted as a lab study, recruiting participants via the institute's recruitment platform. Participants received credits mandatory for obtaining their program of study's final degree as compensation for their participation. A total of 18 participants were surveyed, of whom nine were male and nine were female. The age ranged from 20 to 28 years, with an average of 23.72 (*SD* = 2.42). Most participants were students (n = 16), with varying levels of VR experience. No participants reported color blindness or hearing impairments. However, nine participants presented with visual impairments. Specifically, five individuals wore glasses, three utilized contact lenses, and one had an uncorrected visual impairment. Despite this, the participant with uncorrected visual impairment was retained in the analysis after verbally confirming clear perception of the VR application. The remaining nine participants reported no visual impairments. All participants were native German speakers. Furthermore, 13 had been speaking English for over ten years, while the remaining five had between five and ten years of experience with the language.

5 RESULTS

In order to sort out inattentive participants, two attention-checks were included in the questionnaire, which were passed by all participants. Additionally, every participant indicated that they answered conscientiously at the end of the questionnaire. That way, all 18 participants could be evaluated. Data preprocessing was performed in Excel, with analysis conducted in JASP. The VR competence scores were normalized prior to the analysis for comparability across levels. To test our hypotheses, we used Pearson correlations, assuming normally distributed data with no outliers. If assumptions of normality or linearity were violated, or outliers were present, we used Spearman's ρ instead. Table 1 and Table 2 show the descriptive results of our performance measurements.

5.1 Control Variables

Presence

Participants reported a mean presence score of 7.28 (*SD* = 1.71), indicating a generally good experience of presence in the virtual environment. That way, the likelihood of negative effects on the data due to low presence is small.

Usability

The SUS yielded an average score of 81.5 (*SD* = 13.0) after reverse coding and scaling, which is considered good (70). This indicates that the usability of the system did not significantly influence participant performance in the VR competence assessment.

Cybersickness

We calculated the simulator sickness scores as described by Kennedy et al. (65). Four participants reported simulator sickness scores above 20 before the experimental trail. The change in symptoms between preand post-VR measures showed that five participants experienced no change, seven reported a decrease, and five had a slight increase, with a maximum of eight points. One participant had a significant increase of 45 points but was included in the analysis nevertheless, as they did not report any issues during or after VR use and were otherwise inconspicuous.

5.2 VR Competence

[Table 1 about here.]

[Table 2 about here.]

[Table 3 about here.]

Table 1 and Table 2 give an overview of the participants' performance across the eight levels of our VR application. In order to calculate the percentages, each level score was normalized to allow for comparison between the levels. As we only set the unattainable maximum scores of the levels using initial balancing with two colleagues, we used our measurements to improve our balancing and derive first thresholds. For this purpose, we used the highest achieved score and multiplied it by 1.2 to get a new, unattainable maximum score for each level. The calculated scores are as follows: Button press 36, Teleportation 96, Selection 59, Rotation 42, Scaling 31, Raycasting 110 and Touching 79.

We calculated Cronbach's α to assess the internal consistency and conduct an exploratory factor analysis of the VR competence assessment application. The internal consistency of the application was good, with $\alpha = .816$.

Next, it was of interest to look at each level score in detail. Due to the extensive nature of the findings, this section focuses exclusively on discussing prominent patterns. A complete overview of all results is provided in Table 4.

Spatial ability shared a significantly positive correlation with all levels but button press. This even surpassed VR experience in hours, which correlated significantly and positively with the levels scale, touch, teleport, rotate, and raycast. In comparison, the experience in frequency of usage only correlated positively and significantly with teleport, rotate, and raycast. Additionally, technology literacy demonstrated a significant positive relationship with the levels scale, rotate, and raycast. Immersive tendency, on the other hand, had significant positive correlations with select, teleport, and rotate. Presence and self-efficacy were only significantly correlated with the orientation level.

As spacial ability was most strongly associated with performance in executing 3D interactions, we explored whether it increases with previous VR experience. The Spearman's correlation test between spatial ability and VR experience in hours revealed a moderate, non-significant bidirectional relationship ($\rho = 0.444$, $p = 0.065$).

[Figure 5 about here.]

[Figure 6 about here.]

[Figure 7 about here.]

[Table 4 about here.]

5.3 Hypotheses Testing

The results for the hypotheses are summarized in Table 5.

VR Experience

A significant strong positive correlation was found between VR experience in hours (*M* = 7.08, *SD* = 6.32) and VR competence score, $\rho = 0.531$, *p* = 0.012, supporting H_1. Figure 7 visualizes the correlation.

The correlation between the number of exposures to VR (*M* = 10.58, *SD* = 6.80) and VR competence score was significant and moderately positive, $\rho = 0.445$, *p* = 0.032, supporting H_2.

Spatial Ability

A significant strong positive correlation was found between spatial ability (*M* = 14.56, *SD* = 3.49) and VR competence score, $\rho = 0.739$, $p < .001$, supporting H_3. Figure 5 visualizes the correlation.

Self-Efficacy

There was a moderate but non-significant positive correlation between self-efficacy (*M* = 69.22, *SD* = 9.98) and VR competence score, $\rho = 0.230$, *p* = 0.180, indicating that H_4 is not supported.

