Towards the Acceptance of Virtual Reality Technology for Cyclists

Research Paper

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Abstract. A popular digital indoor cycling platform is Zwift, which offers a variety of environments displayed on a screen in front of the user. Nevertheless, a virtual reality (VR) connection, which would make the training more immersive and could increase motivation, remains unavailable. Based on the scenario of a VR integration in Zwift, this study investigates the factors influencing the technology acceptance of 314 recreational and competitive cyclists using an extended Technology Acceptance Model (TAM). The findings show that perceived enjoyment and perceived usefulness are strong predictors for cyclists' acceptance, whereas perceived ease of use, in contrast to prior studies in a more general context, does not influence the acceptance. Moreover, social norms and technology openness are significant factors in evaluating technology acceptance. Our results contribute to the ongoing discussions on potential use cases of the VR technology as well as how digitalization influences sports, especially cycling.

Keywords: Technology Acceptance, TAM, Cycling, Extended Reality, XR.

1 Introduction

As the digitalization continues to pervade all aspects of contemporary life, sports is no exception. In the field of cycling, several technological advances have been made in recent years. One of the most significant and far-reaching innovations are indoor race simulations. Platforms such as Zwift and Rouvy enable cyclists to complete realistic race scenarios in virtual environments while competing against other athletes or participate in organized group rides (Parker et al. 2021; Westmattelmann et al. 2022). In these solutions, cyclists are equipped with a screen situated in front of their stationary bike, which displays a virtual racetrack based on their actual movement, which in turn is tracked by the sensors of their trainer.[1] This creates an engaging experience for the cyclists. The advantages of such platforms include a high degree of independence with regard to time, place, and other cyclists as well as the additional motivation provided by competition, which serves to enhance the incentives for regular training (Bentvelzen et al. 2022).

[1] https://www.zwift.com/

One promising way to further enhance the immersiveness, the feeling of being surrounded by a virtual world (Biocca & Levy 1995), of indoor training is the utilization of head-mounted displays (HMDs). HMDs are devices that are strapped to the head of the users and belong to the virtual reality (VR) technologies. VR enables users to fully immerse themselves into virtual worlds and fade out their real environment (Walsh & Pawlowski 2002). In comparison to augmented reality, which integrates virtual components with real objects in the physical world, VR exclusively incorporates virtual elements (Milgram et al. 1995). While some studies have categorized Zwift as virtual reality technology (Seong & Hong 2022), it is noticeable that it exhibits a rather low immersion when compared to HMDs, which are able to produce VR that fully immerse users in virtual worlds. Although VR has been successfully implemented in various fields, including gaming (Shelstad et al. 2017) and healthcare (Tao et al. 2021), its potential in the realm of sports remains largely theoretical.

The utilization of virtual reality for the purpose of indoor cycling training is associated with a number of advantages. Such devices cover the whole field of view of the cyclists, thereby offering the potential to realistically simulate visual outdoor conditions. Furthermore, it has been demonstrated that cycling in VR can increase the users' motivation and enjoyment compared to conventional training methods (Liu et al. 2019; Zeng et al. 2017). Moreover, VR training has the potential to enhance the duration and intensity of cycling sessions (McMahon et al. 2020; Saiz-Gonzalez et al. 2023). Although preliminary studies have demonstrated several potential benefits of VR cycling, the accdeptance of an integration into contemporary cycling training remains untested. However, the acceptance of cyclists is crucial for their usage behavior and adoption. We want to close this research gap between theoretical advantages and unexplored usage intention by examining whether cyclists would accept VR as training medium and identify factors influencing their acceptance. Our study is based on an extended version of the technology acceptance model (TAM) that includes the additional factors technology openness and subjective norms. The objective of the present study is to test the technology prior to its actual roll-out. This approach may appear unconventional at first glance; however, it is a common practice in technology acceptance literature (Mascret et al. 2022; Venkatesh & Bala 2008). In light of the aforementioned considerations, the present study seeks to address the following research question: *RQ1: "What factors influence cyclists' acceptance of virtual reality training?"* Furthermore, we compare whether the acceptance of VR technology differs between recreational and competitive cyclists in order to derive research opportunities and practical implications for the design of such VR cycling applications. We hence propose the research question: *RQ2: "Are there differences in the acceptance of VR cycling technologies between different levels of cyclists?"* For that purpose, we collected 314 responses to an online questionnaire, which we analyzed using structured equation modelling (SEM).

