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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-Hanley 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

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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.

STUDY 1

Materials and Methods

Participants

Thirty-one adults (13 women and 18 men) participated in this study (mean age = 28.61, *SD* = 7.63). All participants were users of the local gym, where the study was conducted. Participation was not compensated. Each participant provided informed consent to take part in the study, in accordance with the Declaration of Helsinki.

Equipment

Stationary bike Tomahawk E-Series–equipped with a device that measured time and distance and allowed to adjust variable-ratio transmission. During a pretest, a moderate intensity was established, which was then set for all the participants.*Oculus Rift DK2* - participants saw the game through head-mounted displays: Oculus Rift DK2 (960x1080 pixels per eye, refresh rate 75 Hz, 100 deg FOV). The HMD's provided head-tracking, enabling participants to look around in the virtual environment.

Computer software–created for this study in the Unity environment, using C# language. In the application, participants were embodying a cycling avatar and could see his moving legs, arms (placed at the handlebars of the bike) and torso. Avatar was cycling at the beach on the island. Participants could freely look around via HMD; they saw a sea at one side and mountains on the other. VR application was run on Asus ROG laptop (i7, 16 GB RAM, GeForce 1060).

Measures

Attitudes towards the game scale–in an explorative vein, all participants completed a questionnaire constructed for the purpose of the study, regarding 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 immersed into the virtual world were you?') on a six-point scale, ranging from zero to five (a higher number indicated a higher agreement with the statement in the question).

Procedure

The experiment was conducted in a local gym, in a quiet room, designed for indoor cycling exercises. Participants were randomly assigned to one of the two conditions (with different cycling speed of the virtual avatar: Fast and Slow). Participants were first seated on a stationary bike. They were asked to sit comfortably and set the height of the saddle at a comfortable level. Then, they put on the HMD and prepared for the cycling. The instruction for the participants did not suggest in any way to pay attention to the speed of cycling. If participants directly asked how fast they should be cycling, the answer was: "You can drive at the speed that is comfortable for you." When participants were ready, they were asked to start cycling. All participants cycled for 5 minutes and 30 seconds. When the virtual avatar stopped, an experimenter 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, $F(1,28)=.05$, $p=.82$, $\eta^2=.00$. 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*=31.33km/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%,

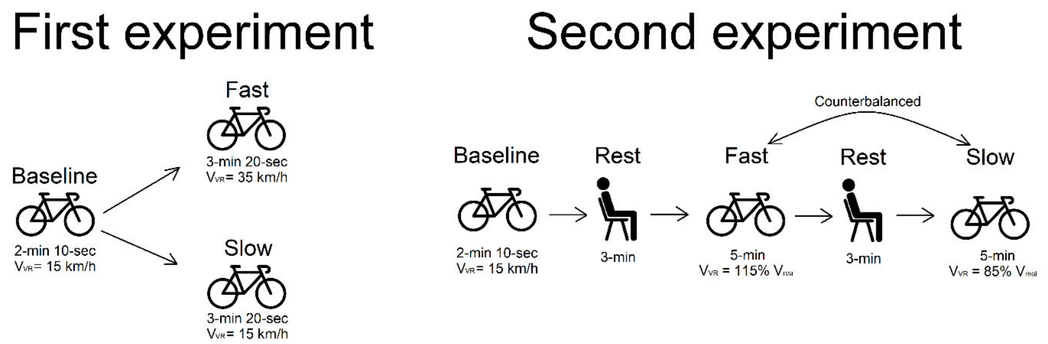

Figure 1. Cycling protocols in both experiments (in the first experiment, half of the participants experienced the Fast condition, while the other half–the Slow condition; in the second experiment, all participants experienced both the Fast and Slow conditions in a counterbalanced order).

Table 1. Participants' descriptive across two experiments.

