Virtual Reality Could Improve Exercise Performance on a Stationary Bike

Abstract: The present study aimed to investigate the effects of manipulating visual information about one’s movement in Virtual Reality (VR) during physical training on a stationary bike. In the first experiment, the participants’ \(N=30\) task was to cycle on a stationary bike while embodying a virtual avatar. Fifteen participants experienced the Slow condition, in which a virtual avatar cycled at the constant speed of 15km/h, while the other fifteen participants experienced the Fast condition, in which a virtual avatar cycled at the constant speed of 35km/h. In the second experiment, we tested whether introducing agency (i.e., linking real-life cycling speed with the cycling speed of a virtual avatar), would improve exercise performance. Participants \(N=31\) experienced counterbalanced conditions: Faster optic flow (avatar’s speed was 15% faster than the participants’ real cycling speed), and Slower optic flow (avatar’s speed was 15% slower than the participants’ real cycling speed). Results showed that all participants increased their cycling speed when experiencing altered cycling speed of a virtual avatar compared with their baselines, but in the first experiment, participants cycled faster in the faster optic flow condition, while in the second experiment, when participants controlled the virtual avatar’s cycling speed, there were no differences between the Fast and Slow conditions. Participants described the cycling in VR as a pleasant experience. The present study suggests that the addition of Virtual Reality during exercise training may increase cycling performance.

Keywords: Virtual Reality; stationary bike; cycling; optic flow; physical training.

INTRODUCTION

Virtual Reality (VR) has been successfully used in various areas of psychology (Slater & Sanchez-Vives, 2016). It is widely recognized as an effective tool used to: reduce pain (Atzori et al., 2019; Malloy & Milling, 2010), fear (e.g., of spiders, heights, or movement: Fowler et al., 2019; Garcia-Palacios et al., 2002; Parsons & Rizzo, 2008; Rothbaum et al., 2000); social bias (Peck et al., 2013), influence physiology (Czub & Kowal, 2019), or enhance learning (Caro et al., 2018). Another large area in which VR has a vast potential is a sport (Bideau et al., 2009).

To date, many scholars explored the effects of using VR during physical activity. For instance, VR was used to test the power of social facilitation in sport (Anderson-Haney et al., 2011); increase motivation towards training (Bryanton et al., 2006; Finkelstein & Suma, 2011); decrease boredom and fatigue during physical activity (Annesi, 2001), or even decrease pain (Wender et al., 2019). Although the main goal of most of the studies was to improve athletes’ performance training with the help of VR, the agreement has not been yet reached upon the specific conditions under which usage of VR in sport is the most effective.

For instance, in MacRae (2003) study, participants cycled on a stationary bike with either the music and VR or only with the music. Results provided evidence that participants cycled at a higher speed in the condition with VR. Another study (IJsselsteijn et al., 2006) explored whether the level of immersion in Virtual Reality affects the effectiveness of training on a stationary bike. Analysis showed that participants who embodied a virtual avatar from the 1st person perspective (as compared with the 3rd person perspective), cycled at a higher speed, reported less intense fatigue, and higher psychological involvement in training. A similar experiment was conducted by Huang and colleagues (2008). Participants cycled in three conditions: with screens placed in front of them, with Head Mounted Display (HMD), and without VR in any form. Virtual Reality applied via HMD was found to be the
most effective: participants cycled at the highest speed and reported the least fatigue compared with other groups.

Another uncertain issue is whether feedback about one’s performance has a positive impact on sports performance. In Micklewright and colleagues (2010) study, false feedback (displayed on a computer bike’s monitor) did not influence the effectiveness of physical training. Participants from a false feedback condition did not modify their cycling speed (but, interestingly, participants from a blind feedback condition cycled with a faster average speed). On the other hand, Albertus et al. (2005) showed no differences in cycling speed between participants who were given accurate, inaccurate, and random oral distance feedback.