In order to respond to our research questions, we have structured the article as follows: First we review literature in the areas of VR sports, cycling, and their acceptance in Section 2. Then, we explain our research framework and methodology in Section 3 and Section 4. Following the statistical analysis presented in Section 5, we discuss the results and conclude our study in Section 6.

2 Related Work

VR devices allow users to fully immerse themselves into virtual environments, independent of external conditions, such as time and place. In the context of sports training, which often requires specific scenarios, HMDs present a viable alternative for the provision of immersive training and gaming experiences. Research in the area of VR sports already covers various disciplines, such as rowing (Arndt et al. 2018), skiing (Matsumoto et al. 2024), table tennis (Michalski et al. 2019), and weight lifting (Gulec et al. 2023). Nevertheless, the practical application of VR sports, especially cycling, remains in its infancy, with the technology currently mostly confined to theoretical cycling applications (Elsholz et al. 2025). While there are applications like Zwift that allow for virtual training, races, and social purposes (Westmattelmann et al. 2021a; Westmattelmann et al. 2021b), the usage of HMDs remains a theoretical construct (Elsholz et al. 2025). This low adoption rate may be due to current issues of sports in VR such as sweating under the headset and cybersickness, which can cause nausea and dizziness (Shaw et al. 2015).

In the domain of VR sports, several studies exist that focus on the technology acceptance. Based on literature, Kunz & Sanomier (2019) developed a model based on the Unified Theory of Acceptance and Use of Technology (UTAUT) 2, showing that performance expectancy, social influence, and hedonic motivation positively influence the behavioral intention for VR sports (Kunz & Santomier 2019). Mascret et al. (2022) investigated the technology acceptance of French athletes across various disciplines, employing the TAM by means of an online questionnaire. They identified perceived usefulness, perceived enjoyment, perceived ease of use, and subjective norms as important factors in athletes' acceptance of VR sports. Especially for 24 cyclists participating in their study, they observed that the means of subjective norms and intention to use were significantly lower than for other sports disciplines. However, the authors suggest that mentioning possible application areas for each sport individually could have led to other results (Mascret et al. 2022). Our study addresses this gap for cyclists by presenting them specific scenarios where VR could be employed. In the VR cycling field, literature pertaining to the construct of acceptance is rather rare. There are first studies that measure acceptance, albeit as a secondary outcome rather than as a primary focus of the study. Moreover, acceptance models such as the TAM were not evaluated in this domain to our knowledge. Instead, for instance, patients enrolled in a pulmonary rehabilitation program showed a high intention to use VR cycling (6.25/7 points) (Colombo et al. 2019). Moreover, the acceptance of a spatially immersive track cycling simulator was measured. Of the 50 participants in the study, 38 preferred the VR simulation in comparison to a conventional projector. Compared to static training, 90% of the users preferred exercising in VR (Yap 2018). Based on the promising results of recent works, this study aims to further explore the technology acceptance of VR cycling.