	First experiment		Second experiment	
	N (%) / Mean (SD)	**Range**	**N (%) / Mean (SD)**	**Range**
A number of participants	31	–	30	–
Men	18 (58%)	–	17 (57%)	–
Age	28.61 (7.63)	18-49	26.02 (5.94)	19-45
Virtual avatar's cycling speed				
Baseline	15.00 (km/h)	–	100% V_{real} km/h	–
Fast condition	35.00 (km/h)	–	115% V_{real} km/h	–
Slow condition	15.00 (km/h)	–	85% V_{real} km/h	–
Participants' cycling speed (km/h)				
Baseline	23.68 (5.31)	13.85-36.01	27.15 (7.03)	13.85-41.55
Fast condition	29.83 (5.34)	19.46-36.97	31.33 (5.51)	21.61-43.22
Slow condition	24.56 (4.54)	13.62-31.13	31.89 (5.85)	21.61-43.22
Estimated travel distance (km)				
Fast condition	2.26 (1.32)	0.50-5.00	3.12 (1.73)	0.50-10.00
Slow condition	2.29 (1.27)	0.60-6.00	3.05 (2.23)	1.00-13.00
Estimated time of cycling (min)			14.30 (5.49)	5.00-30.00
Fast condition	5.47 (1.51)	4.00-10.00	–	–
Slow condition	5.06 (1.77)	3.00-10.00	–	–
Pleasantness of cycling in VR				
Fast condition	4.07 (0.79)	3.00-5.00	7.80 (1.52)	5.00-10.00
Slow condition	4.06 (0.85)	3.00-5.00	6.20 (2.39)	1.00-10.00
Immersion in VR				
Fast condition	3.93 (0. 96)	2.00-5.00	5.67 (2.79)	0.00-10.00
Slow condition	4.13 (0.96)	2.00-5.00	4.73 (3.17)	0.00-10.00

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 14.80% (*M*=3.05 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).

Discussion

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

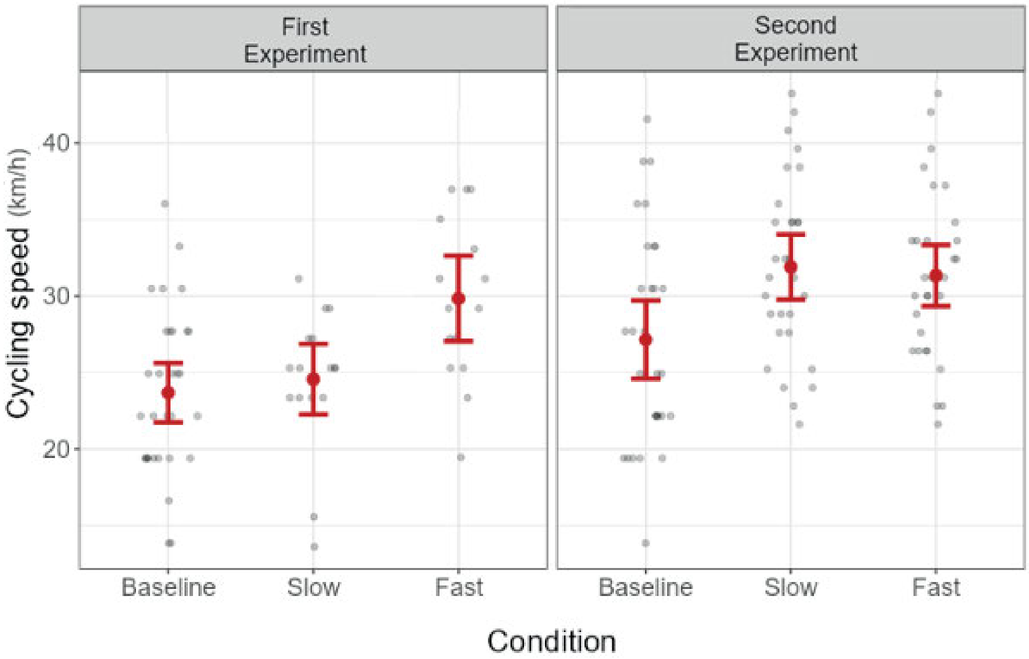

Figure 2. Means and standard errors of participants' cycling speed in both experiments (in the first experiment, participants embodied a virtual avatar, which cycled at a fixed speed: baseline 15km/h, a fast condition 35 km/h, and a slow condition 15 km/h; and in the second experiment, participants had 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).

