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An Optical Intervention to Improve Cycling Time Trials: A Feasibility Study

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Abstract: (1) Background: Many professional and recreational cyclists experience that neck extension in time trial position negatively impacts either speed, comfort, or power production—especially at high cycling speeds or for long distances. We conducted a feasibility study with one subject to assess whether redirecting the sight of a cyclist while in time trial position could reduce aerodynamic drag and neck strain by maintaining a more neutral neck position. (2) Methods: A physical immersive exercise bike was developed (called a FAAST-trainer) that emulates posture, velocity, and power to be delivered by the user through an adaptable power load adjusted in real time. As an optical intervention, we used prism glasses to redirect the cyclist's sight. The subject trained his perceptive-muscular system while cycling on the FAAST-trainer to get used to wearing prism glasses. He feels confident that the glasses are safe to test for future experiments in a velodrome. (3) Results: A consistent reduction in drag was found ($p < 001$) when wearing prism glasses with the FAAST-trainer, ranging from 3.5% to 4.7%. Accordingly, the cyclist could thus save between 9.7 watts and 13.0 watts cycling at 45 km/h, compared to having his head in an upright position. (4) Conclusions: Our experiment on the FAAST-trainer indicates that an optical intervention to reduce neck extension by redirecting sight might be safe to use for outdoor cycling. However, no vestibular effects, neither auditive nor complex combinations, were assessed, so we recommend additional research and development of a dedicated design for the prism glasses. Outdoor experiments should be conducted to confirm this reduction in aerodynamic drag and further asses the safety when wearing prism glasses.

Keywords: cycling aerodynamics; prism glasses; biomechanical efficiency; immersive exercise bike

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1. Introduction

In cycling, metabolic energy is provided to the skeletal muscles of a cyclist, thus delivering biomechanical energy for propulsion to overcome resistive forces and eventual gravitational forces. The resistive force (F[r]) is composed of the rolling resistance (F[rolling]) and air friction (F[air]) [1]:

At cycling speeds between 35 km/h and 55 km/h—the typical range of speed for cycling competitions, time trials, triathlons and amateur cycling—the percentage of resistive force caused by air friction goes up to 90% [2]. Given that F[air] far exceeds the rolling resistance, most gains in power-versus-speed optimization can be achieved by minimizing air resistance while, at the same time, maximizing the biomechanical energy produced by the cyclist.

$$F[r] = F[rolling] + F[air] \quad (1)$$

Without a lateral wind component, a cyclist's air friction F[air] on a flat surface can be calculated with the following formula:

$$F[air] = 1/2\ \textit{rho}[air] \times Cd \times A[frontal] \times v[air] \times v[air] \quad (2)$$

Here *rho* is the density [of the ambient air]; Cd is a dimensionless constant that represents the shape of the object; and v[air] is the speed of the ambient air, relative to the cyclist and their bike. Given that power is force multiplied by the speed of the cyclist, the power needed to overcome the air friction is calculated with:

$$P = 1/2\ rho[air] \times Cd \times A[frontal] \times v[air] \times v[air] \times [air] \times v[ground] \quad (3)$$

The authors of [3] discuss an extended classical treatise on aerodynamics and the above-mentioned formulas. In cycling aerodynamic assessment, it is common to retrieve only one free parameter from the above-mentioned formula, namely Cd × A or CdA, allowing for a clear quantification of a cyclist's aerodynamic drag.

The CdA of a cyclist ranges from 0.17 m^2 to 0.34 m^2, depending on the measurement technique and the cyclist's posture [4]. Considering the variation in Cd and in frontal surface area A separately, the drag coefficient of a cyclist ranges from Cd = 0.6 for an exceptionally streamlined time trial position to Cd = 0.8 for a non-aerodynamic upright position [5,6], while the frontal surface area triples in that range. Therefore, when changing cycling positions, the frontal surface area of a cyclist and bike has, on the whole, a greater effect on total drag than the drag coefficient.