3 Research Framework

Cyclists' acceptance of VR technology is essential to facilitate its adoption once commercial solutions are available. In order to answer our first research question, which should identify factors influencing the technology acceptance, we relied on one of the most frequently used frameworks for evaluating technology acceptance, the TAM. It investigates psychological factors influencing the attitude towards the technology and the behavioral intention to use it (Davis 1989; Venkatesh & Davis 2000). The TAM states that perceived usefulness (PU) and perceived ease of use (PEOU) positively influence users' usage intentions, mediated by the attitude towards the technology. While PU describes the extent to which a person believes a technology will improve their performance, PEOU is the degree to which an individual believes that the technology usage will be effortless (Davis 1989; Venkatesh & Davis 2000). Since both factors are the main elements of the TAM (Davis 1989) and were proven to play a significant role in the acceptance of VR sports (Mascret et al. 2022), we propose:

H1: Perceived usefulness (PU) positively influences behavioral intention to use (BI).

H2: Perceived ease of use (PEOU) positively influences behavioral intention to use (BI).

Depending on the type of information system, hedonic or utilitarian, further variables can have an impact on the technology acceptance. For technologies with a hedonic dimension, e.g., entertaining cycling environments that aim to motivate users, perceived enjoyment (PE) also plays a major role in determining the usage intention (Van Der Heijden 2004). PE refers to the degree to which an information system is perceived as enjoyable, independent of performance consequeces (Davis et al. 1992). As virtual sports, and especially cycling, should motivate users and increase their enjoyment (Mascret et al. 2022), we state:

H3: Perceived enjoyment (PE) positively influences behavioral intention to use (BI).

As perceived ease of use, enjoyment, and usefulness are connected (Mascret et al. 2022; Van Der Heijden 2004), we state:

H4: Perceived enjoyment (PE) positively influences perceived usefulness (PU).

H5: Perceived ease of use (PEOU) positively influences perceived enjoyment (PE).

One major criticism of the TAM is that social factors are neglected (Venkatesh & Davis 2000), which is why the TAM was extended by subjective norms. Studies showed that subjective norms are a good predictor for perceived usefulness, perceived enjoyment, and perceived ease of use (Schepers & Wetzels 2007; Zhou & Feng 2017). Athletes who were positively influenced by their environment, such as trainers, family, or other athletes, tend to perceive information as evidence of reality, leading them to ascribe more positive attributes to a technology. In this context, we propose:

H6: Subjective norms (SN) positively influence perceived usefulness (PU).

H7: Subjective norms (SN) positively influence perceived enjoyment (PE).

H8: Subjective norms (SN) positively influence perceived ease of use (PEOU).

Moreover, technology openness represents a significant factor in users' acceptance of technology. Individuals with higher technology openness tend to perceive innovations as more useful due to their ability to discern added value (Agarwal & Prasad 1999; Camadan et al. 2018; Devaraj et al. 2008; Kim & Chiu 2019). Also, an individuals' perceived ease of use is positively influenced if their technology openness is high due to fewer reservations regarding novel technologies (Agarwal & Prasad 1999; Kim & Chiu 2019; McElroy et al. 2007). Finally, studies have demonstrated that technology openness significantly influences the perceived enjoyment derived from technology use. Individuals who are more open to new technologies display curiosity and a willingness to explore innovations. This disposition leads them to see the technology as an opportunity for personal enrichment and enjoyment (Agarwal & Prasad 1998; Guntuku et al. 2015). As technology openness plays a major role in understanding the technology acceptance, we state:

H9: Technology openness (TO) positively influences perceived usefulness (PU).

H10: Technology openness (TO) positively influences perceived enjoyment (PE).

H11: Technology openness (TO) positively influences perceived ease of use (PEOU).

A visual presentation of the research framework, including its evaluation, can be found in Section 5.1.

Furthermore, in oder to answer the second research question, which compares different levels of cyclists, we use the proposed model to conduct a multigroup analysis (MGA). This part of the analysis aims to identify suitable target groups for VR cycling and derive practival implications for the application design.

4 Methodology

For the report of our online questionnaire, we relied on the checklist for reporting results of internet e-surveys (CHERRIES) (Eysenbach 2004). In the following, we will present an overview of the study setup and data analysis.

