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Pedaling technique enhancement: a comparison between auditive and visual feedbacks

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Abstract. In cyclism, the pedaling technique is rarely optimal but could be improved using sensory feedbacks. The most common media used to display data of cycling power meter is a small screen placed on the handlebars. However, it could be dangerous by distracting the visual attention of the cyclist. That is why auditive feedback, called sonification, is investigated. In this paper, the effects of auditive or visual feedbacks on pedaling technique (evolution of the torque effectiveness) are compared using a lab experimental setup when subjects were engaged or not in a dual-task paradigm (cycling and detecting obstacles on the road). Improvement of pedaling technique is observed with both auditory and visual feedbacks, and reaction times to detect obstacles were not different between all conditions. However, sonification allows gaze behaviors more centered on the road, i.e. more secure. These results suggest that sonification could be a good solution to improve pedaling technique.

Keywords: Sonification, Gesture Efficiency, Cycling Ergometer, Torque Effectiveness, Cognitive Load

1 Introduction

Performance in cycling depends of a lot of parameters [1], [2], such as physiological factors, nutritional strategy, bike design, and also pedaling technique [3].

Technically, the pedal stroke simply consists in 4 phases: pushing and pulling phases and high and low transitions. Despite this apparent simplicity, the pedal stroke is rarely optimal even for expert cyclists, and difficulties are mainly observed during the pulling and transition phases, leading to loss of power then to less efficient performance. Based on this observation, the need to find efficient solutions to improve the performance has become a major issue in the domain of training but also of sport research.

The augmented reality approach, which consists in providing sensory information not naturally and directly available to the subjects remains one of the most promising technique. For instance, some studies have demonstrated that an augmented visual feedback may help to improve pedaling technique [4], [5]. However, for sports cognitively mastered with visually information like cycling (necessity to keep the eyes on the road), providing augmented visual feedback may overload cognitive processing [6] and distract vision from his major guiding role. For these reasons, augmented auditory feedback (usually called "sonification" [7]), has been recently considered as a beneficial alternative for sport training [8], [9].

Our hypothesis is that auditive feedback could be a better solution compared to visual feedback to provide information to the cyclist by allowing him to keep the eyes on the road. However, these two modalities of sensory feedbacks in cycling have not been compared for now, and a comparison is conducted in this paper. Three characteristics are compared: the evolution of the pedaling technique, by means of torque effectiveness measurement, the gaze behavior, and the cognitive load induced by each sensory feedback. The paper is organized as follow: the second section of this paper details method of the experiment, the main results are presented in the third section, and results are then discussed in the fourth section. A conclusion ends the paper.

2 Method

24 participants took part to the experiment (mean age 26.2 +/- 9.4). They were not expert in cycling technique, but most of them practiced bike regularly. Three of the participants declared that the left foot was their preferred foot, the rest of participants declared to be right-footers. All participants signed an informed consent form in accordance with the Helsinki convention informing them about the conditions of the experiment and their right of withdrawal. The protocol was approved by the institutional review board of the Institute of Movement Sciences. The data were analyzed anonymously.

The experimental setup was made of a road bike Merida RaceLite, a HomeTrainer Tacx Flux and a screen (27 inches) placed in front of the cyclist, showing a virtual road moving in accordance to the cyclist cadence. The interface of this virtual environment was developed using the Unity platform and represented a straight road. The crank was a Rotorbike 2InPower, measuring the torque applied on both pedals. The Rotorbike crank was used with ANT+ transmission. The "fast-mode" of this crank was selected to transmit torque applied on each pedal at 50 Hz, whereas cadence and angular position were transmitted at 4 Hz. The resistance of the Home-Trainer was set to 130 W, and the cadence was not imposed: the cyclist had only to pedal at a regular and moderate cadence. Cyclist was also wearing Tobii Pro Glasses 2, allowing to measure the eyes behavior. A small screen (5 inches) was placed at the center of the handlebars, to display the visual feedback. Sounds were diffused through headphones (Sennheiser HD 201). Figure 1 represents the experimental setup.