When cycling at high speeds in time trial position, riding with the head up, looking at the road ahead, the cervical spine is extended to watch the road. This might increase the frontal surface area, thereby increasing aerodynamic drag. In addition, there is more tension in the anterior neck muscles, caused by the arms and shoulders, to counterbalance the forces exerted by the legs. From an ergonomic point of view, this position in the time trial bars with a very small torso angle—that is almost parallel to the ground in some cases—creates this tension in the posterior neck muscles due to the head flexion needed to look at the road ahead. This is extremely undesirable and the most common overuse injury in cycling [7]. It is interesting to note that sport climbers are already aware of this, which is why they use prism glasses as an optical aid for monitoring their companion above their head to avoid straining the posterior neck muscles [8]. This pilot study investigates an optical intervention—the use of prism glasses—to possibly resolve the problems caused by this extended head and neck position in the time trial position. Using prism glasses redirects a cyclist's sight, potentially improving safety by giving a clear view of the road ahead, while at the same time allowing the neck to maintain a more ergonomic—and possibly a more aerodynamic—position.

Objectives

We present a one-subject case study with the objective to confirm that cycling in racing position—with the head down and with the neck in a neutral position—reduces the frontal surface area and thus drag force. We also take the first step in the investigation of the feasibility and safety of using prism glasses in this racing position. The prism glasses redirect the cyclist's sight ahead in the frontal-sagittal direction. This pilot study is a first step into further development of the glasses and towards field testing in the velodrome for further insights on safety and reduction of drag.

2. Materials and Methods

The same test subject was used in all tests. The subject's characteristics are described in Table 1.

The combined mass of the cyclist and his bike was 82 kg. The cyclist kept a constant position on the saddle and armrests throughout all tests (see Figure 1), with eventual neck articulation.

Table 1. Characteristics of the test subject.

Characteristic	Value
Height	185 cm
Weight	69 ± 0.5 kg
Threshold heart rate	187 bpm (inc. power test)
Age	24 years
Functional power (1 h max P)	360 W
Cycling experience	15+ years
Weekly hours on the bike	10–16 h
Level of competition	Professional (triathlon)
Gender	Male

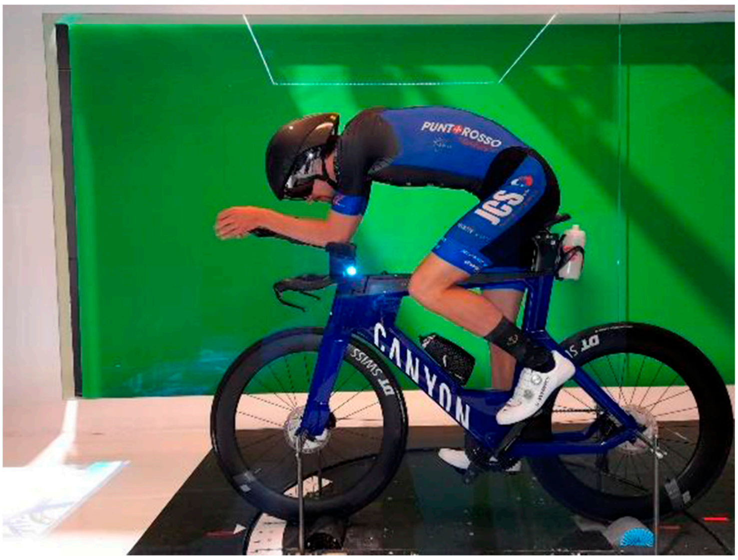

Figure 1. Lateral view of the subject with the test equipment.

The indoor tests described in this feasibility study were all conducted on the FAAST-trainer, a newly developed physical immersive exercise bike designed to map various biomechanical metrics of the cyclist while cycling [9]. In this study, the cyclist's position was continuously tracked in real time using the FAAST-trainer's stereo camera. The camera registers the frontal view of the cyclist and calculates the projected frontal surface area using pixel calculation and depth correction, after calibrating with a calibration frame.

As an optical intervention, we used prism glasses or belay glasses that redirect sight through double reflection of each eye (Chamonix/Decathlon), which meant that there was no mirroring and a wide field of view. The optical properties of a dense yet transparent material caused reflection (see Figure 2).

Figure 2. Belay glasses (prism glasses) that redirect sight (Decathlon).

Sight in the time trial position was thus redirected by approximately 45 degrees, allowing the subject to see in front of himself while keeping the head and neck in a neutral position (Figure 3, right).