In order to identify the factors that influence the acceptance of VR cycling, we propose an extended version of the TAM framework. We posted the survey online on LimeSurvey. The survey starts with an introductory text, which provides an overview of VR, indoor cycling training, and a description of the scenario, namely, the utilization of software such as Zwift for VR devices. Anyone could access the survey, however, we directly filtered whether the participants are cyclists. No registration was required to fill the questionnaire, and we offered no incentive to complete the questionnaire. The participants were recruited through the use of online cycling forums, social media, and student groups, employing the method of virtual snowball sampling (Baltar & Brunet 2012). Participation in the study was anonymous, voluntary, and all participants provided their consent to survey length, data storage, study investigators, and study purpose electronically. Prior to fielding, three reviewers tested the questionnaire. Data was collected between August and September 2024.

The online survey consisted of six blocks of questions, containing questions on cycling and VR experience, demographical data, general questions on VR cycling and specific TAM questions. Due to the inclusion of certain conditions in the questions, the total number of questions varied between 64 and 75 questions, with an approximate duration of ten minutes to complete. For the TAM questions, we applied a five-point Likert scale due to its high reliability and lower answer distortions due to a lower cognitive load (Cox 1980; Revilla et al. 2014). All items were measured from 1 (strongly disagree) to 5 (strongly agree). Our questions used for the survey were adapted from the original TAM and TAM2 questions (Davis 1989; Venkatesh & Davis 2000) and prior literature on the acceptance of VR sports apps (Mascret et al. 2020) or VR apps for other areas

(Byun et al. 2018). Questions on the technology openness were adapted from Agarwal & Prasad (1998). Example items for each construct are: "*I think using VR glasses would improve my training performance*" (PU), "*I think it would be easy to use the VR glasses*" (PEOU), "*I think using the VR glasses would make my indoor training more fun*" (PE), "*If the technology with VR glasses was available [...] I would use them for training*" (BI), "*I would use it if I heard from other people how good it would be for my training*" (SN), and "*I like to try out the functions of new technical systems*" (TO).

A total of 781 individuals started the survey. Of that total, 231 people aborted the study at an earlier stage and 550 individuals submitted their answers. Of those, we needed to exclude 197 answers that contained wrong answers to quality assurance questions (e.g., *"Quality assurance - please enter 4 here"*). In addition, 15 responses from individuals that never cycled and nine answers from underaged participants were excluded. In the final stage of the process, we excluded records with a considerable number of incomplete fields. The final sample is comprised of 314 responses. An overview of the participants' demographics is shown in Table 1.

Table 1. Participants' demographics

Category	**Characteristic**	**Frequency**	**Ratio**
Gender	Male	274	0.87
	Female	39	0.12
	No answer	1	0.00
Age	18-24	54	0.17
	25-34	94	0.30
	35-44	80	0.25
	45-54	57	0.18
	55-64	29	0.09
VR experience	Yes	199	0.63
	No	115	0.37
Cycling level	Competative (license, e.g., world team, continental team, elite amateur, amateur)	56	0.18
	Recreational (no license)	258	0.82
Zwift experience	Yes	198	0.63
	No	116	0.37

For the data analysis and the evaluation of the SEM, we used the statistical software JASP.[2] Following the literature on SEMs, a sample size of 200 is required for creating a robust SEM (Boomsma & Hoogland 2001), which is met by the present study with 314 participants. The TAM analysis begins with another descriptive analysis, where we calculated mean, standard deviation, skewness, and kurtosis for every TAM variable. Moreover, McDonald's omega was calculated to verify the internal consistency of each