Three conditions were assessed: one without any sensory feedback on performance (called "Control" condition hereafter), another using sonification (called "Auditive") and a last one with a visual feedback (called "Visual"). For each condition, cyclist had to pedal during 3min. A rest (2min) was interleaved between each condition. The order of these conditions was permuted across all participants, in such a way all possible permutations were presented the same number of times.

These three conditions were presented twice: a first time without obstacles (reference task) on the road, and a second time with obstacles to be detected (dual-task). For a specific participant, order of conditions was the same with and without obstacles. For conditions with obstacles, the participants were required to detect them as quickly as possible by saying “Top”. Oral answers were recorded, allowing to compute the Reaction Time (RT) for each obstacle detection. During each condition, 16 obstacles were presented, in four locations possible: Far away on the Left side (FL), Far away on the Right side (FR), Close on the Left side (CL), and Close on the Right side (CR). The instants of apparition of obstacles were randomly chosen but were the same for all participants. Two obstacles were separated by 3 s at least.

For the Auditive condition, a squeak was generated through headphones when the torque applied on the pedal was negative, lasting as long as the negative torque. The squeak was synthesized based on a Coulomb friction model, as presented by Thoret *et al* [10]. Both feet were sonified through a stereo reproduction: sound associated to the left (respectively right) pedal was diffused through the left (respectively right) earphone.

For the Visual condition, the same information was provided but visually on the small screen on the handlebars. A red light came on if the torque applied on the pedal was negative, lasting as long as the negative torque. As for the Auditive process, both feet were analyzed: a red light on the left side (respectively on the right side) of the screen was associate to the left pedal (respectively right).

Instructions were systematically read by the participants and then orally explained by the experimenter. These instructions presented the experiment and described the feedback process (the cyclist had to adapt his technique to avoid squeaking or turning on the red lights).

The data recorded with the crankset were sampled at regular time intervals, but this sampling did not enable each cycle or crank position to be analyzed independently of the speed rotation of the crank. Therefore, the torque was interpolated in such a way as to be sampled at regular angular intervals. The interpolation was performed in Matlab using the cubic interpolation of the function *interp1* with a 0.5° step. To assess performance on each stroke cycle, Torque Effectiveness TE was computed:

$$TE = 100 * \frac{T^{+} + T^{-}}{T^{+}}$$

with T^{+} the total positive torque over the cycle and T^{-} the total negative torque over the cycle (absolute value). TE was thus considered 100 % if there was no negative torque during the cycle. Mean Torque Effectiveness was computed for both feet (R-TE and L-TE).

Gaze behavior data recorded with the Tobii glasses were analyzed using the product software. 3 Areas of Interest were defined: the 27” screen displaying the road, the 5” screen displaying the visual feedback, and the rest of the visual field. Percentage of the time of visit duration was computed for each area.

Statistical analysis was conducted with Statistica. Four Repeated Measures Analysis of Variance (RM-ANOVA) were conducted:

- First, a two levels RM-ANOVA was conducted on the Cadence considering the factors Condition (three conditions) and Obstacle (with or without).

- A three levels RM-ANOVA was conducted on the Torque Effectiveness of both feet considering the factors Condition (three conditions), Obstacle (with or without) and Foot (left or right).
- A two levels RM-ANOVA was conducted on Reaction Time for obstacle detection considering the factors Condition (three conditions) and Position of the obstacle (four positions).
- A three levels RM-ANOVA was conducted on the percentage of the time of visit duration with the eyes considering the factors Condition (three conditions), Obstacle (with or without) and Area of Interest (three areas).

To go further these ANOVA, post-hoc tests applying the Bonferonni procedure were then conducted using a significance level of 0.05.

