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Development of a new product for unrestrained heart rate measurement in swimming: a user centered design approach

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Abstract

This paper reports the development of a new product for unrestrained heart rate measurement to provide feedback and target training efforts in professional swimming. While training is considered to be the key to becoming a top athlete, little is known about how to determine the right training course for individual athletes (Maase, 2009, [1]). In order to optimize the training load of an individual athlete, coaches need to monitor physiological indicators that are linked to performance.

Interviews with the Dutch Olympic swimming team have shown that coaches feel the need for ways "to be able to look inside the athlete's body" (Wouda, 2009) and get insight in their capacities without restraining them. In swimming coaches use VO2 levels, heart rate, lap times and lactate to adapt the training load. However measuring VO2 levels and lactate is too invasive and expensive for regular use. This makes heart rate a suitable measure.

For land sport, there are several devices on the market that measure heart rate at appropriate costs, however these are not suitable for professional swimmers. Interviews with coaches of the Dutch Olympic team have shown that anything that increases the resistance of the body will not be acceptable for swimmers. Existing products were deemed inappropriate because they restrict the athlete's movement, tend to shift in the water during jumps or turns or are not accurate. Therefore current heart rate monitors are not used on top level and coaches rely only on lap times as direct feedback of the training load during regular trainings. This might lead to under training or over reaching.

A new product designed to measure a swimmer's heart rate without using inconvenient sensors is being developed within Philips Research. Heart rate is measured through analysis of visual signs in between laps and direct feedback is given to the swimmer and coach during the training. The measurement data is not only shown during training, but is also stored for later analysis. This paper will report that development from a user-centred design perspective. The design focuses on the special needs of top athletes represented by the national swimming training centre in Eindhoven, The Netherlands. The use of this new product will enable unobtrusive measurement with direct feedback to optimise the individual training load and push athletes to the limit.

Keywords : Heart rate; Heart rate measurement; Heart rate monitor; Swimming; Camera, Training: product design, user-centred design;
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1. Introduction

In order to avoid under-training or over-reaching, training efforts need to be targeted at the performance and physiology of the individual athlete. This paper addresses the development of a device for appropriate feedback in elite swimming. Despite multiple training load indicators that are available in principle, coaches still rely only on lap times as direct feedback during regular trainings. Other measures, such as VO_2 levels, heart rate, lap times and lactate are only used to adapt the training load. However measuring VO_2 levels and lactate is too invasive and expensive for regular use. This makes heart rate a suitable measure. Desk research and interviews with coaches and swimmers however showed that heart rate is still not used during regular swim trainings because the current products do not fulfil the user's needs. Moreover coaches explained that too little is known about the actual implementation of heart rate in swimming. Target heart rate zones have been developed for land sports, but are not directly applicable in swimming and do not take into account individual heart rate zones. Swim coaches therefore feel the need to gain more insight in training load and heart rate and are looking for a product that fulfils their special needs in measuring heart rate. An analysis of existing products and interviews with the coaches of the Dutch national swimming team showed that current heart rate products on the market do not fulfil the needs of these coaches resulting in the absence of use during regular trainings. Current products either do not withstand water or chloride, or do not allow for direct feedback to both swimmer and coach, and for data storage for later analysis. Current products also restrict the swimmers movements and their "water feeling" because they involve the use of wearable sensors.

A newly developed technology from Philips enabling remote heart rate measurement without the use of wearable sensors offers a great opportunity for unrestrained heart rate measurement in swimming. Therefore Philips Research started a project with Delft University of Technology to develop a heart rate monitor based on this new technology, targeted at swim trainings. The goal is to provide coaches of the Dutch national swimming team with a means to support their training methods and give them insight in the effects of the training on the individual athletes.