[2] https://jasp-stats.org

variable (Dunn et al. 2014). In the literature, values above 0.6 are deemed acceptable and values above 0.7 are considered good (McNeish 2018). We checked that all values are above 0.7 to ensure a high internal consistency. Moreover, we analyzed the SEM results focusing on their path coefficients, standard errors, z-values, and p-levels. Significance was defined at $p < 0.05$. To assess the adequacy of the SEM in fitting the data, we evaluated the most important fit indices: Chi Square test, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Normed Fit Index (NFI), Incremental Fit Index (IFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). In accordance with the existent literature, we defined thresholds for the fit indices as follows: chi-square to degrees of freedom χ^2/df < 3.0, CFI > 0.9, TLI > 0.9, NFI > 0.9, IFI > 0.9, RMSEA < 0.08, and SRMR < 0.08 (Browne & Cudeck 1992; Hu & Bentler 1999; Kline 2023). In the final stage of the TAM assessment, we evaluated if there are noticeable discrepancies in the TAM scores between recreational and competitive athletes through a MGA. First, we examined differences in the TAM variables using t-tests (for items with similar variance in both groups) or Welch tests (for items with different variances in both groups). The Levene test was used to compare the variances. Then, we evaluated whether the path coefficients differ significantly by comparing the difference between both groups using the Welch-Satterthwaite test, which is suitable for constructs with different variances.

5 Results

Having described our data and metrics in the previous section, we now focus on the evaluation of the TAM. Furthermore, we conducted an MGA to find significant differences between different levels of cyclists.

5.1 Evaluation of the TAM

First, we calculated descriptive statistics for each TAM variable. For that purpose, mean, standard deviation, skewness, and kurtosis were calculated, as shown in Table 2. Further, McDonald's Omega was used to measure the internal consistency for the questions of each TAM variable. The research model proposed in Section 3 was assessed via a SEM in JASP. All hypotheses (H1-H11) were modeled through paths.

Table 2. Descriptive statistics of TAM variables

TAM variable	PU	PEOU	PE	BI	SN	TO
Mean	2.494	3.368	3.658	2.878	2.725	4.543
Std. deviation	0.954	0.775	1.064	1.013	0.935	0.523
Skewness	0.196	-0.068	-0.766	-0.168	0.084	-1.200
Kurtosis	-0.458	-0.073	-0.116	-0.648	-0.308	1.299
McDonald's omega	0.779	0.824	0.821	0.733	0.821	0.741

Table 3 shows the evaluation of the research hypotheses. The SEM was calculated with a maximum likelihood estimator and a 95% confidence interval. The results show that all hypotheses except for H2, H8, and H9 are supported. Hence, social norms influence the perceived usefulness and perceived enjoyment. Additionally, perceived enjoyment and perceived ease of use are positively influenced by technology openness. Perceived usefulness is significantly influenced by perceived enjoyment, which in turn depends on the users perceived ease of use. Finally, the behavioral intention to use VR cycling is influenced by perceived usefulness and perceived enjoyment. Of those significant hypotheses, five show a very high significance level of $p < 0.001$, while the other three hypotheses show a lower significance level of $0.001 < p < 0.05$. An overview of the path coefficients and significance levels is depicted in Figure 1.

Table 3. Regression coefficients of the TAM

Hpo-thesis	Construct	Esti-mate	Std. error	z-value	p-value	Result
H1	PU → BI	0.285	0.070	4.096	<0.001	Supported***
H2	PEOU → BI	0.006	0.072	0.080	0.936	Rejected
H3	PE → BI	0.682	0.067	10.104	<0.001	Supported***
H4	PE → PU	0.476	0.062	7.656	<0.001	Supported***
H5	PEOU → PE	0.449	0.096	4.693	<0.001	Supported***
H6	SN → PU	0.209	0.077	2.720	0.007	Supported*
H7	SN → PE	0.518	0.094	5.520	<0.001	Supported***
H8	SN → PEOU	0.091	0.068	1.327	0.185	Rejected
H9	TO → PU	-0.167	0.139	-1.198	0.231	Rejected
H10	TO → PE	0.453	0.191	2.374	0.018	Supported*
H11	TO → PEOU	0.497	0.171	2.907	0.004	Supported*