Immersive Tendency

A strong positive correlation between immersive tendency (*M* = 83.67, *SD* = 12.75) and VR competence score was significant, *r* = 0.560, *p* = 0.016, supporting H_5. Figure 6 visualizes the correlation.

Presence

The correlation between presence and VR competence score was moderately positive but not significant, $\rho = 0.314$, *p* = 0.102, leading to the conclusion that H_6 is not supported.

Technology Literacy

The correlation between technology literacy (*M* = 3.86, *SD* = 0.68) and VR competence score was moderately positive but non-significant, *r* = 0.337, *p* = 0.086, thus H_7 is not supported.

[Table 5 about here.]

6 DISCUSSION

The goals of our research project were twofold. We intended to investigate whether a specific VR competence can be measured. Additionally, we aimed at identifying human abilities and characteristics contributing to a VR competence. In general, our results indicate that individuals differ in their performance to execute 3D interactions in VR, and that our VR application successfully detected these differences between our participants. We further managed to identify human abilities that appear to have a direct connection with the performance of the users.

6.1 VR Competence

Using our VR application, we detected individual differences in the participants' performance in executing the tested 3D interactions. We hypothesized that a higher experience with using VR would improve the VR competence and hence positively affect a user's performance when executing grounding 3D interactions. The significant correlation between VR experience in hours and VR competence (H_1) validates the VR competence assessment application and confirms its ability to measure the VR competence and experience of users. Thus, we can accept H_1.

VR experience measured by number of exposures (H_2) also correlated with VR competence, though less strongly than hours of use. That way, it seems that the latter is a more accurate indicator of VR experience, as the number of exposures does not have any information on the length of each session. We can still accept H_2.

In terms of general feedback, participants provided positive feedback on the application. They described the levels as fun and interactive, with some likening them with respect to the mini-games and calling it one of the best VR studies they had participated in so far.

We did an exploratory factor analysis to check dimensionality of our VR competence measurement tool by computing Cronbach's α. The Cronbach's α analysis revealed a good internal consistency. As indicated in Table 3, all levels testing a user's performance in executing a specific interaction have a good consistency. Only the factor of the orientation level had a low inter-item covariance. This is explainable by the requirements of the task. While all other levels tested a user's performance in executing a specific interaction either with the hardware or the available 3D interaction metaphors, the orientation level mainly assessed spatial orientation. The participants needed to remember from where they came after several teleportations. Hence, the results are not contributing strongly to an individual VR competence level. However, when using VR applications for exams, being able to spatially orientate in the virtual environment might still be an important aspect. Thus, it should still remain a factor that is being tested when assessing a subject's VR competence.

As indicated in Table 4, the level for rotating and inserting an item correlated with five out of seven variables. This level combined various interaction metaphors at once, i.e., selection by touch as well as grabbing an object and carefully manipulating it. Hence, the level tests a user's overall VR competence with respect to interaction with objects and the virtual environment in general. The correlations observed support that our assumptions of a VR competence and its composition of human abilities and characteristics are correct. In contrast, the button press level did not correlate with any variable. This is explainable by the requirements of the task. The layout of a game controller and the distribution of the buttons mainly require hand-eye-coordination and the internalization of the controller's layout. The users need to spot the highlighted buttons and subsequently press it with the respective finger. In contrast, the tested 3D interaction techniques require users to overcome a certain level of abstraction with respect to representation as well as interaction modality. Also, 3D interaction techniques need to be spatially processed to be used effectively. Yet, when it comes to using VR applications for graded exams, testing a candidate's hand-eye-coordination and controller layout internalization might still be of importance. Hence, we argue to keep it part of a user's VR competence assessment.

Although our results are notable and allow researchers and educators to assess the VR competence level of their target group, they also spark future work. Importantly, the question arises as to what extent the demonstrated VR competence influences results of future VR-based exams. Pre-assessing VR competence would enable the correlation of individual VR competence levels with final grades from VR-based examinations. This could further clarify the significance of the aspects *spatial orientation* and *hardware proficiency* for exam performance.

6.2 VR Performance and Human Abilities

The strong correlation between spatial ability and VR competence (H_3) confirmed hypothesis 3. This is in line with previous research on its importance for object manipulation (34) and VR task performance (35). Also, it further supports research on observed mental rotation skill improvements when playing 3D computer games (71). This finding suggests that spatial ability may play a more critical role in VR interactions than previously assumed, as it correlated with all but one level. This could be important for developers and researchers who intend to train users in using their VR applications by providing an interactive tutorial. As our results indicate that the mere VR experience causes no direct training effect of a user's spatial ability, such a tutorial should ideally combine instructions about the central interactions of the respective application with tasks requiring spatial abilities. Such a combined approach might result in the strongest improvements of user performance.

The lack of a significant correlation between self-efficacy and VR competence (H_4) was unexpected. Although self-efficacy is linked to ease of use and intention to use VR (44, 43), it seems that these factors may be more relevant to the perception of the application than the actual user performance. Interestingly, self-efficacy did correlate with the orientation level, indicating its potential relevance for wayfinding in virtual environments.