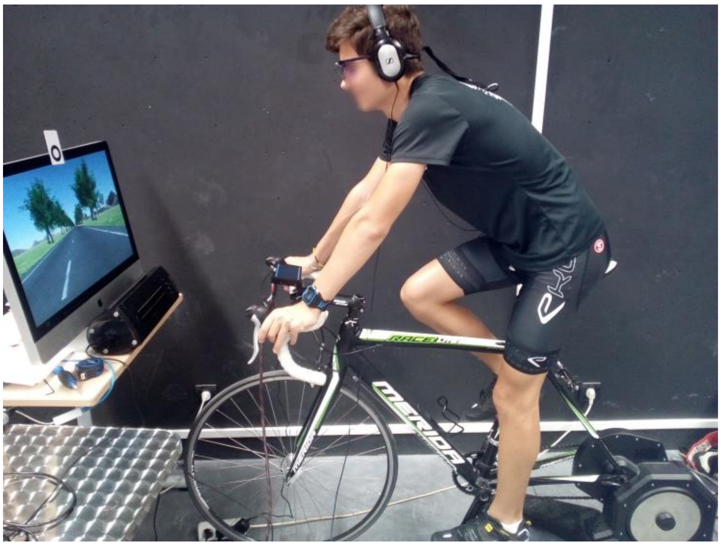

Figure 1: Experimental setup: 27” screen displaying a virtual road, 5” screen on the handlebars reporting visual feedback, bike Merida, Home-Trainer Tacx. The cyclist is wearing headphones during the Auditive condition, and is wearing Tobii glasses during the whole experiment.

3 Results

In this section, we analyze both the cadence, the torque effectiveness, the obstacle detection (RT and missed obstacles) and the gaze behavior.

3.1 Cadence

According to the ANOVA, the mean cadence did not significantly differ between Condition ($F(2, 46) = 0.206$, $p = 0.814$), and the presence of obstacles had no influence ($F(1, 23) = 3.747$, $p = 0.065$). The interaction of Obstacle and Condition also did not influence the cadence (F(2, 46) = 2.009 , p = 0.146). The mean cadence for all conditions and all cyclists was 59.2 Rounds Per Minute.

3.2 Torque Effectiveness

The ANOVA yielded a significant effect of Foot (F(1,23) = 4.382, p = 0.048) and of Condition (F(2,46) = 8.265, p = 0.001), but no effect of Obstacle (F(1,23) = 1.886, p = 0.183). The Figure 2 reports the mean TE according to the Foot, and according to the Condition. Mean TE was significantly higher for the left foot (86.5 %) than for the right foot (85.2 %).

Mean TE during the Control condition (83.0 %) was significantly lower than the two other feedbacks (87.6 % during the Auditive condition, and 87.0 % during the Visual condition). However, there was no significant differences between the two conditions with sensory feedbacks.

The ANOVA did not yielded significant effect of interactions.

