Improving Cyclists Training with Tactile Feedback on Feet

Dominik Bial[1], Thorsten Appelmann[1], Enrico Rukzio[2], Albrecht Schmidt[3]

[1] Paluno – The Ruhr Institute for Software Technology, University of Duisburg-Essen,
Gerlingstraße 16, 45127 Essen, Germany
Dominik.Bial@paluno.uni-due.de, Thorsten.Appelmann@uni-due.de

[2] Institute for Media Informatics, Ulm University,
James-Franck-Ring, 89081 Ulm, Germany
enrico.rukzio@uni-ulm.de

[3] SimTech & VIS, University of Stuttgart,
Pfaffenwaldring 5a, 70569 Stuttgart, Germany
Albrecht.Schmidt@vis.uni-stuttgart.de

Abstract. This paper explores how tactile feedback can support cyclist in order to fulfill user-defined training programs. Therefore, actuators are integrated in cyclists' shoes. The rhythm the cyclist should pedal is communicated via tactile feedback so that the heart rate is kept in an interval which is, for example, optimal for increasing stamina. After a preliminary study, which was used to gather the optimal position for the actuators on feet, a working prototype of such a system was developed. This prototype was tested in a preliminary study by two participants in the wild. They were able to understand the communicated tactile feedback, enjoyed using our system and stated that they could imagine using such a system regularly. This indicates that communicating tactile feedback via the user's feet is another application domain where vibration signals can be of high benefit and can be used to communicate information to the user as audio or visual information are not appropriate.

Keywords: human computer interaction, tactile feedback, actuators, traffic, mobile phone, cyclists, prototype.

1 Introduction

Our feet are an elementary part in our everyday life and are necessary during activities such as cycling, driving motorcars and motorcycles. Nevertheless, their tasks are rather limited to, for example, braking and pedaling, and are very rarely used for human-computer-interaction. The usage of tactile feedback broadens the spectrum of communication channels beside the obvious visual and audio channels. Moreover, research shows that tactile feedback is even less intrusive and distractive [2].Tactile feedback on feet promises to be beneficial for users especially if other parts of the body are already engaged. Moreover, there are many nerve ends in the human foot so

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that it is an extremely sensitive body part regarding vibration signals. This can be of special interest for motorcyclists, drivers and cyclists.

Out of this mentioned group we focused on cyclists to gather information about the feasibility to communicate information via tactile feedback on the human foot. First, an initial user study was conducted to test suitable positions and arrangements for actuators. Then, a prototype was designed to support individual training programs of cyclists based on their heart rate. A vibration based pulse generator was developed to find out about the feasibility of such a system. Vibration signals were sent to a cyclist telling which pedal rhythm to keep so that a certain heart rate interval is not exceeded or underrun. Two participants were asked to test the prototype.

Fig. 1. Participant testing the final prototype

This paper starts with an overview over related work in section 2, section 3 discusses the overall concept and section 4 different components of the prototype while section 5 introduces results from a user study testing the configuration of the tactile feedback being provided. This study was used to determine the best position and arrangement of the actuators on feet. Section 6 reports on results gathered with the help of participants who tested the prototype in the wild.

2 Related Work

Current research shows that tactile pulses are automatically decoded from anatomical into external coordinates, as in the paper of Roeder et al. [11] who compared the response time of congenitally blind and late blind with sighted humans. The participants had to wear headphones and to press a left or right response key depending on the acoustical signal bursts presented from either the left or right loudspeaker.

Within this context one could distinguish the follow two research strands: firstly, tactile feedback as navigational aid, secondly, tactile feedback in the health and sports domain. In the field of supporting navigation several approaches can be found. Bial et al. investigated the recognition rate of actuators fixed in two motorcyclists' gloves [1]. The aim was to find suitable positions of actuators for a navigation prototype based on tactile feedback. The Tactile Wayfinder is a prototype consisting of six actuators placed around a belt, which can assist users by means of directed impulses [4]. Poppinga et al. installed tactile motors in the handlebar of a bike to support the navigation of cyclists by varying the signal strength on the handles [10]. By combining tactile feedback in a steering wheel with a navigation device Kern et al. examined the opportunity to communicate directions through vibration pulses [7]. A similar approach was pursued by Hogema et al. who placed actuators in a driving seat [6]. The works mentioned before show the benefit of tactile feedback in traffic. Besides that, there is further information which could be communicated to road users than navigation. For example, giving hints about approaching cars and training performance while cycling seems to be promising.