A strong positive correlation was found between immersive tendency and VR competence (H_5). This is a novel finding since previous studies found no impact on learning gains (48), reading performance (49), or task accuracy (51). That way, our findings support the suggestion that individuals with higher immersive tendency might focus more effectively on tasks (48). Our study found that it is particularly relevant for object manipulation tasks in VR. Alternatively, as the ITQ also measures a subject's current alertness and fitness (46), users with a high immersive tendency score might have had higher energy levels during the experiment. To advance the research of the impacts of immersive tendency, it might be of interest to investigate whether the overall subjective ability to completely redirect the own awareness to a virtual situation or the current alertness and fitness influences task performance in VR.

Although a relationship between presence and VR competence was hypothesized (H_6), its absence is not too surprising, with prior research showing weak or indirect relationships with performance (55, 46). However, presence did correlate with the orientation task, supporting findings on how increased presence can enhance performance in spatial perception tasks (57). It also supports the concept of presence, indicating the realness of the virtual experience (26). When perceiving a virtual environment as real, users can compile a mental model for it more easily and hence point to their initial position with a higher accuracy.

The weak, non-significant correlation between technology literacy and VR competence (H_7) was surprising, especially given its theoretical relevance and connections in other domains like education (53, 54). One reason for this could be that the questionnaire items might not transfer well to VR technology. Looking at the individual levels, technology literacy correlated with object manipulation tasks and selection using raycast.

6.3 Limitations

This study has several limitations. First, the sample exclusively comprised students, predominantly from technology backgrounds and with prior VR experience. This limits the generalizability of the findings to broader populations, particularly those unfamiliar with VR. In addition, our sample size is rather small which might further limit the generalizability. Second, minor bugs within the application, such as unintentional teleportation during level transitions, occasionally disrupted the user experience. In these instances, verbal assistance from the experimenter may have inadvertently reduced user presence. Third, the spatial ability questionnaire proved to be both challenging and time-consuming. This could have contributed to participants reporting simulator sickness even before VR use, potentially affecting their subsequent performance within the VR environment. Fourth, while participants reported high English language proficiency, the assessment instruments in our questionnaire were administered in either German or English, depending on the availability of a validated translated version. Although this approach aimed to prevent issues from non-validated translations, it might have still influenced the accuracy of participants' self-reports. Finally, all participants completed the levels in an identical sequence, which may have introduced an order bias to the results.

Also, it is important to address the implementation of the VR competence assessment application. While we aimed at creating a general skill assessment, it is important to acknowledge that we are currently testing only a small subset of possible interaction techniques in VR. In the future, it would be ideal to create fitting levels for all possible types of interaction techniques, allowing the examiner to choose the ones relevant for their VR application.

7 CONCLUSION

The increasing integration of VR into educational contexts provides the opportunity for employing VR applications in graded examinations. Given that effective VR interaction relies on specific human abilities and characteristics, we postulate the existence of a distinct VR competence. VR competence is a subject's proficiency with VR input/output devices and the capacity of executing interaction metaphors as well as comprehending the information conveyed through them. For VR-based examinations, this inherent VR competence can affect a user's performance, thereby necessitating its explicit consideration. To investigate and quantify individual VR competence, we designed and developed a novel VR competence assessment application. This application incorporates eight distinct challenges, as illustrated in Figure 1, which are grounded in generic 3D interaction techniques. In a user study involving 18 participants, we systematically measured their performance within this application. We hypothesized that higher VR experience would correlate directly with heightened VR competence. Our analysis revealed a statistically significant positive correlation between participants' VR experience and their measured VR competence scores. This finding constitutes initial evidence for the validity of our assessment instrument in quantifying an individual's VR competence level.

To comprehensively explore the constituent elements of VR competence, we additionally administered questionnaires to record participants' levels of presence, immersive tendency, self-efficacy, technology literacy, and spatial ability. Our analyses demonstrated that spatial ability, and to a lesser extent immersive tendency, were strongly associated with higher VR competence scores. This insight empowers educators and researchers to not only assess but also proactively equalize the VR competence level of their subjects, thus ensuring fairer assessments. Furthermore, these findings provide guidance for designers in developing highly effective tutorials for novice VR users. Our study indicated that superior spatial ability directly enhances VR performance, suggesting the benefit of incorporating a spatial training aspect into the practice of general 3D interaction techniques.

Future work needs to focus on investigating whether the VR competence level influences a candidate's grade in a VR-based exam. To ensure similar conditions for a VR-based exam, e.g., objective structured clinical examinations, it should be integrated into a curriculum that already uses VR-based learning tools, e.g., emergency simulation training (8). By measuring the candidates' VR competence level, an in-depth analysis of the potential influences can be conducted. Also, it is of importance to advance the structure of the VR competence score by investigating the aspects of hardware knowledge and orientation in virtual environments. A last research avenue could be investigating VR competence training that takes into account the importance of simultaneous spatial ability training.

CONFLICT OF INTEREST STATEMENT

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.

AUTHOR CONTRIBUTIONS

SO and MH contributed equally to the conception of this research. SO and MH designed the user studies. MH analyzed the data. SO, MH, and TM wrote the manuscript. SO, MH, TM, VS, SK, and ML contributed to the final version of the manuscript.