Different results were yielded when feedback was provided via VR (Shei et al., 2016). In Shei et al. (2016) study, participants were deceived into thinking that the speed of a virtual avatar was set to match their own speed from a previously recorded day. The real speed was set to be 2% higher (102% of the initial participants’ speed from the previous day). Results showed that participants who were convinced that they were cycling at the same pace as previously, cycled, in fact, faster (by approximately 2%) than the control group. Using the same 4-km time trial design, other studies also confirmed findings of Shei et al. (2016) study. Participants, led to believe they are competing with the virtual avatar of their prior performance (while in fact, the virtual avatar cycled 2% faster), cycled faster the same 4-km distance by an average of six seconds as compared to the baseline (Ansdell et al., 2018), 6.2 seconds (Stone et al., 2012), or 16 seconds (Jones et al., 2016).

Further insight into VR, false feedback, and optic flow (i.e., retinal motion arising because of the observer’s movement; Warren & Rushton, 2009) was provided by Parry et al. (2012) study. The authors conducted a within-subject experiment, in which participants cycled in VR on a stationary bike in three conditions: (1) when both avatar’s and person’s speed was equal, (2) when avatar’s speed was 15% faster than participants’ speed, and (3) when avatar’s speed was 15% slower than participants’ speed. Participants cycled at the highest speed in slower optic flow condition (when the avatar’s speed was decreased by 15% from the person’s real cycling speed), what, contrary to Shei et al. (2016) study, suggests that faster optic flow does not lead to faster cycling speed.

Considering the discrepancies in previous studies, we decided to investigate the relationship between the perception of movement speed in VR, and the effectiveness of physical training on a stationary bike. We aimed to shed some more light on the conditions under which physical training is the most efficient. In two experiments, we manipulated virtual speed in VR (the first and second experiment) and control over the speed of a cycling virtual avatar (the second experiment). We hypothesized that different visual cues (increased or decreased cycling speed in Virtual Reality) would lead to differences in real-life cycling speed; we also predicted that control over the cycling avatar would affect the participants’ cycling speed.
helped the participant to remove the HMD and administered the questionnaire.

Half of the participants experienced Fast condition, and the other half experienced Slow condition:
1. Fast condition–during the first 2 minutes and 10 seconds, a virtual avatar cycled at the 15 km/h (baseline). Immediately after the baseline, a virtual avatar started to increase his speed, up to 35 km/h, and maintained this velocity until 15 seconds before the end, when he started to slow down, until the complete stop of cycling.
2. Slow condition–the only difference between the Fast condition was that the virtual avatar remained cycling at the 15 km/h entire for the entire time, until the 15 seconds before the end, when he started to slow down, until the complete stop of cycling.

Statistical analyses
In the first step, we conducted a repeated-measures ANOVA to assess the differences within-subjects (baseline vs condition), and between participants (Fast vs Slow condition), followed by post-hoc comparisons with Tukey correction. In the next step, using paired samples t-test, we analyzed participants’ subjective estimation of the time that passed during cycling, and traveled distance with real-time and real covered distance. All statistical analyses were performed using Jamovi (version 1.0).

Results
We found differences in participants’ cycling speed between baselines and conditions, $F(1,29)=26.61, p<.001, \eta_p^2=.48$, and also in cycling speed between participants from Fast versus Slow condition, $F(1,29)=8.92, p<.01, \eta_p^2=.24$. Post-hoc comparisons revealed that differences in cycling speed during baselines between Fast ($M=26.04$ km/h, $SD=5.32$ km/h), and Slow condition ($M=21.47$ km/h, $SD=4.58$ km/h) were non-significant, $t(29)=2.57, p>.07$, whereas there were significant differences between cycling speed during Fast ($M=29.83$ km/h, $SD=5.34$ km/h) and Slow condition ($M=24.56$ km/h, $SD=4.54$ km/h), $t(29)=2.97, p<.05$. Results showed that participants from both conditions increased their cycling speed after the baseline (Fast condition: $t(29)=3.96, p<.01$; speed increase by 16.32%, $SD=14.77$; Slow condition: $t(29)=3.33, p<.05$, speed increase by 16.32%, $SD=14.77$).