* significant for $p < 0.05$; *** significant for $p < 0.001$

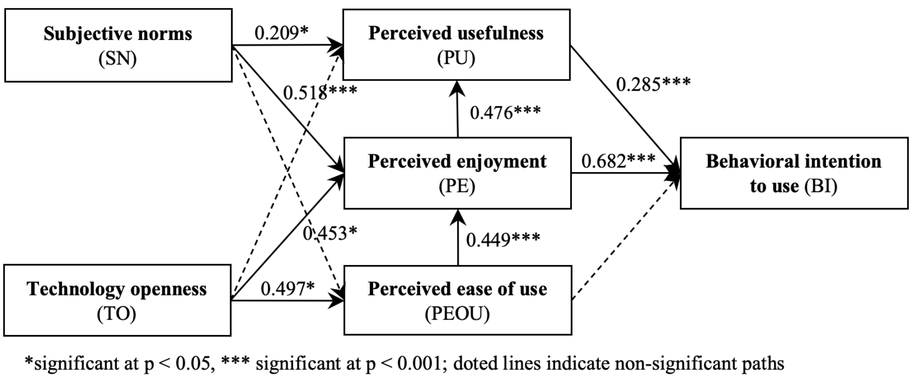

Figure 1. Results of the SEM

To assess the fit of the resulting SEM, we computed several fit indices, as described in Section 4. We found values of: χ^2/df = 0.880, CFI = 0.970, TLI = 0.961, NFI = 0.935, IFI = 0.971, RMSEA = 0.049, and SRMR = 0.040. All fit indices are far above the threahholds defined in Section 4, implying that the proposed model offers a good fit for the data.

5.2 Multigroup Analysis

While in the previous section we evaluated the TAM for the whole dataset, we now conduct an MGA to ascertain whether there are discrepancies between the acceptance of recreational and competitive cyclists. For that purpose, we first compared the values for each individual TAM item. In the second step, we compared the path coefficients of the SEMs for both groups. For the individual TAM items, the Levene test for variances determined whether a t-test or a Welch Test should be applied. Table 4 shows the results for each individual item. No TAM item showed a significant difference between recreational and competitive cyclists.

Table 4. Comparison of TAM variables for recreational and competitive cyclists

TAM variable	**Levene p-value**	**Equality of variances**	**t-p-value**	**Welch test p-value**	**Result**
PU	0.769	Equal	0.327	-	No significant difference
PEOU	0.672	Equal	0.962	-	No significant difference
PE	0.011	Inequal	-	0.146	No significant difference
BI	0.034	Inequal	-	0.522	No significant difference
SN	0.978	Equal	0.561	-	No significant difference
TO	0.008	Inequal	-	0.057	No significant difference

In the second step of the MGA, we compared the path coefficients for recreational and competitive cyclists. Since some of the TAM items have different variances, we relied on the Welch-Satterthwaite test for comparing the path coefficients, as shown in Table 5. The results of the test show that for most of the constructs, the regression coefficients do not significantly differ from each other. However, for H5 and H7, we could observe significant differences, i.e., competitive cyclists have a higher correlation between perceived ease of use and perceived enjoyment as well as subjective norms and perceived enjoyment.

6 Discussion and Conclusion

Based on an extended version of the TAM, we evaluated the acceptance of VR technology in the context of cycling. We surveyed 314 recreational and competitive cyclists online with the objective to identify factors influencing their intention to use VR cycling and finding discrepancies between the different levels of the cyclists. The results show that perceived enjoyment is the strongest predictor for cyclists' intention to use

VR cycling, followed by perceived usefulness. Furthermore, social norms and technology openness postitively contribute to their technology acceptance. Our findings allow for several contributions.