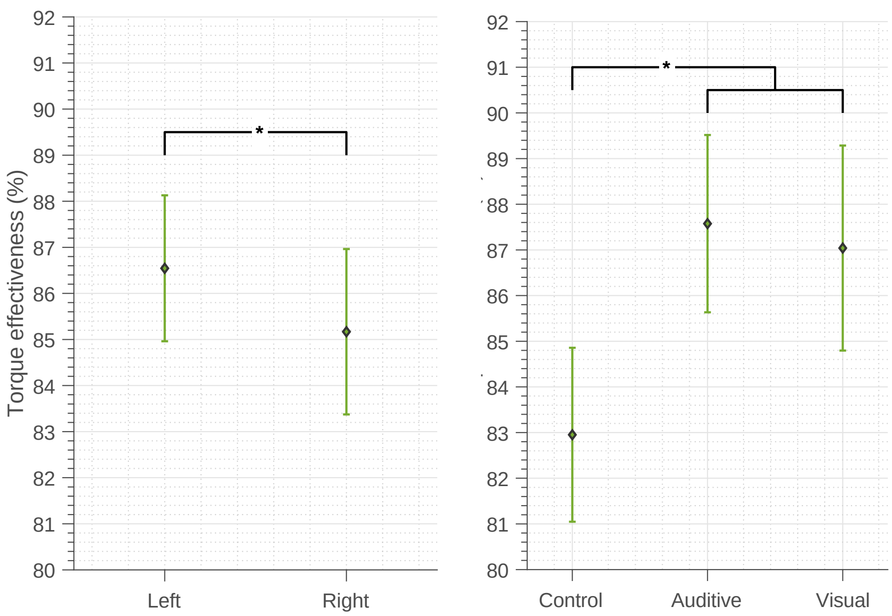

Figure 2: TE according to the foot (left) and according to the condition (right). Errorbars refer to a confidence interval of 95%. * means significant difference according to post-hoc tests with Bonferroni procedure, at significance level of 0.05.

3.3 Obstacle detection: Reaction Time and Missed obstacles

The ANOVA on RT yielded a significant effect of the Position of the obstacles (F(3,69) = 6.916, p < 0.001), no effect of the Condition (F(2,46) = 1.214, p = 0.306) and no effect of the interaction of the Position and the Condition ($F(6,138) = 1.622$, $p = 0.146$).

Figure 3 reports the mean RT according to the position of the Obstacle. Post-hoc tests revealed that obstacles at position CR (RT = 0.53 s) were detected quicker than obstacles at positions FL (RT = 0.61 s) and FR (RT = 0.59 s). RT of obstacles at position CL (RT = 0.56 s) was not significantly different from all others.

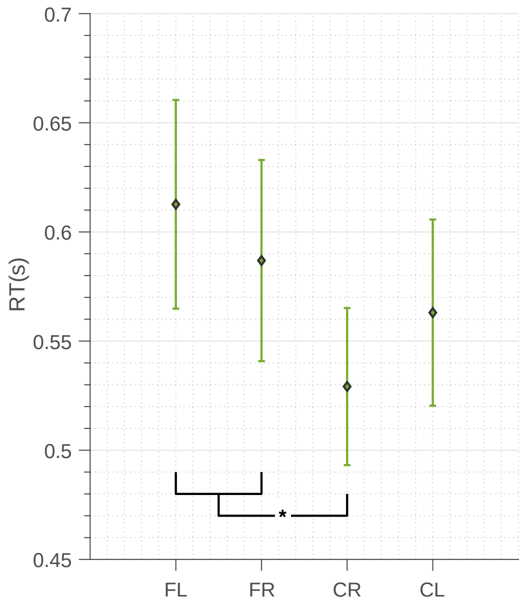

Figure 3: Reaction Time according to the position of obstacles (Front Left, Front Right, Close Right, Close Left). Errorbars refer to a confidence interval of 95%. * means significant difference according to post-hoc tests with Bonferroni procedure, at significance level of 0.05.

Figure 4 reports the missed obstacles according to the conditions. For each condition, there was a total of 384 obstacles to be detected (24 cyclists, 16 obstacles per condition). During the visual condition more obstacles were missed (6 obstacles) compared to other conditions. Only 3 obstacles were missed during the control condition and none during the Auditive condition.