The technology used in the product is based on remote heart rate measurement with a video camera which is an advancement of classical photo-plethysmography (PPG). Like the PPG-sensor, this camera is able to detect small changes of color caused by the heart pulse in the skin. This is due to the fact that blood absorbs more light than the surrounding tissue, so the variations in blood volume affect the absorption of the light on the skin [2]. These color changes can be detected by a camera in combination with dedicated algorithms that filter out disturbances arising from lighting conditions and movements. Parallel to the hardware & software development, an industrial designer was involved to ensure a user centered design which successfully implements the new heart rate measurement technology in a product that fits the needs of the coaches of the Dutch national swimming team. The scope of this paper is on the design of a device to use this technology therefore the development of this technology is not discussed further in this paper.

2. Methods

The main goal of the project was to develop a product that was not based on technology push, but on a user centered design approach. User centered design aims to explore the context of use and empathize with future users [3, 4]. Especially in the conceptual stage of product development, users are consulted to elicit possible scenarios and inspire designers to generate ideas for products that properly fulfill the users' needs.

First a desk research on swim trainings and on current heart rate products and the meaning of the use of heart rate in sports was conducted. Then relevant stakeholders and users were involved in the process of analyzing the user-context. Based on experiences from previous research, great care was taken to focus on top athletes, as their needs have been found to be radically different from even the league below them [5, 6}. Interviews were conducted with coaches, swimmers and swimming pool managers as well as innovation managers to get insight in the user context and user needs. During these semi-structured interviews brain writing was used as an unobtrusive interview tool in order to help structuring the user's thoughts [7]. Jacco Verhaeren, Marcel Wouda and Martin Truijens, the three main coaches of the Dutch national swimming team, were asked to write down all factors they knew that could influence the performance of individual athletes.

Observational research was performed during trainings of the Dutch national swimming team in Eindhoven to explore and map the user-context, involving currently used training tools and observe the interactions between

swimmers and coaches. During intensive swim trainings a heart rate measurement test was performed to test the developed software in the complex environment of the swimming pool (Fig. 3 & 7) and get insights in the boundaries the user context poses for the technology.

After these observations and interviews a wish list for the user's needs and requirements for the product features was formulated. Then in an early stage of development, the end-users were involved in feedback sessions whereby they were shown many product idea sketches to illustrate the designer's ideas. These sessions also helped to manage the expectations of all stakeholders. Finally a user test was performed with a mock-up product to test the designed user interface and test the practical implementation of the product in regular trainings.

3. Results

3.1. Insight in context of use

To practice their trainings, the members of the Dutch national swimming team perform their trainings in public swimming pools during hours in which the pool is reserved for them. When the product will be integrated in the swimming pool it will have to fit the requirements of a product which is used in public areas: robustness, suitable for multiple users and ease of use. The swimming pool environment itself requires water tightness and usability in a warm, humidity and chloride containing environment. The limited space around the starting blocks gives the need for a compact product design placed close to the starting block without limiting the use of the starting block.

Literature research and interviews showed that swim trainings can be divided into different categories and are different in content during different periods of the year [8]. However the main goals of the trainings are to reach the right super compensation in athletes [8] and improve their swim technique, efficiency and endurance. Interviews and observational research have shown that although a lot of technology is available, it is typically not available in convenient products that fit the special target group of swimmers and swim coaches [9]. Therefore coaches mostly use down-to-earth tools like stopwatch, clipboard and laptop (Fig. 1). This indicates the need to develop and apply technology in a user-centered design approach to meet these special needs.