Table 5. Comparison of the regression coefficients of the MGA

Hypothesis	**Construct**	**Difference (recreational - competative)**	**p-value**	**Result**
H1	PU → BI	-0.069	0.459	No significant difference
H2	PEOU → BI	0.069	0.383	No significant difference
H3	PE → BI	-0.111	0.213	No significant difference
H4	PE → PU	0.221	0.110	No significant difference
H5	PEOU → PE	0.292	0.012	Significant difference*
H6	SN → PU	-0.217	0.097	No significant difference
H7	SN → PE	-0.173	0.043	Significant difference*
H8	SN → PEOU	0.236	0.084	No significant difference
H9	TO → PU	-0.121	0.238	No significant difference
H10	TO → PE	-0.187	0.086	No significant difference
H11	TO → PEOU	0.012	0.932	No significant difference

* significant for $p < 0.05$; *** significant for $p < 0.001$

First, we built upon the findings of Mascret et al. (2022), who examined the acceptance of VR in general sports. In their broader context, perceived usefulness and perceived ease of use were found to be strongest predictors of behavioral intention. However, in the specific case of VR cycling, perceived enjoyment emerged as a key factor in predicting users' intention to use the technology. This indicates that VR cycling is perceived as a hedonic information system rather than a utilitarian one (Van Der Heijden 2004). Cyclists seem to see most of the potential of VR in enhancing their training experience rather than in its ability to improve performance. This finding is consistent with the observations of Mascret et al. (2022) who noted that cyclists perceived the usefulness of VR training as significantly lower than athletes from other disciplines, with a sample size of 24 cyclists. Their result aligns with the findings of our descriptive analysis, which indicate that perceived usefulness had the lowest ratings among the three factors. Although cyclists recognize the potential for enhancing their experience and perceive VR cycling applications as easy to use, potentials for performance improvement and hence usefulness remain unidentified.

Second, we found one additional factor, namely technology openness, that was not regarded in former literature on the acceptance of VR sports. Technology openness strongly influenced perceived enjoyment and perceived ease of use of VR cycling. This result is not surprising since people who are open to technology tend to have fewer reservations about it (Agarwal & Prasad 1998; McElroy et al. 2007) and enjoy technology usage more (Guntuku et al. 2015). However, in the VR sports context, this important factor requires more attention.

Third, we highlighted the differces in acceptance between recreational and competitive cyclists. While most current research does not define a target group or focuses on beginners, and commercial VR sports applications are accessible for any group (Elsholz et al. 2025), we showed that in the context of VR cycling there are no significant differences between both groups. Instead, both recreational and competitive cyclists perceive VR cycling as easy to use and enjoyable rather than useful. The comparison of TAM path coefficients of the hypotheses, however, has revealed some significant discrepancies between recreational and competitive cyclists. The perceived enjoyment of competitive cyclists was found to be more strongly influenced by their subjective norms and perceived ease of use than of recreational cyclists. This is not surprising since competitive athletes are more susceptible to social influences as they are active in training communities where adherence to standards is important (Hagger & Chatzisarantis 2007). Social pressure could therefore increase the motivation to utilize novel cycling technologies. In terms of wider research into VR sports, this means that there is a need to study not only novices, but also more professional groups to identify use cases that enhance their performance.

Fourth, we contribute to the broader discussion on how VR technology can change human lives for the better. While VR has already found application in other areas, most notably gaming (Stecuła 2022), the field of sports, and cycling in particular, remains in its infancy. The majority of commercial applications are so called exergames, which are designed for fun purposes rather than training (Elsholz et al. 2025). Hence, it is important to ascertain whether VR would be accepted beyond its current gaming purposes. Although the research has demonstrated several physical benefits of VR cycling, cyclists especially recognize the hedonic attributes of VR, showing that ultriliarian attributes and use cases are unexplored and require further attention and promotion.