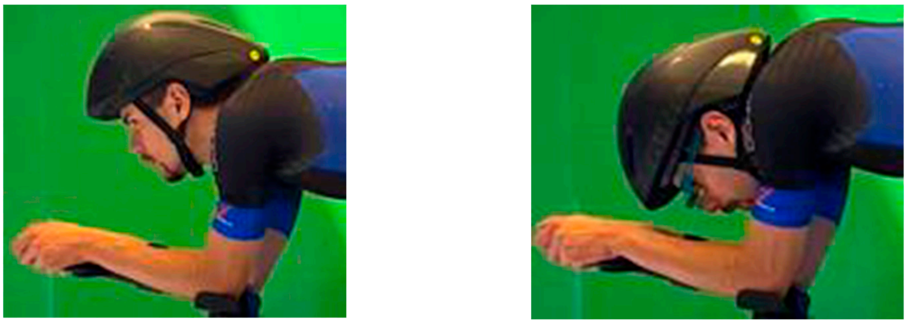

Figure 3. Test subject with normal sight (**left**) and redirected sight (**right**).

A screen was placed in front of the subject at the center of the subject's field of vision, horizontally covering about 30 degrees, to simulate how the subject would have seen the road when cycling outside. The screen displays a video of a first-person view of a cyclist riding downhill with numerous U-turns. The power output of the cyclist was kept constant at 250 W with a fixed gear. Cadence was around 95 rpm and simulated speed around 45 km/h, depending on the cyclist's position and simulated drag in the Formula (5). The power was around the cyclist's aerobic threshold, requiring some effort but not compromising the focus on the video and keeping the position steady. The cyclist's heart rate was tracked as a proxy for eventual systematic variations in the subject between different tests.

A micro controller (Arduino) was attached to the frame mounted on the FAAST-trainer (Figure 4, left), wired to two buttons on the front of the handlebars (Figure 4, right). When pressed, the micro controller converted the left button into a yellow LED light and the right button into a green LED light.

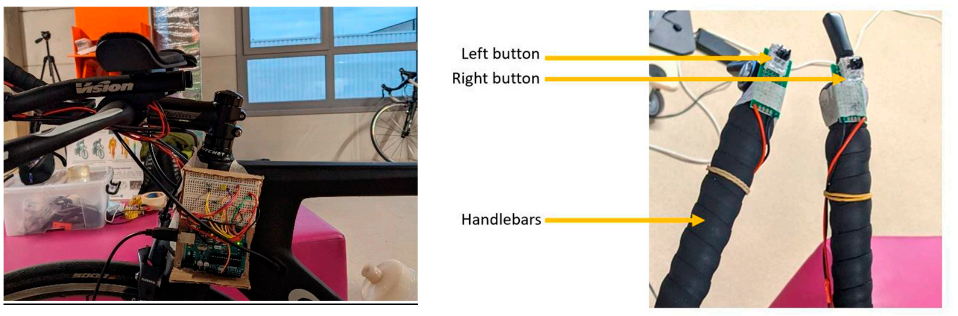

Figure 4. Arduino board (**left**) mounted to the time trial handlebars (**right**).

The physical tests were conducted on two different days, one week apart. The subject was asked to press the corresponding button each time a left or right U-turn was displayed on the screen. The subject was explicitly requested to not miss any turns, because this represented a fall in the real world. This meant that the subject had to maintain the same level of focus on the screen as he would in real life to safely steer through a challenging outdoor cycling track.

On the first test day, the subject cycled 10 min without the prism glasses, followed by 10 min cycling with the glasses. To eliminate the possibility of the first test influencing the second, the order was reversed on the second test day. A camera recording of the experiments was used to control how the turns matched with activating the LED lights. The frontal surface area A[pose[t]] of the cyclist and his bike was captured at 4 Hz, resulting in a time series with around 3600 datapoints. The resulting four datasets from the two test days were processed and analyzed separately to eliminate the influence of temperature, different calibration, time of day and other possible factors that were not controlled for. The frontal surface area of the cyclist during the 10-min interval was subjected to multiple statistical tests to assess and compare the influence of the optical intervention, i.e., the prism glasses. The results of this analysis can be consulted in the Section 3.