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DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

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Table 1. Descriptive values for absolute scores in each level

Level	Mean	SD	Min	Max
Button	25.33	3.34	18	30
Select	36.11	7.09	24	49
Scale	17.61	5.19	9	26
Touch	49.17	8.51	34	66
Teleport	67.11	10.42	39	80
Rotate	26.17	4.91	17	35
Raycast	80.50	7.76	62	92

Table 2. Descriptive values for percentage scores in each level (in %)

Level	Mean	SD	Min	Max
Button	70	9	50	83
Orientation	81	16	48	99
Select	61	12	41	83
Scale	57	17	29	84
Touch	62	11	43	84
Teleport	70	11	41	83
Rotate	62	12	40	83
Raycast	73	07	56	84
Total	67	8	53	80

Table 3. Cronbach's α if scale items were dropped

Item	If item dropped Cronbach's α	Item-rest correlation
Button	0.806	0.460
Orientation	0.864	0.169
Select	0.781	0.637
Scale	0.794	0.582
Touch	0.795	0.543
Teleport	0.769	0.750
Rotate	0.762	0.773
Raycast	0.784	0.759

Table 4. Correlation between level scores and personal characteristics

		Button	Orientate	Select	Scale	Touch	Teleport	Rotate	Raycast
Spatial Ability	ρ	0.134	0.46 *	0.562 **	0.536 *	0.542 *	0.522 *	0.615 **	0.573 **
	p	0.298	0.027	0.008	0.011	0.01	0.013	0.003	0.006
Self-Efficacy	ρ	-0.283	0.42 *	0.011	0.164	0.15	0.06	0.278	0.198
	p	0.872	0.041	0.483	0.257	0.276	0.407	0.132	0.215
Immersive Tendency	ρ	0.074	0.299	0.556 **	0.397	0.106	0.463 *	0.505 *	0.331
	p	0.385	0.114	0.008	0.051	0.338	0.027	0.016	0.09
Presence	ρ	-0.11	0.53 *	0.085	0.103	-0.027	0.11	0.2	0.073
	p	0.668	0.012	0.369	0.342	0.543	0.332	0.213	0.387
Technology Literacy	ρ	0.097	0.288	0.037	0.483 *	0.174	0.222	0.425 *	0.436 *
	p	0.35	0.123	0.441	0.021	0.245	0.188	0.039	0.035
VR Hours	ρ	0.271	0.052	0.183	0.422 *	0.417 *	0.552 **	0.469 *	0.66 ***
	p	0.138	0.418	0.234	0.041	0.043	0.009	0.025	0.001
VR Exposures	ρ	0.348	-0.034	0.17	0.321	0.375	0.514 *	0.425 *	0.57 **
	p	0.079	0.554	0.25	0.097	0.063	0.015	0.039	0.007

Note. All tests one-tailed, for positive correlation. * $p < .05$, ** $p < .01$, *** $p < .001$

Table 5. Summary of hypotheses variables and their results

	Variable	Correlation	p-value	Supported
H_1	VR hours	$\rho = 0.531$	0.012	Yes
H_2	VR frequency	$\rho = 0.445$	0.032	Yes
H_3	Spatial ability	$\rho = 0.739$	$<.001$	Yes
H_4	Self-efficacy	$\rho = 0.230$	0.180	No
H_5	Immers. tendency	$r = 0.560$	0.016	Yes
H_6	Presence	$\rho = 0.314$	0.102	No
H_7	Tech. literacy	$r = 0.337$	0.086	No