In the Fast condition, participants overestimated traveled distance on average by 9%, and the time they traveled by 4%. Nevertheless, distance estimations compared with the real traveled distance were non-significant ($t(14)=0.58; p=57$). In the Slow condition, participants overestimated the traveled distance on average by 12%, and they underestimated the time they traveled by 4%. Again, differences between distance estimations and real covered distance were non-significant ($t(15)=0.76; p=.46$). Participants described the cycling experience as pleasant ($M=4.07; SD=0.66$; a scale ranged from zero to five, where five indicated the highest pleasure); and they also felt a high level of immersion into the virtual world ($M=4.03; SD=0.75$; a scale ranged from zero to five, where five indicated the highest immersion). See Table 1 for detailed participants’ descriptive.

Discussion
We expected that participants assigned to different conditions (i.e., Slow and Fast) would cycle at different speeds. Results revealed that, contrary to Parry et al. (2012) study, participants cycled faster in Fast condition than in Slow condition (i.e., participants cycled faster when they saw the virtual avatar cycling at 35 km/h compared with Slow condition, when participants saw the virtual avatar cycling at 15 km/h). Surprisingly though, participants from both groups increased their overall speed during manipulation phases compared with the baseline. This may indicate that false visual feedback leads to increased power output, regardless of the direction (either slowed down or speed up). However, because we did not include a non-VR control group, the observed effect can also be attributed to the warming-up effect or other factors related to performing the cycling exercise.

A general tendency to increase efforts while experiencing VR may be explained by one’s fatigue perception. The consequences of immersion in Virtual Reality include paying more than usual attention to the visual channel (Slater & Sanchez-Vives, 2016), which favors visual rather than interoceptive cues when assessing own fatigue and bodily exertion. For instance, in Milanez et al. (2011) study, participants experiencing VR decreased their Ratings of Perceived Exertion (RPE), and paid more attention to the visual, rather than other interoceptive stimuli. Being focused on the virtual and not real-world allowed participants to achieve objectively higher output while not experiencing the negative effects of the bodily exertion on the conscious level. Other studies (MacRae, 2003; Robergs et al., 1998) provide evidence supporting this view: adding VR to the training helps people to dissociate from their exhaustion, which, in turn, leads to better performance. Moreover, in accordance with previous studies (Hou et al., 2018), participants rated the cycling experience in the first experiment as pleasant. Thus, another explanation of the observed phenomenon may be that higher than usual entertainment during cycling on a bike (due to the addition of VR), fostered increased power output (i.e., cycling speed).

The cycling speed of a virtual avatar in the first experiment was independent of the participant’s speed (it was either 15 km/h or 35 km/h) throughout the whole time. As previous studies provided only indirect evidence that the control over a virtual avatar may be beneficial in terms of higher motivation (Kim & Biocca, 2018), or engagement (Birk et al., 2016), we wondered, whether participants’ control over the virtual speed would positively affect participants’ cycling speed.

STUDY 2
In the second experiment, we intended to increase the level of participants’ control over the virtual speed. We used a smartphone, which was attached to a participant’s leg, and measured participant’s movement. The smartphone was synchronized with the computer software, which governed what the participant saw in VR. This
allowed us to allocate the control over cycling speed to the participant. Moreover, not only optic flow and the speed of the virtual bike were under the participant’s control, but also the movement of the avatar’s legs. We expected that greater control over the avatar’s body and virtual speed would cause a more substantial increase in the participant’s speed of cycling on a physical bike.

Materials and Methods

Participants
Thirty persons, different from the first experiment (13 women and 17 men) participated in this study (age $M=26.02$, $SD=5.94$). All participants were users of the local gym, where the study was conducted; participants were not compensated for participation in the study. Each participant provided informed consent to take part in the study, in accordance with the Declaration of Helsinki.

Equipment
Equipment and set were almost the same as in the first experiment. The only difference was the addition of the bracelet (with Samsung Galaxy s5 attached), worn by participants on the right leg, at the height of the calf. The smartphone was sending the data from the inbuilt accelerometer (Anguita et al., 2012) to the computer software. This allowed matching real-life participant’s cycling speed with the cycling speed of a virtual avatar.