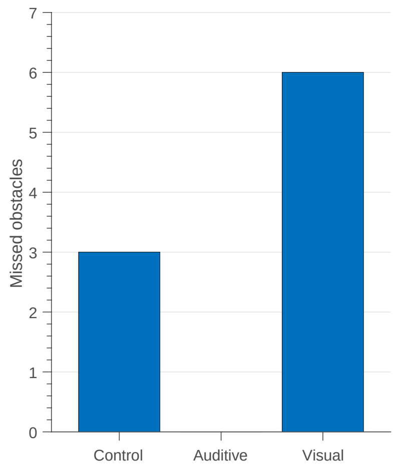

Figure 4: Total missed obstacles according to the condition

3.4 Gaze behavior

The ANOVA yielded a significant effect of the Area ($F(2, 30) = 106.61$, $p < 0.001$), a significant interaction of Obstacle and Area ($F(2,30) = 29.035$, $p < 0.001$), and a significant interaction of Condition and Area ($F(4,60) = 19.131$, $p = 0.001$).
Figure 5 represents the Total Visit Duration according to the Area of Interest. The 27" screen was significantly most viewed (73.5 %) than the other Areas (12.5 % for the 5" screen and 14.1 % for the rest).
The presence of obstacles on the road implied a modification of the visual behavior. Figure 6 represents the Total Visit Duration according to the presence of Obstacles and the Area of Interest. The 27" screen was significantly more looked when obstacles were present (97.3 %) than when obstacles were absent (50.0 %).
Figure 7 represents the Total Visit Duration according to the Condition and the Area of Interest. The Total Visit Duration of the 5" screen was significantly more important during the Visual condition (33.0 %) than during the two other conditions (1.1 % during the Auditive condition and 3.3 % during the Control condition). Moreover, the Total Visit Duration of the 5" screen was significantly less important during the Visual condition (56.2 %) than the two other conditions (79.8 % during the Control condition and 84.5 % during the Auditive condition).

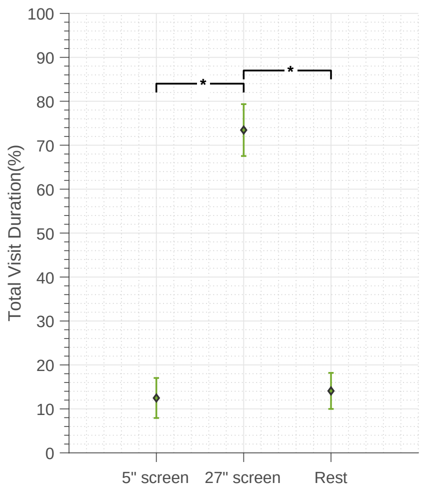

Figure 5: Total Visit Duration according to the Area of Interest. Errorbars refer to a confidence interval of 95%. * means significant difference according to post-hoc tests with Bonferroni procedure, at significance level of 0.05.

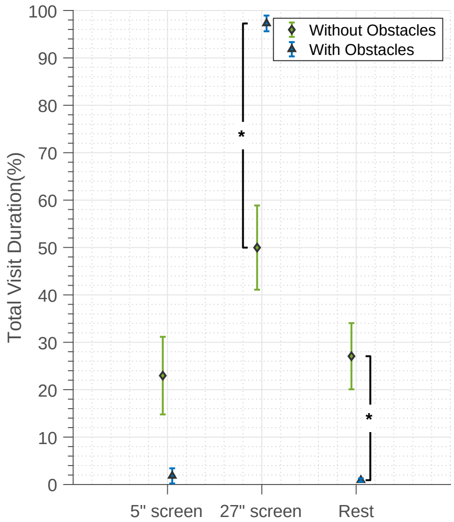

Figure 6: Total Visit Duration according to the presence of obstacles and the Area of Interest. Errorbars refer to a confidence interval of 95%. * means significant difference according to post-hoc tests with Bonferroni procedure, at significance level of 0.05.