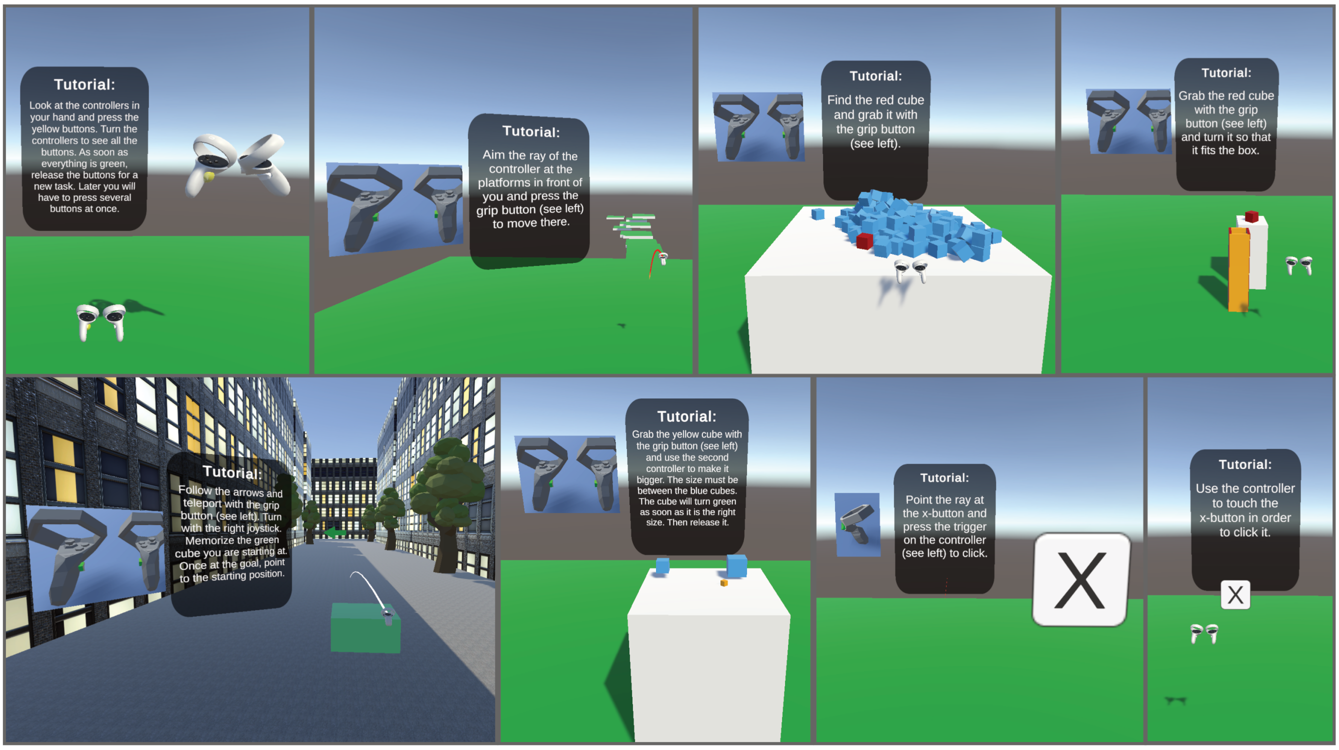

Figure 1. VR competence assessment level overview; From left to right, top to bottom: Button press, teleport, select, rotate & translate, orientation, scale, raycast and touch.

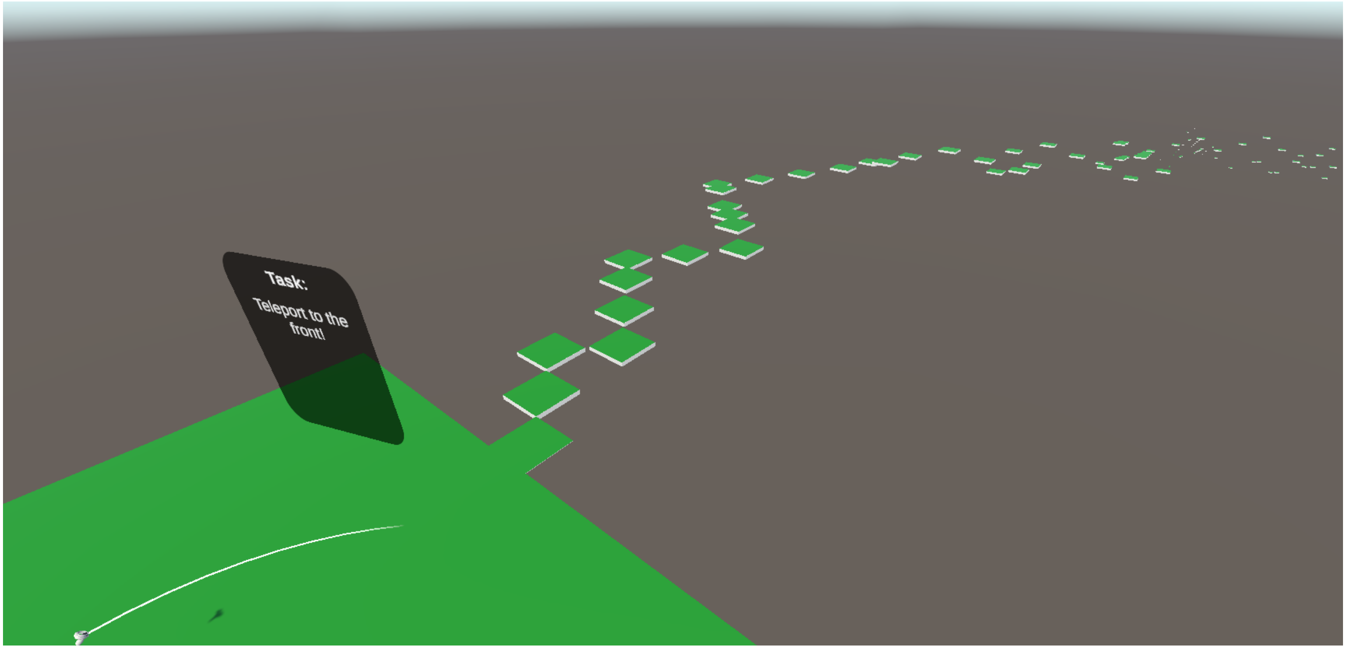

Figure 2. The travel level requires users to teleport from one small platform to the next, while the distance between the platforms increases and the size of the platforms decreases.

Figure 3. The rotation level requires users to grab a cube and move it into a nearby box, adjusting the cube's rotation and position.