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 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.

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REFERENCES

Albertus, Y., Tucker, R., Gibson, A. S. C., Lambert, E. V., Hampson, D. B., & Noakes, T. D. (2005). Effect of distance feedback on pacing strategy and perceived exertion during cycling: *medicine & science in sports & exercise, 37*(3), 461–468. https://doi.org/10.1249/01.MSS.0000155700.72702.76

Ali, S. F., Azmat, S. A., Noor, A. U., Siddiqui, H., & Noor, S. (2017). Virtual reality as a tool for physical training. *First International Conference on Latest trends in Electrical Engineering and Computing Technologies (Intellect)*, 1-6. https://doi.org/10.1109/INTELLECT.2017.8277617.

Anderson-Hanley, C., Snyder, A. L., Nimon, J. P., & Arciero, P. J. (2011). Social facilitation in virtual reality-enhanced exercise: competitiveness moderates exercise effort of older adults. *Clinical interventions in aging*, *6*, 275-280. https://doi.org/10.2147/CIA.S25337

Anguita D., Ghio A., Oneto L., Parra X., Reyes-Ortiz, J.L. (2012) Human Activity Recognition on Smartphones Using a Multiclass Hardware-Friendly Support Vector Machine. In: Bravo J., Hervás R., Rodríguez M. (eds) Ambient Assisted Living and Home Care. IWAAL 2012. Lecture Notes in Computer Science, vol 7657. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-35395-6_30

Annesi, J. J. (2001). Effects of music, television, and a combination entertainment system on distraction, exercise adherence, and physical output in adults. *Canadian Journal of Behavioural Science, 33*(3), 193–202. https://doi.org/10.1037/h0087141

Ansdell, P., Thomas, K., Howatson, G., Amann, M., & Goodall, S. (2018). Deception improves TT performance in well-trained cyclists without augmented fatigue. *Medicine and science in sports and exercise, 50*(4), 809-816. https://dx.doi.org/10.1249%2FMSS.0000000000001483

Atzori, B., Hoffman, H. G., Vagnoli, L., Messeri, A., & Grotto, R. L. (2019). Virtual reality as distraction technique for pain management in children and adolescents. *Advanced Methodologies and Technologies in Medicine and Healthcare,* 483-494. https://doi.org/10.4018/978-1-5225-2255-3.ch518

Baños, R. M., Escobar, P., Cebolla, A., Guixeres, J., Alvarez Pitti, J., Lisón, J. F., & Botella, C. (2016). Using virtual reality to distract overweight children from bodily sensations during exercise. *Cyberpsychology, Behavior, and Social Networking, 19*(2), 115-119. https://doi.org/10.1089/cyber.2015.0283

Berg, D. V. D. (2017). Time perception in virtual reality (Master's thesis). Leiden University.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2009). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications*, *30*(2), 14-21. https://doi.org/10.1109/MCG.2009.134

Birk, M. V., Atkins, C., Bowey, J. T., & Mandryk, R. L. (2016). Fostering intrinsic motivation through avatar identification in digital games. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems,* 2982-2995. https://doi.org/10.1145/2858036.2858062

Bryanton, C., Bossé, J., Brien, M., Mclean, J., McCormick, A., & Sveistrup, H. (2006). Feasibility, motivation, and selective motor control: Virtual reality compared to conventional home exercise in children with cerebral palsy. *CyberPsychology & Behavior, 9*(2), 123–128. https://doi.org/10.1089/cpb.2006.9.123

Caro, V., Carter, B., Dagli, S., Schissler, M., & Millunchick, J. (2018). Can virtual reality enhance learning: A case study in materials science. *IEEE Frontiers in Education Conference (FIE)*, 1-4. https://doi.org/10.1109/FIE.2018.8659267

Czub, M., & Kowal, M. (2019). Respiration entrainment in virtual reality by using a breathing avatar. *Cyberpsychology, Behavior, and Social Networking, 22*(7), 494-499. https://doi.org/10.1089/cyber.2018.0700

Donohue, K., Sadorf, A., Schmidt, K., & Kieffer, H. (2018). The effects of virtual reality training on balance and stability in female athletes. *International Journal of Exercise Science: Conference proceedings, 9*(6), 31.