In the field of health and sports domain Spelmezan et al. examined the use of actuators for learning complex movement sequences, such as snowboarding [12]. Therefore, a bodysuit equipped with several actuators was developed which communicated how to move the body best while snowboarding. A corresponding study showed that the participants equipped with actuators performed equally well compared to participants who received instructions given by a trainer. Music-touch Shoes are dancing shoes with actuators in a sole [13]. This shall help deaf people to *feel* music and allow them to move to its beat. Lylykangas et al. [10] used tactile feedback to regulate behaviour of users. Tactile signals varied in frequency, modulation and waveform to distinguish various information. The results indicate that tactile feedback can be used to guide users without overloading their visual and auditory channels. Additionally, vibration feedback can be accompanied by other haptic feedback as shown by Jirattigalachote et al [8]. Jirattigalachote et al. conducted a study to analyze the perception of tactile feedback in combination with a haptic feedback device called virtual pebble. This work suggests combining haptic feedback devices with vibration patterns which shall be addressed in future work.

3 Concept

Tactile feedback can be used to communicate warnings, threats or simply to give hints. To test the feasibility of tactile feedback under real conditions we imagine an application which supports cyclists in their training. In a gym, typically, the heart rate is measured to compute the energy consumption, to give hints to the user or to control the speed or resistance. Pulse watches like the POLAR heart rate monitor watches[1] allow users to control the current pulse visually and some devices provide audio feedback when a certain hart rate is reached. Tactile feedback provides distinct advantages when running or cycling as the usage of visual or audio information might distract the users from the environment, other people and the surrounding traffic.

Our concept is different from previous approaches as the tactile feedback is provided via the user’s feet through where the user doesn’t have to wear a potentially disturbing wirstlets or gloves. Tactile feedback could be provided by the handles as well when the user is cycling but the handles are not always touched and tactile feed-

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1 http://www.polarusa.com/us-en/products/get_active/running_multisport/RS100

back is significantly reduced when the user wears gloves. Tactile shoes don't suffer from those disadvantages.

Our system communicates various information such as the frequency with which the user should pedal or run (e.g. in order to achieve a certain hart rate) and whether she should change gears when cycling. The frequency in which the user should pedal or run is communicated by alternating tactile feedback on the left and right foot. Such information can't efficiently be communicated by a pulsed watch or the handles. When communicated via boots the user receives the feedback on the foot which should push the pedal forward and should make the next step. Through this a behavior can be simulated that is well-known from various exercise machines (e.g. from cross trainers that change the resistance in relationship to the current hart rate) and allows cyclists or runners an effective training with direct feedback.

We envision that the overall system consists of a pulse watch measuring the users pulse and allows the user to define her training program. The pulse watch communicates then with the tactile shoes in order to give related feedback to the user. Alternatively the user could wear a pulse belt or could control the settings via her mobile phone.

4 Prototype

We developed a prototype in order to test the feasibility of our approach. The prototype consists of six different components which are shown in figure 2.

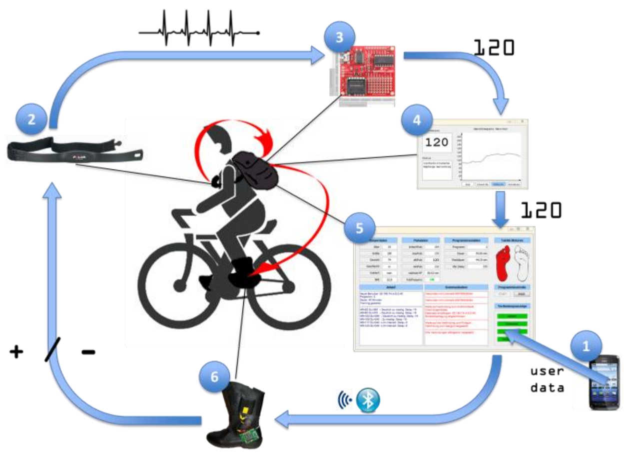

Fig. 2. (2.1) mobile phone as end-user device, (2.2) Polar pulse belt, (2.3) Sparkfun heart rate monitor, (2.4) heart rate recording component, (2.5) actuator controller, (2.6) vibration shoes.