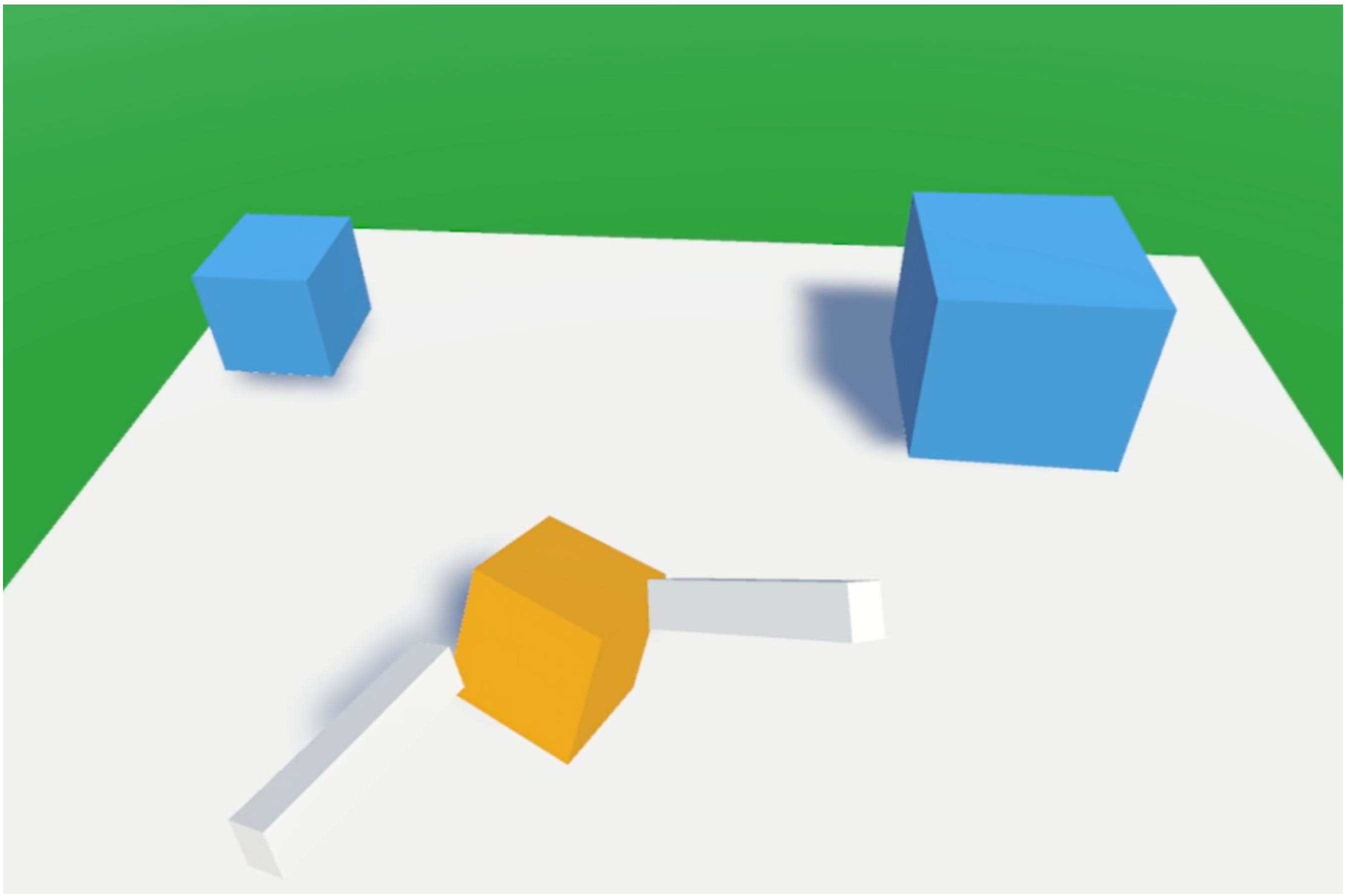

Figure 4. The scale level requires users to grab and scale a cube according to two reference cubes.