Finally, we also contribute to the general discussion on how virtual technologies can contribute to cycling training, beyond the COVID-19 pandemic. Previous literatue already focused on how virtual cycling based on a non-immersive version of Zwift is perceived by athletes. It was demonstrated that cyclists perceived digital races mostly as positive, thereby highlighting advantages such as financial and time effort, broadcasting opportunities, and cooperation with the team (Westmattelmann et al. 2021b). However, examining the next step of the virtualization, our study showed that cyclists have reservations: We observed that the general intention to use VR cycling was at an intermediate level (2.9/5 points). This is in contrast to the results reported by Mascret et al. (2022) who observed a much higher level of intent (3.8/5 points) for sports in general. This discrepancy suggests that VR cyclists may exhibit a particular degree of skepticism towards this technology. This could have several reasons: (a) the existence of several platforms that already fulfil most of the needs regarding indoor cycling, e.g., Zwift or Rouvy, (b) lower need for visual cues in comparison to other disciplines where VR can help with skill acquisition and (c) the current limitations in graphics quality of available headsets. An actual trial of VR cycling applications to demonstrate possible features could, however, increase their acceptance (Venkatesh & Bala 2008).

Besides the theoretical implications of our study that are highlighted above, our results have several practical implications that are outlied in the following guideline. As our results show, behavioral intention was stongly influenced by cyclists perceived usefulness and perceived enjoyment, however the perceived ease of use had no influence on the intentions. From a practical point of view, this implies that developers should focus on two key areas, enjoyment and the implementation of useful functions, to reach the highest acceptance. The inclusion of engaging environments and gamification elements is a simple recommendation to increase the enjoyment. However, based on the relatively low mean scores for perceived usefulness, we note that cyclists seem to have problems in identifiying how VR training could improve their performance to in turn find the application useful. While the hedonic potential has already been acknowledged, the potential benefits of VR training, such as lowering perceived pain and exertion (McDonough et al. 2020; Wender et al. 2019), require further promotion. One potential avenue for promoting the positive utilitarian effects is through the involvement of cyclists' fitness trainers, as the social environment of athletes strongly influences their behavior (Donohue et al. 2007). Furthermore, our results show that recreational and competitive athletes exhibit similar levels of acceptance. Hence, it is necessary to develop use cases for both groups in order to enhance their perceived usefulness and, ultimately, their usage intention. Potential applications for recreational cyclists include the discovery of diverse and engaging sceneries which allows them to combine entertainment and indoor training from home. Given the significant role that subjective norms play in perceived usefulness, social aspects should also be considered. With regard to applications for professional cyclists, specific race segments could be trained before a real race. In addition, real-time feedback regarding posture, pedal movement, or cadence could represent interesting application fields of VR cycling.

Finally, we would like to stress the limitations of the present study, thereby establishing a foundation for future research avenues. Our first limitation is the sample diversity: The survey was conducted exclusively with German cyclists. The findings therefore might not be generalizable to other countries with different sport cultures and ecosystems. In the future, it would be interesting to investigate whether the results also apply to an international audience. Furthermore, the survey was predominantly answered by male respondents (87%). The homogenous sample in terms of gender was not intended and is likely attributable to the predominance of male members within the online cycling community. Therefore, it is possible that this limits the generalizability of the results to female cyclists. Secondly, our study was based on a theoretical scenario rather than an actual trial. Although this is a common approach in the technology acceptancy research, e.g., Li et al. (2019) and Mascret et al. (2022), an actual trial could impact the results. We hence suggest testing the acceptance of VR cycling based on an actual trial. Furthermore, we propose to investigate additional factors, beyond subjective norms and technology openness, that could have an influence on the technology acceptance. The UTAUT model, which is an extension of the TAM, identifies several additional factors that influence the technology acceptance, including performance expectancy, effort expectancy, and facilitating conditions (Venkatesh et al. 2012), and may therefore be a suitable choice for future research. Additionally, future research on the acceptance of VR for cycling should adress VR-specific challenges, such as sweating, cybersickness, and headsets shifting due to intense movements, as these factors may influence the behavioral intention.

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