An Android application for a mobile phone has been developed to allow the user the configuration and definition of individual training programs (Fig. 2.1). The users can specify their gender, height, age, weight and if they are sporty. Additionally, the users can select the duration for their training as well as one out of four different training programs for cardiovascular training, fat burning, stamina increase and muscle growth. These parameters are used as input to support cyclists' training programs with tactile feedback.

A POLAR sensor needs to be worn by a user to monitor the heart rate (Fig. 2.2). The POLAR Heart Rate Monitor Interface[2] acts as a mediator (Fig. 2.2). It receives data from the sensor and forwards it to a Java Application via a serial connection over USB (Fig. 2.4). This Java application requests the heart rate every second and is responsible for tracking and analyzing this data. A second Java application (Fig. 2.5) is placed on top which controls actuators being attached to the users' feet. In addition, it is responsible for the tactile feedback which shall be used to support the cycling. The actuators are wired to a self-built micro controller board that receives input via Bluetooth and which controls the tactile feedback (Fig. 2.6). This allows controlling the intensity of the actuators in order to communicate different tactile patterns.

The training programs are based on the work by Edward [3] who defines five different zones for the maximum heart rate. Keeping the heart rate in one of these zones has a specific effect on the human body. The health, fat burning, aerobe and anaerobe zones are offered as training zones. The maximum heart rate for a person can be computed with Hills' equations [5]. Hills mainly differentiates between a trained or untrained person in combination with the gender. To find out, if a person is trained or not the body mass index is used. Details are provided in figure 3.

Person	Max. Heart Rate (HR_{max})
Heavily overweighed	200 - (0,5 * Age)
Untrained Woman	209 - (0,7 * Age)
Untrained Man	214 - (0,8 * Age)
Trained Woman	211 - (0,5 * Age)
Trained Man	205 - (0,5 * Age)

Heart Rate Interval	Zone	Wirkung
50 – 60% HR_{max}	Health Zone	Improvement of the cardiovascular system
60 – 70% HR_{max}	Fat Burning Zone	Fitness improvement and fat burning
70 – 80% HR_{max}	Aerobe Zone	Stamina improvement
80 – 90% HR_{max}	Anaerobe Zone	Strength and muslce development
90 – 100% HR_{max}	Warnzone	Risk for untrained persons

Fig. 3. Left: Max heart rate equations by Hills; Right: Edward's training zones [3, 5]

With the help of the parameters which the user specified on the mobile phone the maximum heart rate can be calculated. The maximum heart rate is monitored by our prototype. Clock pulse vibration patterns are used to inform the cyclist to speed up or to slow down.

5 Informing User Preferences

Although the realization of the concept was straight forward, the best positioning of actuators on users' feet was uncertain. We wanted to find out if actuators should be arranged in a line or in an array. Additionally, the position on the foot had to be tested. Therefore, a preliminary user study has been conducted. 12 participants (4 female

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2 http://www.sparkfun.com/products/8661

and 8 male) took part in the study. The oldest participant was 70, the youngest 25 years old. In average the participants were 36.5 years old.

5.1 Study Design

Actuators which can be found in a Nokia 8800 mobile phone where taken and fixed in a piece of foam (see figure 4). Four actuators were arranged in line while four different ones were placed in a rectangle. These pieces were placed on the ball of the foot, the heel or the ankle. A third order Latin square was used to control the order of the tested configurations for the different positions of the actuators while the arrangement of the actuators was rotated. One participant always started with the actuators in line while another participant always had the array configuration first. Three different pulses were sent which participants had to distinguish. The tested durations were 100ms, 300ms and 800ms. All in all, participants had to delimit 9 signals (3 short, 3 medium and 3 long signals) which were tested with every position and arrangement. This results in a 3x2x3 factorial design: 3 positions (ball, ankle and heel) x 2 arrangements (line and array) x 3 signals (short, medium and long).