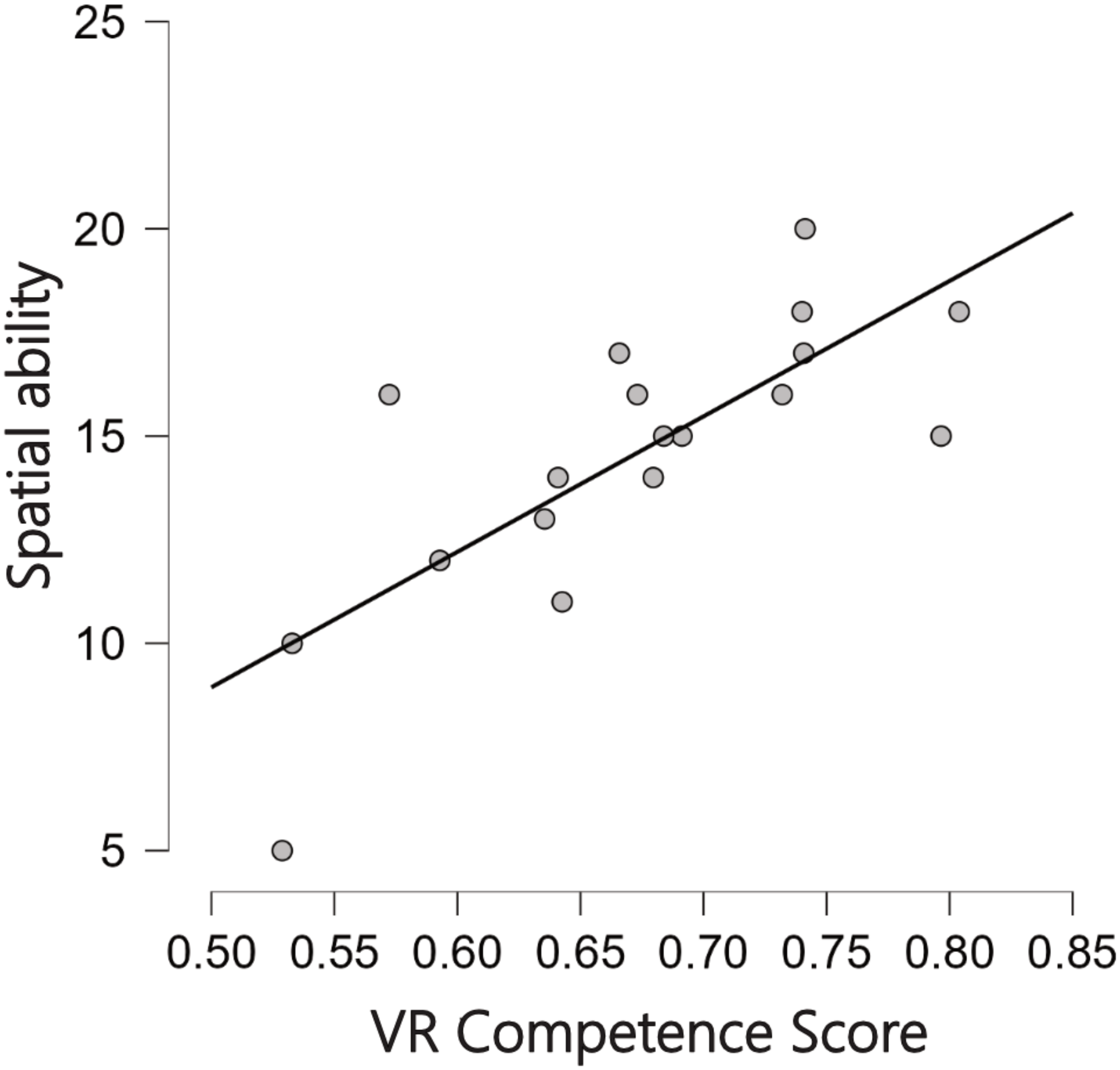

Figure 5. The scatterplot for spatial ability.