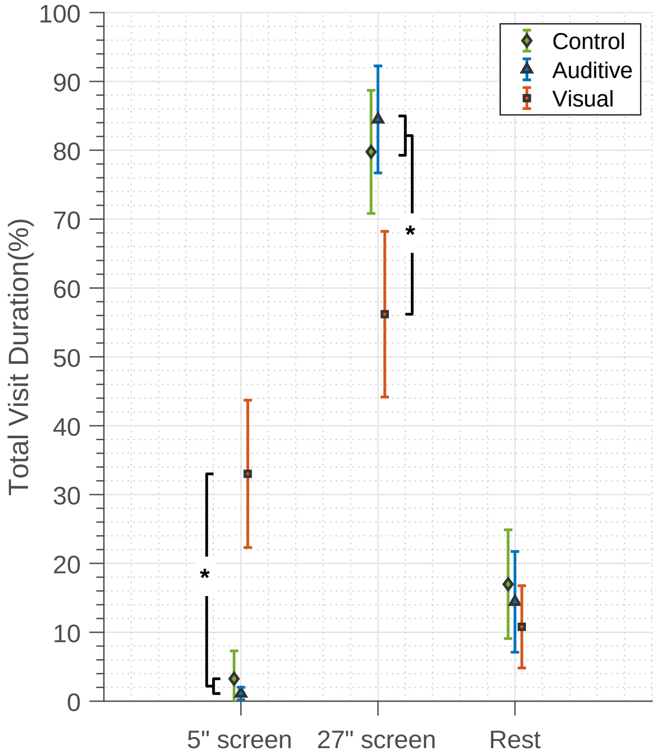

Figure 7: Total Visit Duration according to the Area of Interest and the Condition. Errorbars refer to a confidence interval of 95%. * means significant difference according to post-hoc tests with Bonferroni procedure, at significance level of 0.05.

4 Discussion

The goal of this experiment was to compare the effect of two modalities of sensory feedback used as augmented reality tools for the pedaling technique: auditive and visual feedbacks. These feedbacks were compared to a control condition (without any feedback). During the first part of the experiment, the cyclist had to focus only on his pedaling technique, whereas during the second part, some obstacles were placed on a virtual road and the cyclist had to detect them the most quickly possible.

Cyclists had to pedal at a regular cadence, but they had no specific information about their cadence (excepted the display of the virtual road moving according to the cadence). We first analyze the mean cadence of cyclists, and we showed that there was no significant effect of the feedback and the presence of obstacle on the cadence of cyclists. The cadence could have an effect on the pedaling technique [3]. So, in this experiment, differences observed in pedaling technique were not linked to the cadence.

The TE is then analyzed, informing about the pedaling technique. TE was significantly higher for the left foot than for the right foot. An assumption explaining higher performances for the left foot is that cyclists could have a strongest leg [11], [12]. However, this assumption was not confirmed by the results, since there was no correlation between the observations and the dominant leg of cyclists, and few of the cyclists were left-footers. A further study should be conducted with half of left-footers participants.

TE was significantly lower during the control condition than during the two other conditions. It means that sensory feedbacks on instantaneous torque are effective to improve the pedaling technique, independently of the media.

During the second half of the experiment, cyclists had to detect obstacles on the road as quickly as possible, during the three conditions (Control, Auditive and Visual conditions). Reaction times were not different according to the conditions, suggesting that both feedbacks do not increase the cognitive load. However, some obstacles were missed during the visual condition, whereas none were missed during the Auditive condition.

Moreover, during the Visual condition, cyclists looked more often at the little screen on the handlebars, instead of looking at the road. This could in fact explain the targets missed during the visual condition. As attended, these results suggest that the gaze behavior could be dramatically impacted by the nature of the sensory feedback, visual cues leading the cyclists to take their eyes off the road to get information on their performance, whereas auditory cues allowing them to keep the eyes on the road. The Reaction Time measured in this experiment did not demonstrate this point, maybe because the task was too easy (obstacles were visible in peripheral vision).

Obstacles at position CR were the most quickly detected . It corresponded to the closest obstacles to the cyclists, that is the most dangerous for them. So this special area required the main attention of cyclist.

5 Conclusion

To enhance pedaling technique, visual and auditive feedbacks were compared in this paper during a two parts experiment: first, cyclists had only to focus on their pedaling technique, and in the second part they had to detect obstacles on a virtual road the most quickly possible while they concentrate on their pedaling technique.

Both feedbacks allowed significative enhancement of their pedaling technique in a similar way. However, during the visual condition, the gaze behavior was partially oriented towards the small screen on the handlebars presenting the augmented reality information, so that the cyclist was less attentive to its road (cyclists missed obstacles).

As a conclusion, our results confirm that, in an augmented reality approach, auditive feedback, said sonification, is a promising candidate to allowing for a significant improvement of the performance while preserving the security of the cyclists.

Then, to go further , a similar experiment have to be conducted in real conditions to definitively conclude on the promising effect of sonification on sport performance.

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