Finkelstein, S., & Suma, E. A. (2011). Astrojumper: Motivating exercise with an immersive virtual reality exergame. *Presence: Teleoperators and Virtual Environments, 20*(1), 78–92. https://doi.org/10.1162/pres_a_00036

Fowler, C. A., Ballistrea, L. M., Mazzone, K. E., Martin, A. M., Kaplan, H., Kip, K. E., Murphy, J.L., & Winkler, S. L. (2019). A virtual reality intervention for fear of movement for Veterans with chronic pain: protocol for a feasibility study. *Pilot and Feasibility Studies*, *5*(1), 1-10. https://doi.org/10.1186/s40814-019-0501-y

Gabbett, T. J. (2016). The training—injury prevention paradox: should athletes be training smarter and harder?. *British journal of sports medicine*, *50*(5), 273-280. https://doi.org/10.1136/bjsports-2015-095788

Garcia-Palacios, A., Hoffman, H., Carlin, A., Furness, T., & Botella, C. (2002). Virtual reality in the treatment of spider phobia: a controlled study. *Behaviour Research and Therapy, 40*(9), 983–993. https://doi.org/10.1016/S0005-7967(01)00068-7

Hou, Y., Kang, S., & Moon, T. (2018). Customers' continuous usage intention of virtual reality (VR) product. *International Conference on Software Engineering, Artificial Intelligence, Networking and*

Parallel/Distributed Computing, 14-26. https://doi.org/10.1007/978-3-319-98367-7_2

Huang, S.-F., Tsai, P.-Y., Sung, W.-H., Lin, C.-Y., & Chuang, T.-Y. (2008). The Comparisons of heart rate variability and perceived exertion during simulated cycling with various viewing devices. *Presence: Teleoperators and Virtual Environments, 17*(6), 575–583. https://doi.org/10.1162/pres.17.6.575

IJsselsteijn, W.A., Kort, Y.A.W., Westerink, J., Jager, M., & Bonants, R. (2006). Virtual fitness: Stimulating exercise behavior through media technology. *Presence: Teleoperators and Virtual Environments, 15*(6), 688–698. https://doi.org/10.1162/pres.15.6.688

Jones, H. S., Williams, E. L., Marchant, D., Sparks, S. A., Bridge, C. A., Midgley, A. W., & Mc Naughton, L. R. (2016). Improvements in cycling time trial performance are not sustained following the acute provision of challenging and deceptive feedback. *Frontiers in physiology, 7*(399), 1-9. https://doi.org/10.3389/fphys.2016.00399

Kim, G., & Biocca, F. (2018). Immersion in virtual reality can increase exercise motivation and physical performance. *International Conference on Virtual, Augmented and Mixed Reality*, 94-102. https://doi.org/10.1007/978-3-319-91584-5_8

Lazzari, C.D., Diefenthaeler, F., & Marques, J. L. B. (2020). Virtual cycling effort is dependent on power update rate. *European journal of sport science, 20*(6), 831-838. https://doi.org/10.1080/17461391.2019.1669715

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2001). A cross-media presence questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators & Virtual Environments, 10*(3), 282-297. https://doi.org/10.1162/105474601300343612

MacRae, H. (2003). Cycling with video feedback improves performance in untrained, but not in trained women. *Research in Sports Medicine, 11*(4), 261–276. https://doi.org/10.1080/714041040

Malloy, K.M., & Milling, L. S. (2010). The effectiveness of virtual reality distraction for pain reduction: A systematic review. *Clinical Psychology Review, 30*(8), 1011–1018. https://doi.org/10.1016/j.cpr.2010.07.001