3. Results

The Kolmogorov–Smirnov test found the distribution of the frontal surface area to be normal in all four datasets, i.e., cycling with and without prism glasses on day one and day two. Both test days show a significant decrease in frontal surface area when riding with the prism glasses ($p < 0.001$). On day one, the frontal surface area without glasses (0.451 ± 0.0025 m^2) was found to be 4.7% higher than with glasses (0.430 ± 0.0029 m^2). The mean difference on day two was smaller, at 3.5% (0.446 ± 0.0030 m^2 without prism glasses versus 0.430 ± 0.0040 m^2 with the prism glasses). Figure 5 shows a box plot of the data of all tests.

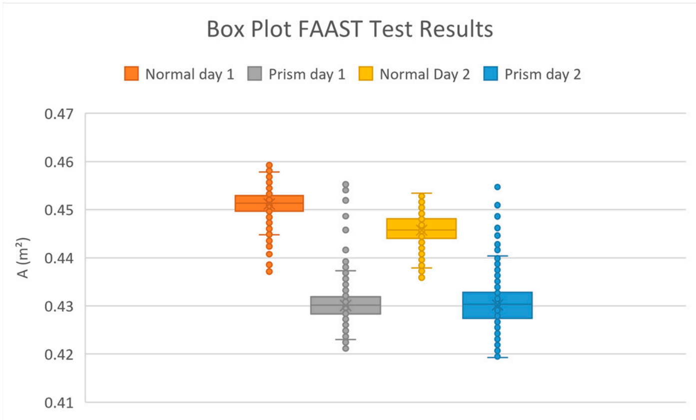

Figure 5. Frontal surface area with and without prism glasses.

While maintaining a constant power of 250 watts, this reduction in frontal surface area of 3.5% and 4.7% translated into an energy saving of respectively 9.7 watts and 13.0 watts, respectively, when cycling at 45 km/h. All tests had a similar average heart rate ranging from 155 to 165 bpm.

The subject's perceptive-muscular system quickly adjusted to using the prism glasses on the FAAST-trainer: no U-turns were missed, indicating that the prism glasses convey all visual information required for adequately reacting to visual stimuli in front of the cyclist. After this safety indication, the subject indicated that he felt confident in starting to use prism glasses on a 250 m wooden indoor track at racing speeds for a sustained period of time. This will be the next step in assessing the use of prism glasses in cycling time trials.

4. Discussion

We have studied whether it is possible to mediate neck extension during cycling by using an optical intervention that redirects cyclists' sight. The energy-saving potential was investigated by an adaptable resistance using the following formula:

$$P = 1/2\ \mathit{rho}[\text{air}] \times \text{Cd} \times \text{A}[\text{frontal}] \times \text{v}[\text{air}] \times \text{v}[\text{air}] \times [\text{air}] \times \text{v}[\text{ground}] \quad (4)$$

A fixed drag value of Cd = 0.6 was used with a variable frontal surface area of the cyclist and his bike, which was tracked continuously using a stereo camera. This case study showed a significant decrease in frontal surface area when wearing the prism glasses and maintaining a lower head position. Besides using the prism glasses for outdoor cycling in a velodrome with the current test subject, future research will be focused on assessing several cyclists in the same way, both on the FAAST-trainer and in a velodrome—after safety of the optical intervention is ensured—to present sufficient data to potentially further prove this claim. Additionally, there will be further research into optimizing the design, prism angle and position of the glasses on the nose to further improve safety.

Belay glasses or prism glasses were easy to use on the exercise bike and proved to be an effective intervention to mediate neck extension. The intervention did not hamper visual input required for reacting to visual stimuli in front of the cyclist. Neck extension to look forward while in a low time trial position is an undesirable position from an ergonomic point of view. For this reason, we also recommend the use of prism glasses when power training combined with visual inputs or information that is displayed on a screen in front of the cyclist—as in, for example, the app Zwift—thus attaining a more ergonomic training position.

We conducted a feasibility study with one subject to show that prim glasses with redirected sight can now be tested for cycling in the controlled environment of a velodrome. The test subject was a healthy, highly trained and skilled cyclist who now feels comfortable enough to use prism glasses in a velodrome after training indoors on the FAAST-trainer.

Cycling in a velodrome requires processing and monitoring multiple sensory channels, compared to cycling on the FAAST-trainer. To prove the safety and ease of use of similar optical aids in outdoor cycling time trials, further research will be focused on both velodrome testing and the development of an improved and dedicated design of the glasses for cycling.

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Conflicts of Interest: Author Dries Matthys served as the test subject in this study.

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