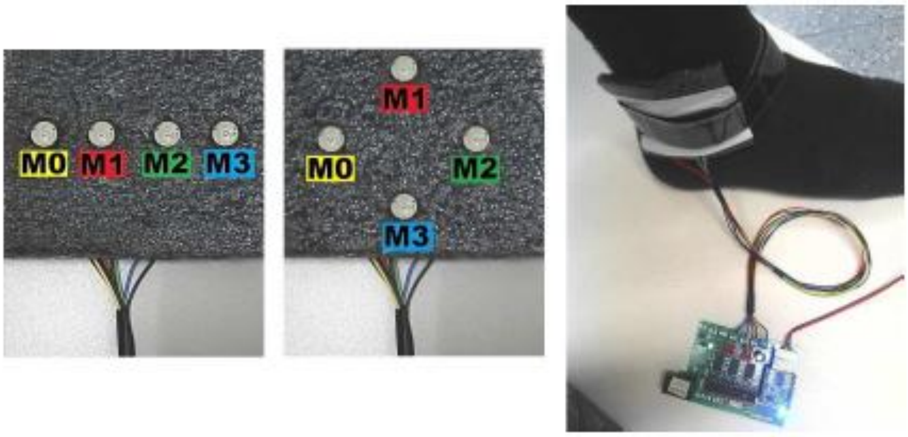

Fig. 4. Actuators arranged in a line and an array - exemplarily positioned at an ankle.

5.2 Procedure

After a short introduction into the study, its configurations and the study's purpose participants were asked to take off their shoes and to sit down on a chair with their back to the examiner. The aim was that the participants could not have a glance at the study material like the randomization and notes. Then, the participants were asked to wear headphones during the different runs to make sure that the vibration of the actuators could not be heard and the duration be guessed.

Then, the signals for each configuration were sent to the actuators. The participants had to state if the last signal sent was a short, medium or long one. The examiner noted the correctness or incorrectness. After each configuration a short questionnaire based on [14, 15] was given to the participants which they were asked to fill in. The questionnaire used 5 Level Likert scales to gather information about mental demand, comfort and subjective performance. Finally, participants were briefly interviewed. All in all, the study took roughly 20 minutes for each participant.

5.3 Results

We applied statistic tests to our gathered results. An ANOVA showed that there is no significant effect for the errors participants made during the experiment. However, we do not believe, that there is no difference among the positions and arrangements. In fact, it could be a result of our setting. Participants could fully concentrate on the vibration and were not distracted by their surroundings. Hence, such a system is heavily influenced by real world conditions so that a test in the wild would be necessary.

Additionally, we used questionnaires to ask for the mental demand required for the signal identification, the comfort for wearing the actuators and the participants' self-assessment. However, Friedman ANOVAs did not show any significant effects. Moreover, the mean values and the standard deviation did not differ so that we had to rely on participants' feedback.

At the end of the different runs of the study, the prototype was discussed with the participants and their impressions as well as ideas were noted. The interviews showed that 11 of 12 participants could imagine using tactile feedback on foot while riding a bike or motorcycle. Only one participant mentioned that the vibration felt strange. Additionally, he was concerned about the information content which can be communicated. Therefore, he cannot imagine that such a system could be useful in a real world scenario. The participants mentioned further applications for tactile feedback, for example communicating warnings or navigation.

Asking the participants for their preferred position and arrangement, 6 of the participants would like to have the line arrangement. The other participants had no preference at all. No participant mentioned the array arrangement. 7 participants preferred the actuators to be placed at the balls of the feet, preferably in combination with a line arrangement. Other participants stated to have no preference. This indicates that the best suited position for actuators is the ball in combination with the line arrangement which was used in the final prototype.

