Howel: A Soft Wearable with Dynamic Textile Patterns as an Ambient Display for Cardio Training

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ABSTRACT

In-situ exploration of heart rate (HR) zones during cardio training (CT) is important for training efficiency. However, approaches for monitoring HR, either depend on complex visualizations on small screens (i.e., smartwatches) or intrusive modalities (i.e. haptic, auditory) that might force the attention to the information. We developed an early prototype, Howel, a novel wrist-worn soft wearable to display HR zone information during CT. Our concept utilizes mapping information onto dynamic patterns (color changing stripes) as an easy-to-understand ambient display. To preserve non-intrusiveness, it uses non-emissive modality by heating thermochromic paints on its textile surfaces. Early feedback from three participants suggests that soft wearables with non-emissive dynamic patterns have potential (1) to embed information organically on the body, (2) to

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Soft Wearables; Ambient Displays; Heart Rate; Sports Wearables; Fashion; Dynamic Patterns.

Figure 1: Howel, representing 3rd intensity zone via the green line on the 3rd stripe.

Table 1: HR Zones and their effects on the body. The zones are defined via Karvonen Formula [5]: **Intensity (%) = (HRresting – HR)/(HRmax-HR)**

Zone	*Intensity*	*Effect on Body*
Health Zone	50-60%	Improvement of the cardiovascular system
Fat Burning Zone	60-70%	Fitness improvement and fat burning
Aerobic Zone	70-80%	Stamina improvement carbohydrate and fat burning
Anaerobic Zone	80-90%	Strength and muscle development
Red Zone	90-100%	Risk of injury for untrained people

give easy-to-understand in-situ intensity information and (3) to keep the attention on the exercise instead of performance measures.

1 INTRODUCTION

Cardiovascular training – CTs in short - (i.e. walking, running, cycling) is important for both physical and psychological health. The most obvious physiological indications during CT is the elevation of heart rate (HR) [1]. Based on individual capacities (i.e., age, training background), working within specific HR zones (see Table 1) is beneficial for achieving specific goals (i.e. weight loss, decreasing blood pressure). Thus, in-situ exploration of HR zones helps exercisers to train efficiently towards their personal goals [2]. However, recent HR monitors either depend on small displays with complex information that are hard to interpret while jogging [2] or intrusive modalities (i.e. alerting haptic notifications or isolation with auditory info representations) that might overwhelm and distract the users by directing their focus to the performance metrics [13]. This situation creates a challenge for receiving in-situ CT information; We assert it should be easily understandable at will, but also remain non-intrusive at other times as it might cause a distraction.

In this direction, our previous study [7] suggest that abstract visual alterations on clothing might provide in-situ information to their wearers. Also, [4] highlights that non-emissive dynamic alterations on textile surfaces might be useful in terms of providing ambient information without forcefully grabbing attention. These alterations are called *dynamic textile patterns* and often use thermochromic paints on textiles which alter its color with the computable heating elements [18]. Inspired by this line of research, *we argue that non-emissive dynamic alterations on fabric surfaces can be designed for conveying easy-to-understand HR information without intruding the training experience*. Despite growing interest in exploring dynamic textile patterns [i.e. 15, 16], we did not encounter a wearable ambient device that aims in-situ information representations based on dynamic textile patterns during CT for personal use.

To address this gap, we designed an early prototype named as Howel (Fig. 1), a novel wrist-worn soft wearable to monitor HR zone information during CT. While designing the Howel, we were inspired by two strategies from ambient display research [11]: Abstraction and change blind transitions. Abstraction refers to mapping simplified versions of raw data onto the environment to enable easy interpretations. Based on this strategy, we simplified the raw HR data into five widely used [5] HR zones (Table 1) and mapped each zone spatially and colorwise to the patterns (stripes) of the Howel. As a result, each stripe is designated to different HR zones and reveals an assigned color when the wearer exercises within that zone (Fig. 3). “Change blind transitions” refer to the changes on displays which does not attract wearer’s attention and can be understood only when the user wants to attend the information. For that, we used non-emissive color changes achieved through the disappearance of the thermochromic paint layers via heat applied. These transitions are not noticeable unless the user glances at them. Implementing these strategies allowed us not only to design a new wearable display, but also provided a new context for these strategies. After implementing the Howel, we conducted a preliminary user study with 3 potential users to guide our further design processes towards developing soft wearables as easy-to-understand and non-intrusive ambient displays during CT.