Measures
Attitudes towards the game scale—in an explorative vein, all participants completed a questionnaire, modified from the first study. Questions included: subjective measures of one’s speed (‘How fast were you cycling [in km/h]?’), time (‘For how long were you cycling?’), and a general perception of the experience (‘How pleasant was the cycling?’, ‘How much would you like to train on a stationary bike with Virtual Reality in the future?’) on an 11-point scale, ranging from zero to ten (a higher number indicated a higher agreement with the statement in the question).

Procedure
All participants experienced three phases with two three-minutes breaks in between:

1. 2 minutes 10 seconds - baseline. Virtual avatar cycling speed matched the participant’s real-life cycling speed. 3 minutes break
2. 5 minutes of cycling with the Slower optic flow. Virtual avatar cycled 15% slower than the participant. 3 minutes break
3. 5 minutes of cycling with the Faster optic flow. Virtual avatar cycled 15% faster than the participant.

The order of phases II and III was counterbalanced. Half of the subjects cycled first with the Slower optic flow (and then with the Faster optic flow), and the other half cycled first with the Faster optic flow (and then with the Slower optic flow). Figure 1 represents the cycling protocol in both experiments.

Statistical analyses
In the first step, we tested with ANOVA whether the condition order (i.e., whether a person first experienced Faster or Slower optic flow) affected participants’ cycling speed. Next, we conducted repeated-measures ANOVA to assess whether cycling speed during the baseline and two conditions (i.e., Slower and Faster optic flow) was different. We also followed the analyses with post-hoc comparisons (with Tukey correction). Next, using paired samples t-test, we analyzed participants’ subjective estimation of the time that passed during cycling and traveled distance with real-time and real covered distance. All statistical analyses were performed using Jamovi (version 1.0).

Results
Analysis showed that the condition order did not affect participants’ cycling speed, $F(1,28)=.05$, $p=.82$, $\eta_p^2=.00$. There were statistically significant differences in participants’ cycling speed across the three phases (baseline, Slower, and Faster optic flow), $F(2,56)=21.33$, $p<.001$, $\eta_p^2=.43$.

Post-hoc comparisons revealed that differences in cycling speed during baseline ($M=27.15$ km/h, $SD=7.03$ km/h) and Faster optic flow ($M=31.33$km/h, $SD=5.51$ km/h), and during baseline and Slower optic flow ($M=31.89$ km/h, $SD=5.85$ km/h) were statistically significant ($t_{(28)}=-4.45$, $p<.001$, increase in speed by 20.23%, $SD=18.12$; $t_{(28)}=-5.05$, $p<.001$, by 22.12%,

Figure 1. Cycling protocols in both experiments (in the first experiment, half of the participants experienced the Fast condition, while the other half—the Slow condition; in the second experiment, all participants experienced both the Fast and Slow conditions in a counterbalanced order).
In the second experiment, a similar tendency to increase a cycling speed as in the first experiment was observed. Participants after the baseline cycled faster, regardless of the condition (i.e., Faster or Slower optic flow). Nevertheless, contrary to the first experiment, there were no differences in cycling speed between the two conditions—participants increased their speed similarly in both Faster and Slower optic flow conditions. The condition order (i.e., whether a person at first cycled in Faster or in Slower optic flow) did not affect the observed pattern. Moreover, similarly to the first experiment, participants overestimated the distance they traveled, but underestimated the time that passed during cycling; participants also indicated that cycling was pleasant for them, and they would be willing to use VR in future training.