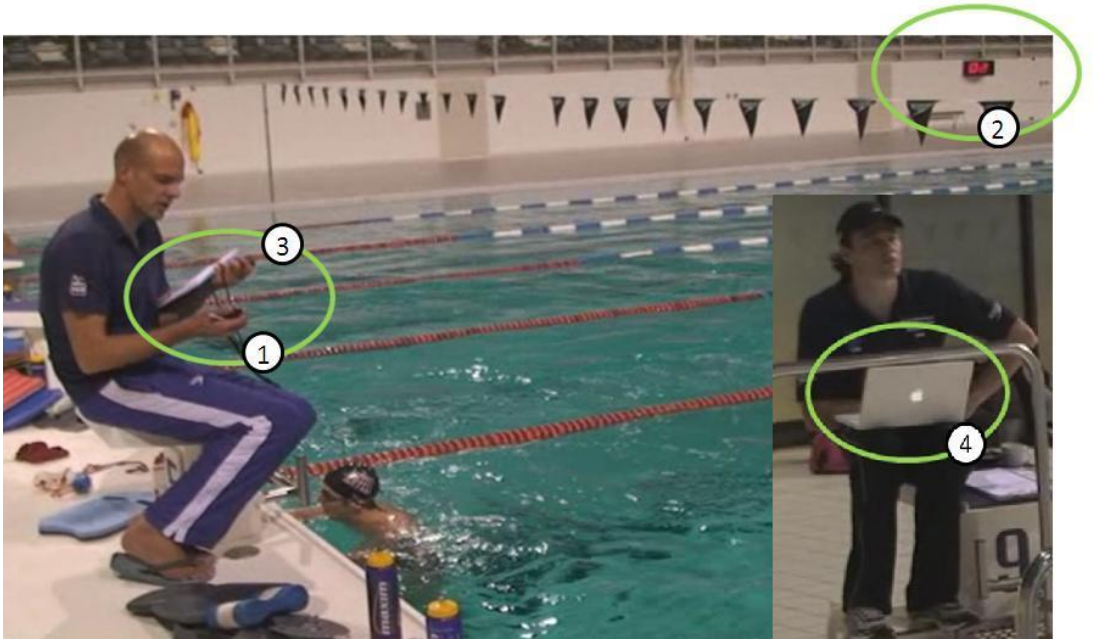


Fig. 1. Coaching tools; stopwatches[1] & pace clocks[2] to control training load and record lap times, Clipboard[3] & laptop[4] to report lap times for later analysis

The observational research showed that swimmers perform their trainings with multiple persons in one lane (fig 2) which will require some sort of person recognition to connect the measured heart rate to the right swimmer.

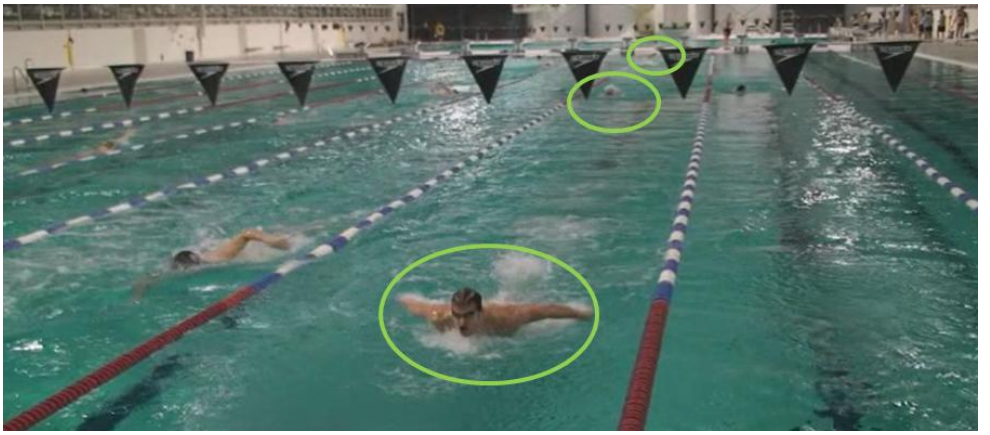


Fig. 2. Multiple swimmers in one 50m lane during a regular training (sometimes up to 4 swimmers)

A test with the developed heart rate camera proved that it is possible to measure the vital signs of the swimmer within 3 to 5 seconds (fig. 3), which also proved to fit within the interval based trainings of the swimming team [8].