Micklewright, D., Papadopoulou, E., Swart, J., & Noakes, T. (2010). Previous experience influences pacing during 20 km time trial cycling. *British journal of sports medicine*, *44*(13), 952-960. http://dx.doi.org/10.1136/bjsm.2009.057315

Milanez, V. F., Pedro, R. E., Moreira, A., Boullosa, D. A., Salle-Neto, F., & Nakamura, F. Y. (2011). The role of aerobic fitness on session rating of perceived exertion in futsal players. *International Journal of Sports Physiology and Performance, 6*(3), 358–366. https://doi.org/10.1123/ijspp.6.3.358

Olmos-Raya, E., Ferreira-Cavalcanti, J., Contero, M., Castellanos-Baena, M. C., Chicci-Giglioli, I. A., & Alcañiz, M. (2018). Mobile virtual reality as an educational platform: A pilot study on the impact of immersion and positive emotion induction in the learning process. *Eurasia Journal of Mathematics Science and Technology Education, 14*(6), 2045-2057. https://doi.org/10.29333/ejmste/85874

Parry, D., Chinnasamy, C., & Micklewright, D. (2012). Optic flow influences perceived exertion during cycling. *Journal of Sport and Exercise Psychology, 34*(4), 444–456. https://doi.org/10.1123/jsep.34.4.444

Parsons, T. D., & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 39*(3), 250–261. https://doi.org/10.1016/j.jbtep.2007.07.007

Peck, T. C., Seinfeld, S., Aglioti, S. M., & Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and Cognition, 22*(3), 779–787. https://doi.org/10.1016/j.concog.2013.04.016

Petri, K., Emmermacher, P., Danneberg, M., Masik, S., Eckardt, F., Weichelt, S., & Witte, K. (2019). Training using virtual reality improves response behavior in karate kumite. *Sports Engineering, 22*(1), 2. https://doi.org/10.1007/s12283-019-0299-0

Robergs, R. A., Bereket, S., & Knight, M. A. (1998). Video-assisted cycling alters perception of effort and increases self-selected exercise intensity. *Perceptual and Motor Skills, 86*(3), 915–927. https://doi.org/10.2466/pms.1998.86.3.915

Rothbaum, B. O., Hodges, L., Smith, S., Lee, J. H., & Price, L. (2000). A controlled study of virtual reality exposure therapy for the fear of flying. *Journal of Consulting and Clinical Psychology, 68*, 1020–1026. https://doi.org/10.1037/0022-006X.68.6.1020

Shei, R.-J., Thompson, K., Chapman, R., Raglin, J., & Mickleborough, T. (2016). Using deception to establish a reproducible improvement in 4-km cycling time trial performance. *International Journal of Sports Medicine, 37*(05), 341–346. https://doi.org/10.1055/s-0035-1565139

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI, 3*. 74. https://doi.org/10.3389/frobt.2016.00074

Stone, M., Thomas, K., Wilkinson, M., Jones, A., St Clair Gibson, A., & Thompson, K. (2012). Effects of deception on exercise performance: implications for determinants of fatigue in humans. *Medicine & Science in Sports & Exercise*, *44*(3), 534-541. https://doi.org/10.1249/mss.0b013e318232cf77

Tsai, W. L., Chung, M. F., Pan, T. Y., & Hu, M. C. (2017, October). Train in virtual court: Basketball tactic training via virtual reality. Proceedings of the 2017 ACM Workshop on Multimedia-based Educational and Knowledge Technologies for Personalized and Social Online Training, 3-10.

Wender, C. L., Ahn, S. J., & O'Connor, P. J. (2019). Interactive virtual reality reduces quadriceps pain during high-intensity cycling. *Medicine & Science in Sports & Exercise*, *51*(10), 2088-2097. https://doi.org/10.1249/mss.0000000000002016

Zeng, N., Pope, Z., & Gao, Z. (2017). Acute effect of virtual reality exercise bike games on college students' physiological and psychological outcomes. *Cyberpsychology, Behavior, and Social Networking, 20*(7), 453-457. https://doi.org/10.1089/cyber.2017.0042