### GENERAL DISCUSSION

The present study aimed to investigate the influence of visual motion cues in Virtual Reality on the effectiveness of physical training on a stationary bike. We conducted two experiments to test, whether manipulating

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**Table 1. Participants’ descriptive across two experiments.**

<table>
<thead>
<tr>
<th></th>
<th>First experiment</th>
<th>Second experiment</th>
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<tbody>
<tr>
<td></td>
<td>N (%) / Mean (SD)</td>
<td>Range</td>
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<tr>
<td>A number of participants</td>
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<td>–</td>
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<tr>
<td>Men</td>
<td>18 (58%)</td>
<td>–</td>
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<tr>
<td>Age</td>
<td>28.61 (7.63)</td>
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<tr>
<td>Virtual avatar’s cycling speed</td>
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<tr>
<td>Baseline</td>
<td>15.00 (km/h)</td>
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<tr>
<td>Fast condition</td>
<td>35.00 (km/h)</td>
<td>–</td>
</tr>
<tr>
<td>Slow condition</td>
<td>15.00 (km/h)</td>
<td>–</td>
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<tr>
<td>Participants’ cycling speed (km/h)</td>
<td></td>
<td></td>
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<tr>
<td>Baseline</td>
<td>23.68 (5.31)</td>
<td>13.85-36.01</td>
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<tr>
<td>Fast condition</td>
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<tr>
<td>Estimated travel distance (km)</td>
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<tr>
<td>Fast condition</td>
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<tr>
<td>Slow condition</td>
<td>2.29 (1.27)</td>
<td>0.60-6.00</td>
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<tr>
<td>Estimated time of cycling (min)</td>
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<tr>
<td>Fast condition</td>
<td>5.47 (1.51)</td>
<td>4.00-10.00</td>
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<tr>
<td>Slow condition</td>
<td>5.06 (1.77)</td>
<td>3.00-10.00</td>
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<tr>
<td>Pleasantness of cycling in VR</td>
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<tr>
<td>Fast condition</td>
<td>4.07 (0.79)</td>
<td>3.00-5.00</td>
</tr>
<tr>
<td>Slow condition</td>
<td>4.06 (0.85)</td>
<td>3.00-5.00</td>
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<tr>
<td>Immersion in VR</td>
<td></td>
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<tr>
<td>Fast condition</td>
<td>3.93 (0.96)</td>
<td>2.00-5.00</td>
</tr>
<tr>
<td>Slow condition</td>
<td>4.13 (0.96)</td>
<td>2.00-5.00</td>
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$SD=17.74$, respectively), whereas differences between cycling speed during Faster optic flow and Slower optic flow were non-significant ($t_{(28)}=1.61$, $p=.26$). Figure 2 represents the average cycling speed across the two experiments.

In the Slower optic flow, participants overestimated traveled distance, on average, by 14.91% ($M=3.12$ km, $SD=2.23$), whereas in Faster optic flow, participants overestimated traveled distance, on average, by 19.41% ($M=3.12$ km, $SD=1.73$). Nevertheless, those estimations compared with the real traveled distance were statistically non-significant (for Slower optic flow: $t(29)=0.95$, $p=.35$; for Faster optic flow: $t(29)=1.58$, $p=.13$). Participants underestimated the time that passed during the cycling by 21.29% (mean estimation of the time: 14 minutes 30 seconds). Distance estimations ranged from 0.5 up to 13 km, and time estimations ranged from 5 up to 30 minutes. Participants described the cycling experience as pleasant ($M=7.00$; $SD=1.73$; a scale ranged from zero to ten, where ten indicated the highest pleasure); and they also indicated that they would be willing to use VR in the future training ($M=6.70$; $SD=2.32$; a scale ranged from zero to ten, where ten indicated the highest willingness).
optic flow (i.e., the speed of a cycling avatar) would lead to a change in participant’s cycling speed. Results of the first study revealed that in Fast optic flow (35 km/h), participants cycled faster than in Slow optic flow (15 km/h). In the second experiment, participants cycled with a similar speed during Faster (set to be 15% faster than participants real speed) and Slower optic flow (set to be 15% slower than participants real speed). Analyses of both experiments provide preliminary evidence that cycling with Virtual Reality: (1) may be a pleasant experience; (2) could lead to an increase in cycling speed; (3) might affect the time perception (i.e., an underestimation of time that passed during physical activity). However, neither the first nor the second experiment used a non-VR control condition—therefore the results need to be interpreted with caution and may be attributed to other factors than VR.