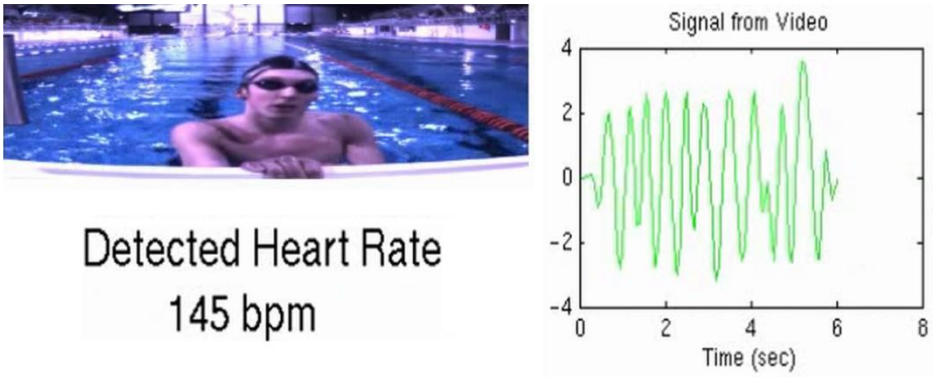


Fig. 3. Screenshot of captured video, video signal and derived heart rate of a swimmer during training

3.2. Product requirements

The research with the end users showed that although heart rate is a suitable measurement of training load, current heart rate monitor products lack one or more requirements needed by swim coaches for the successful application during regular trainings. To successfully implement the new product it needs to comply with the following requirements:

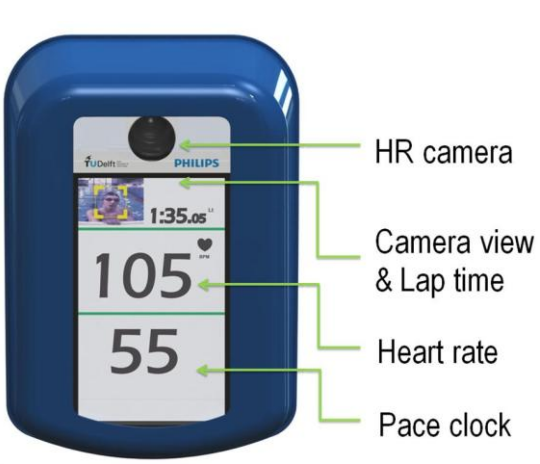
- Measurement of vital signs without interfering the water feeling of the swimmers or the training routine
- Direct feedback of measured data to both swimmer and coach
- Data storage of measured vital signs data for later analysis
- Robust product design (water tight, impact resistance etc.)
- Additional monitoring functions (HR, Pace clock, lap time, video)
- Person recognition to enable multi person use (fig. 2)
- Communication with external devices for displaying to coach
- Shut off function for swimmers display to enable swimming on own feeling

3.3. Concept design and user feedback

With these requirements in mind several concept design sketches were made to explore how the end product could look like and which features can be implemented. Coaches and swimmers were then confronted with these concept idea sketches and asked to give feedback on the different functionalities and embodiments (Fig. 4).

These feedback sessions gave additional input for the design process like the need to know the display angle to optimise the swimmers view and reduce reflections. Also the option to display the measured data on an external device was confirmed by the feedback from the coaches. The coaches pointed out their preference for a product that is integrated into the starting block. This is a natural place for the swimmers to look at and makes the product fit in the user environment. To test the designed user interface and test the usefulness in practise, a mock-up of the product was made (fig. 5, 6) and a user test was performed during a training of the national swimming team in Eindhoven (fig. 7)

Fig. 4. Martin Truijens (NZA) during a feedback session



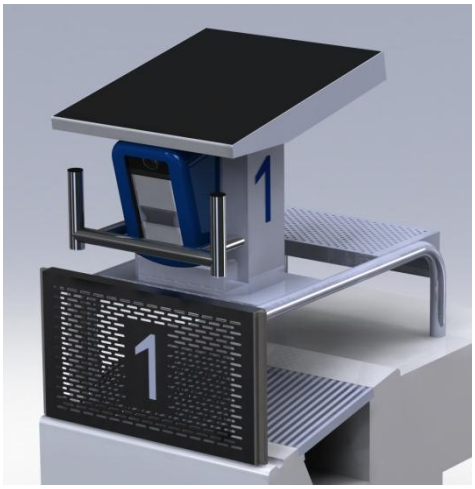


Fig. 5. (a) Features of the new heart rate monitor ; (b) Impression rendering heart rate monitor

This user test showed that the swimmers were very curious to know their own heart rate during the training and see the development during different parts of the training sessions.