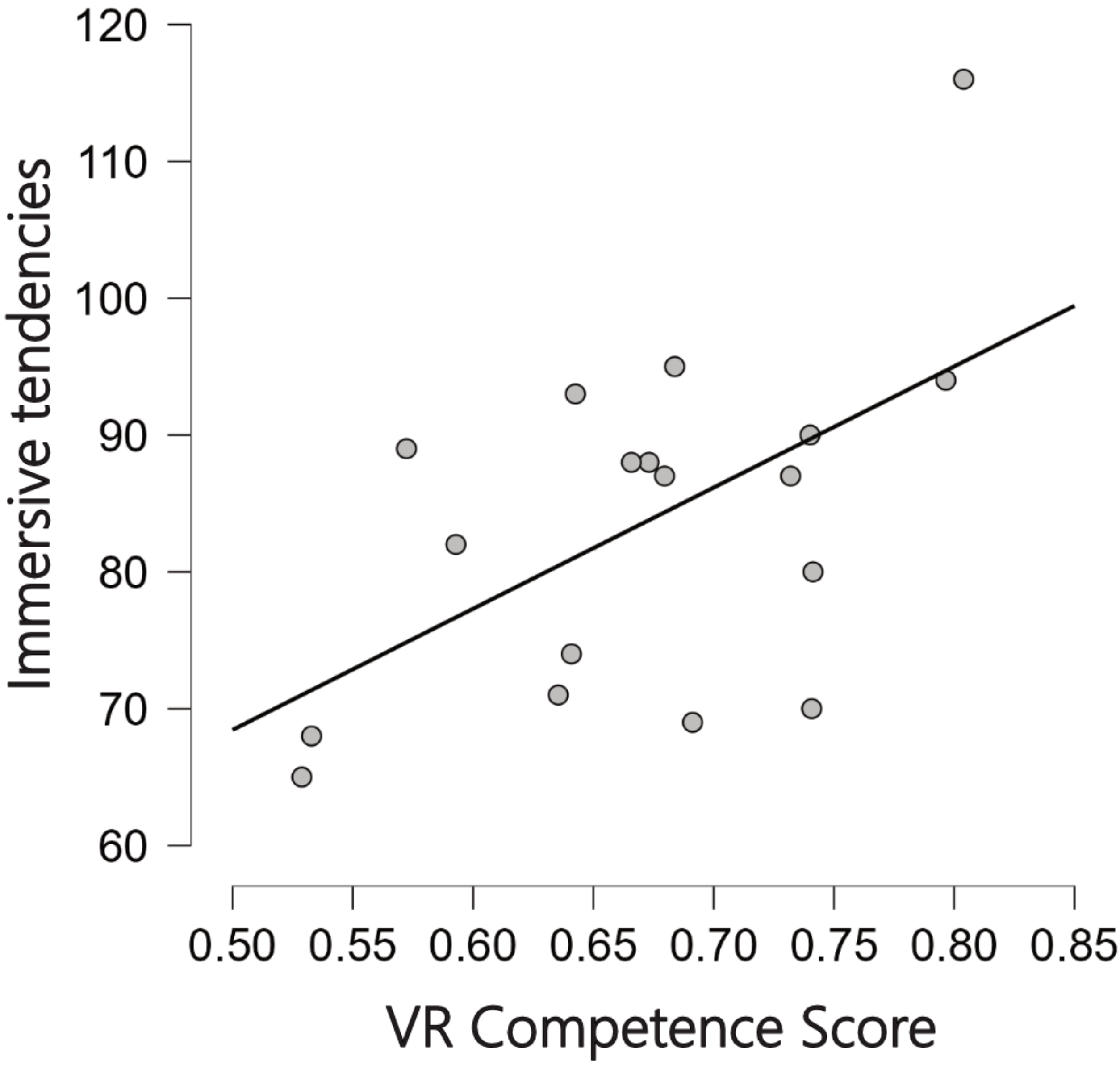

Figure 6. The scatterplot for immersive tendency.

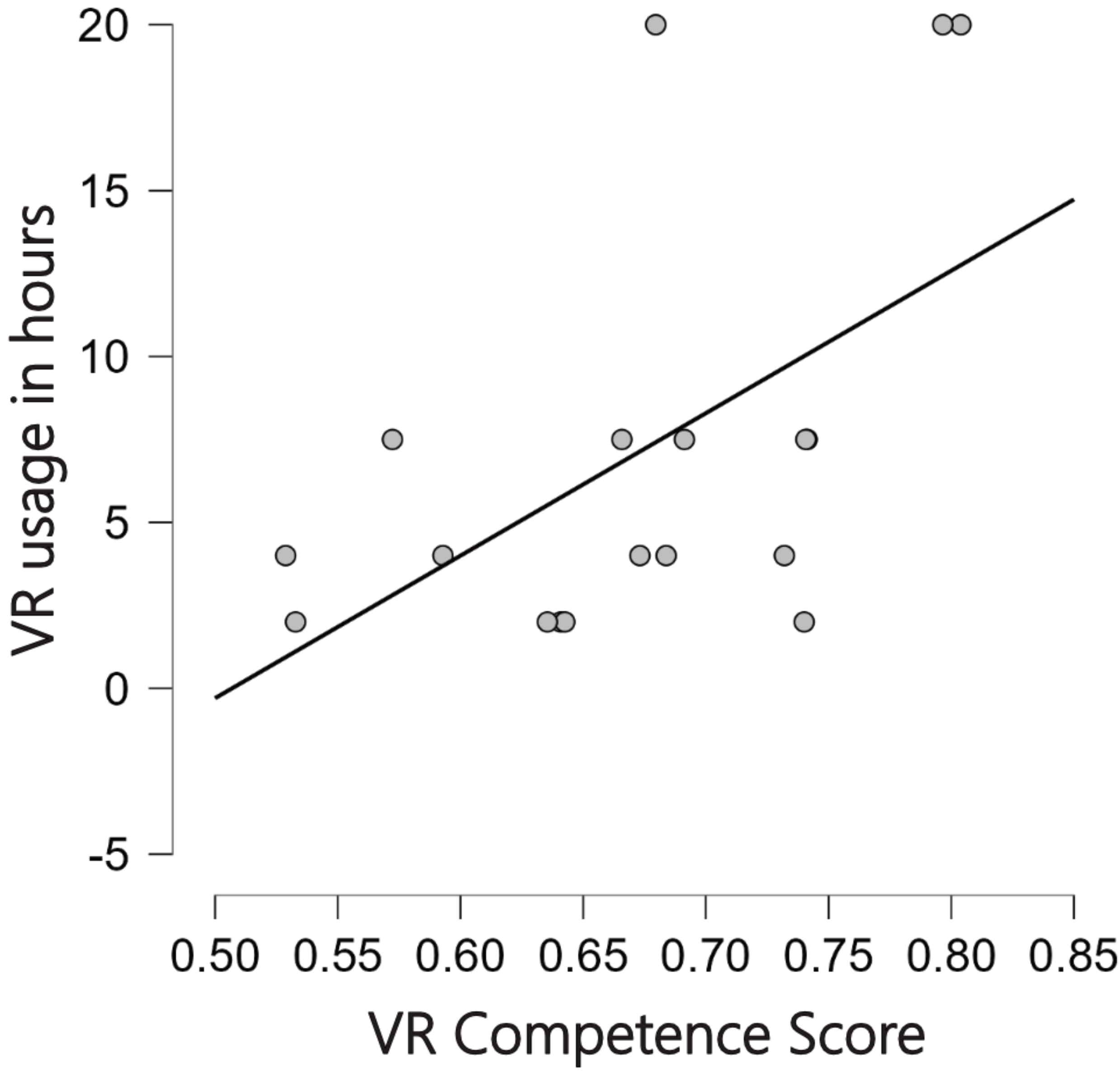

Figure 7. The scatterplot for VR experience.