6 Preliminary Testing in the Wild

After the preliminary study and the development of the shoes (see figure 5) our prototype from section 4 could be fully implemented. The final prototype sends vibrations pulses to a user telling that her training starts or ends and on which foot to put force on to pedal. We used five different vibration patterns to communicate these actions based on the long and short vibration pulses form the preliminary study with a break of 75 milliseconds in between. When the patterns had to be chosen it was focused on easy differentiation between those.

The training started with three long vibrations signals. Five long signals ended the training. When three short and a long signal are sent the cyclist has to shift up a gear. A long followed up by three short signals lets a user shift down a gear. These patterns are sent to both feet at the same time. A single short signal on the left or the right feet tells on which foot to put force on and helps to establish a certain pedaling frequency to reach a certain hart rate.

We asked two participants (1 male, 36 years and 1 female, 48 years old) to test our design and the vibration patterns under real world conditions to find out the suitability in a realistic context. The participants had to wear the shoes, a POLAR belt and a rucksack where a laptop was placed in. The POLAR heart rate interface was connected to the laptop so that the laptop could process the heart rate data and could control the actuators in the shoes. Additionally, a mobile phone was given to the participants so that they could configure their training program. Two different training programs which took five minutes each were tested by the participants. The tests were carried out on the inner courtyard on a nearby University campus. Figure 1 shows a participant testing the prototype.

Fig. 5. Shoes providing tactile feedback for cyclists to support their training.

A short introduction was given to the participants to inform them about the study and its purpose the participants. The participants were not trained to use the system and had to learn its usage during the study. Afterwards we asked them to configure their training and to cycle in circles in sight of the examiner. The examiner observed the participants and made notes which were used during the followed up interviews. Additionally, the participants' heart rate was tracked.

Exemplarily, the results of a 48 years old participant with a weight of 61kg shall be discussed in detail. Figure 6 shows the tracked data.

The participant chose the fat burning training program and stated to be untrained which resulted in his individual training program. Afterwards, the participant had to keep the rhythm suggested by the vibration signals sent to both feet alternatively.

After the experiment the prototype and the participants' experience were discussed. The participants enjoyed the cycling as well as the experiment. Interestingly, one participant stated that he was even motivated by the vibration to keep on exercising. He liked the idea of having a system which keeps track of the performance as well as improving the personal training. Asking the participant if they would use such a system in traffic and if they think it to be dangerous they said that they do not see any risk. However, participants criticized, that the vibration was too weak so that more powerful actuators should be integrated. Nevertheless, they mentioned that they would like to buy the system and even suggested to apply this concept to further domains like jogging.

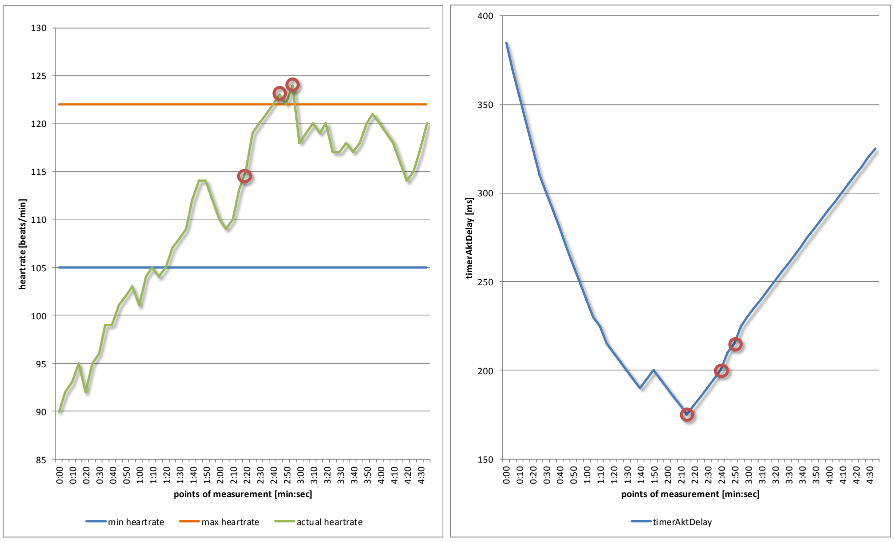

Fig. 6. Exemplary results of one participant

7 Conclusion

This paper explores how tactile feedback communicated via the user's feet can be used to communicate pedaling frequency and shifting gears to achieve an optimal training while cycling. First, a user study was conducted to inform the final design of the tactile actuators. Then, a prototype was developed and preliminary user feedback gathered. Two participants tested the prototype in a realistic setting and reported that they were impressed by the system and could imagine using the system regularly. Only a short introduction was necessary before the participants could use the system. This shows that tactile feedback on feet can be of high value for the sports domain. However, this also demonstrates that a further research needs to be conducted and that further vibration hardware and patterns have to be investigated.