Our findings are consistent with previous studies, which suggested that VR is a valuable tool in mood enhancement (Hou et al., 2018), and evoking positive emotions (Olmos-Raya et al., 2018). Regardless of the discipline (whether it is a sport, medicine, learning, or therapy), Virtual Reality seems to be a positively evaluated medium. Let alone those reasons are sufficient to weigh the benefits of VR application into training protocols (Ali et al., 2017). Moreover, as VR is shown to alter the time perception (van den Berg, 2017), the effect which was also observed in the present study, VR users underestimate the time they spend in the virtual world. Although misjudging the amount of time that passed conveys a great opportunity to effortlessly elongate the time of regular physical training (without having to put in the more conscious effort), this also carries the risk for the exerciser. Losing the track of time may lead to excessively long training and an injury or muscle strain (Gabbett, 2016).

Results of the present study shed some more light on the discrepancies in previous studies, which indicated that, on one hand, the faster optic flow leads to increased power output (Ansdell et al., 2018; Jones et al., 2016; Parry et al., 2012; Stone et al., 2012), and on the other, the slower optic flow leads to increased power output (Shei et al., 2016). This apparent contradiction can be resolved after taking into account findings from the presented experiments: faster optic flow may evoke a higher increase in cycling speed compared with slower optic flow when one has no control over the virtual avatar’s speed, while when the control is granted, altering the speed of the virtual avatar in both directions (i.e., a virtual avatar is cycling faster or slower) leads to a similar increase in real-life cycling speed. What is also worth noting is that we observed a tendency to increase cycling speed during the experimental phases in comparison with baseline in both experiments, which may suggest that any sort of manipulation of optic flow in VR leads to an increase in cycling speed on a stationary bike. However, this possibility needs to be confirmed in further studies employing a non-VR condition or group.

Future studies should focus on testing those patterns on different populations—not only on physically active persons, as in the present study, or sports players (Donohue et al., 2018; Petri et al., 2019; Tsai et al., 2017), but also on non-active persons, who consider becoming more active. VR may serve in such situations as

![Figure 2](image_url). Means and standard errors of participants’ cycling speed in both experiments (in the first experiment, participants embodied a virtual avatar, which cycled at a fixed speed: baseline 15km/h, a fast condition 35 km/h, and a slow condition 15 km/h; and in the second experiment, participants had control over the avatar’s cycling speed, but the optic flow in VR was modified to be 100% of participants’ real cycling speed in baseline, 115% in a fast, and 85% in a slow condition).
an additional help to overcome initial reluctance to training, often observed among beginners who struggle with attending exercises (Baños et al., 2016; Zeng et al., 2017). As stated before, the main limitation of our study is that it consisted of baseline and manipulation phases but lacked the condition in which participants would cycle without altered optic flow the entire time. Such a non-VR condition should be used in further studies to better understand the relationships described here. Furthermore, participants spent relatively small amount of time in VR. It would be insightful to test, how VR impacts prolonged cycling patterns and on different power applied to the crank (Lazzari et al., 2020). Although the present study revealed promising results on the effects of VR on a psychological level, we only used explorative, not validated items, and thus, future studies could benefit from widely used scales (such as ITC-Sense of Presence Inventory; Lessiter et al., 2001).

In conclusion, the results of the present study provide evidence that introducing altered optic flow in Virtual Reality during physical training can be an effective method to increase cycling speed on a stationary bike. Moreover, training with VR evokes positive feelings of pleasure and immersion in a virtual world; participants were also eager to use VR during future physical activity. Thus, we conclude that VR application may be beneficial in terms of increasing the effectiveness of physical training on a stationary bike.

ACKNOWLEDGMENTS

We would like to thank the local gym (Zwycięska Gym & Fitness Center, Wrocław) for lending us the equipment and their space. We would also like to thank students who helped us with data collection and inventing computer software: Marta Kucharczyk, Milena Kudełko, Małgorzata Kulińska, Anna Schichtel, Arkadiusz Ziółkowski, and all individuals who participated in our experiments.

REFERENCES