Both coaches and swimmers pointed out the relevance of the use of heart rate in regular swimming trainings to monitor training load and see progress in the physical condition of the athletes. The test proved that the measurement of heart rate with the heart rate camera can successfully be implemented in regular trainings.

To optimise the use of the new product swimmers will have to swim with an interval of 15 to 20 seconds between each athlete to allow for appropriate measuring time and fluent training speed (Fig. 8).

Fig. 6. User test with product mock-up and interface

It is expected that by measuring vital signs like heart rate variability and heart rate this product can also be used by the supporting staff of the national swimming team to monitor the overall health and stress of the athletes and even predict illness [10, 11, 12].

With the user feedback on the mock-up test, the final user interface and product design can now be made in which the coaches and swimmers will remain involved to ensure a user centered product design.

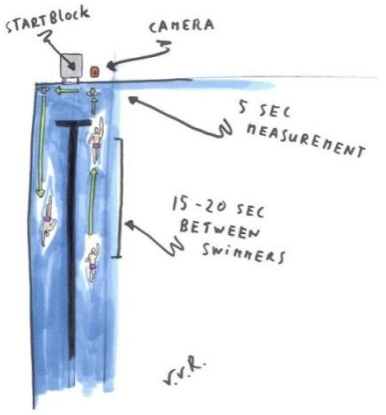


Fig. 7. Use of HR device with multiple swimmers

4. Conclusions

In a collaborative effort between Philips Research, Delft University of Technology and stakeholders of elite swimming, a technology for remote heart rate measurement was developed into a monitoring device for swimmers and coaches. By following a user centered design approach,the specific needs of this group of top athlets were elicited with interviews, brain writing, observations and user tests. By involving end-users early in the design process required product features could be better implemented and the expectations of the users could be managed. The use of concept idea sketches during feedback sessions provided clear communication with the end-users about

desired product features and product embodiment. The feedback on the user tests and concept presentations will now be used as an input for the optimisation of the final user centered product design.

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References

[1] Maase K. (2009), coordinator scientific support topsport NOC*NSF, speaker on Sport science & technology congres Eindhoven, 13 October 2009

[2] Wieringa, F.P. et all (2005), Contactless Multiple Wavelength Photoplethysmographic Imaging: A First Step Toward "SpO2 Camera" Technology, Annals of Biomedical Engineering, vol.33 No. 8, August 2005

[3] Fulton Suri, J. (2003) Empathic design: Informed and inspired by other people's experience. In Koskinen, I., Battarbee, K., Mattelmäki, T. (eds.) Empathic Design: User experience in product design, Helsinki: IT Press.

[4] Buchanan, R. (2001) Human dignity and human rights: thoughts on the principles of human-centered design. Design Issues, 17,35-39.

[5] Van Geer, E. et all , Optimal Swimsuit for forward Crawl, TU Delft 2009

[6] Cuperus N., van der Hijden S.M. and Nieuwenhuijsen K., Swimsuits and performance: The effects of manipulations to a swimsuit on passive and active drag, VU Amsterdam 2009

[7] Buxton, B. (2007) Sketching User Experiences. Getting the design right and the right design. San Francisco: Morgan Kaufmann

[8] Olbrecht J. (1997), The Science of Winning. Planning, Periodizing and Optimizing Swim Training. 2nd edition, F&G Partners, Partners in Sports

[9] Toussaint, H.M. et all, Applying technology to optimise training: A look in the (near?) future, http://web.mac.com/htoussaint/SwimSite

[10] Earnest, C.P., Jurca, R., Church, T.S., Chicharro, J.L., Hoyos, J., Lucia, A. (2004) Relation between physical exertion and heart rate variability characteristics in professional cyclists during the Tour of Spain, British Journal of Sport Medicine, 38:568-575

[11] Heart Rate Variability (HRV): available from www.polar.fi, cited on December 2009

[12] Heart Rate Variability (HRV): available from www.omegawave.com, cited on December 2009