8 References

1. Bial, D., Kern, D., Alt, F., Schmidt, A.: Enhancing Outdoor Navigation Systems through Vibrotactile Feedback. In: Proceedings of the 2011 annual Conference extended Abstracts on Human Factors in Computing Systems. CHI EA '11, pp. 1273–1278. ACM (2011)
2. Brewster, S. A., Brown, L. M.: Tactons: Structured Tactile Messages for non-visual Information Display. AUIC '04, pp. 15–23. Australian Computer Society, Inc. (2004)
3. Edwards, S.: The Heart Rate Monitor Guidebook: To Heart Zone Training. VeloPress (1999)
4. Heuten, W., Henze, N., Boll, S., Pielot, M.: Tactile Wayfinder: A non-visual Support System for Wayfinding. In: Proceedings of the 5th Nordic Conference on Human-Computer Interaction: Building Bridges. NordiCHI '08, pp. 127–181. ACM (2008)
5. Hills, A. P., Byrne, N. M., Ramage, A. J.: Submaximal Markers of Exercise Intensity. In: Journal of Sports Sciences, vol. 16, pp. 71–76. British Association of Sport and Exercise (1998)
6. Hogema, J. H., De Vries, S. C., Van Erp, J. B. F., Kiefer, R. J.: A Tactile Seat for Direction Coding in Car Driving: Field Evaluation. In: IEEE Transactions on Acoustics, Speech and Signal Processing Haptics, vol.2, pp. 181–188. IEEE Computer Society Press (2009)
7. Kern, D., Marshall, P., Hornecker, E., Rogers, Y., Schmidt, A.: Enhancing Navigation Information with Tactile Output Embedded into the Steering Wheel. In: Proceedings of the 7th International Conference on Pervasive Computing. Pervasive '09, pp. 42–58. Springer (2009)
8. Jirattigalachote, W., Shull, P., Cutkosky, M.: Virtual Pebble: A Haptic State Display for Pedestrians. In: Proceedings of 20th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN, pp. 401-406, IEEE (2011)
9. Lylykangas, J., Surakka, V., Rantala, J., Raisamo, J., Raisamo, R., Tuulari, E.: Vibrotactile Information for Intuitive Speed Regulation. In: Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology. BCS-HCI '09, pp.112–119. British Computer Society (2009)
10. Poppinga, B., Pielot, M., Boll, S.: Tacticycle: A Tactile Display for Supporting Tourists on a Bicycle Trip. In: Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services. MobileHCI '09, pp. 41:1–41:4. ACM (2009)
11. Roeder, B., Kusmierek, A., Spence, C., Schicke, T.: Developmental Vision Determines the Reference Frame for the Multisensory Control of Action. In: Proceedings of the National Academy of Sciences, vol. 104, pp. 4753–4758. National Academy of Sciences (2007)
12. Spelmezan, D., Hilgers, A., Borchers, J.: A Language of Tactile Motion Instructions. In: Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services. MobileHCI '09, pp. 29:1–29:5. ACM (2009)
13. Yao, L., Shi, Y., Chi, H., Ji, X., Ying, F.: Music-Touch Shoes: Vibrotactile Interface for Hearing Impaired Dancers. In: Proceedings of the fourth International Conference on Tangible, Embedded, and Embodied Interaction. TEI '10, pp. 275–276. ACM (2010)
14. Hart, S. G., Stavenland, L. E.: In Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: Human Mental Workload (1988), pp. 139-183
15. Lewis, J.: IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. In: nternational Journal of Human-Computer Interaction **7**, 57-78 (1995).