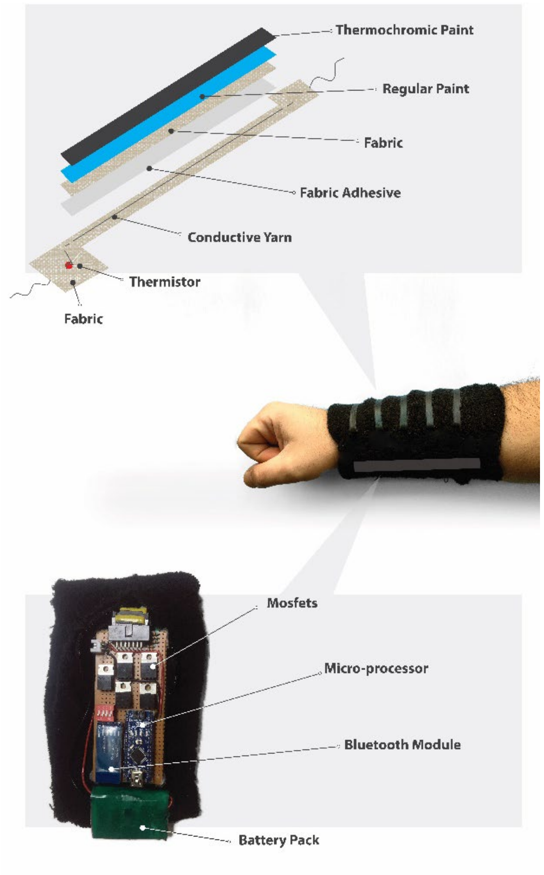

Figure 2: Implementation details of the Howel: (Top) layers of stripes; (Bottom) hard electronics board is taken out of the Howel's pocket.

The contribution with this paper is two-fold: First, we explore a novel wearable ambient display for in-situ HR zone information during CT. Second, we present and discuss early feedbacks to guide our evolving design. We believe that our insights could inspire fashion, interaction and wearable design fields for designing novel ways of aiding and improving the exercise experience.

2 RELATED WORK

2.1 Wearable Devices for Displaying In-Situ Information

Current state-of-art HR monitors are mostly based on small displays with literal and complex performance visualizations on small screens (i.e. smartwatches) that are hard to interpret while running or jogging [2]. Alternatively, some researchers explored abstract representations via light emitting modalities (i.e. LEDs) on larger areas of the body [i.e. 10, 17] or on wristbands (i.e. https://heartzones.com/). However, embedding lights on the body raise attention-related issues both for observers and wearers [10], whereas the small LED indications might be hard to notice while working out. There are also wearables that give auditory [i.e. 9]and vibro-tactile HR feedbacks [i.e. 3] during exercising. Yet, we can argue that these modalities are intrusive in nature putting information into central focus by alerting (i.e. vibro-tactile, auditory notifications) or isolating users (i.e. headphones) with information.

2.2 Soft Wearables as Ambient Displays with Non-Emissive Dynamic Textile Patterns

Previous research proposed and used non-emissive dynamic textile patterns as an ambient display of information. For instance, [4] developed a special type of fiber which is a custom-made conductive thread painted with thermochromic materials. Also, [16] designed an arm-worn wearable that displays affective data based on wearer's HR. [15] implemented another HR-based dynamic pattern representation for directing the observer's attention to heart health. The main difference of our study from these studies is that they primarily aimed for observers, whereas we aim to create a wearable display focuses in-situ information during CT primarily for personal use.

Overall, our approach builds upon in-situ representations on wearable displays for personal uses, extends them via a non-emissive modality to remain non-intrusive and utilizes abstract dynamic patterns on wider areas on the body to be easily glanceable.

3 DESIGN & IMPLEMENTATION

We designed the Howel, an ambient display on an arm-band's surface, with the goal of representing training intensity in an easy to understand and non-intrusive way. As our initial aim was to understand the user reactions, we implemented a semi-working prototype that functions as an output device. For collecting the wearer's real-time HR zone information, we used FITIV Pulse application on a Apple Watch which streams data to an iPhone. During studies, the researchers updated the information on the Howel from a remote computer by looking at the iPhone.

The dynamic patterns involved 5 stripes that can change color (Fig. 3). Each stripe was designated to a different HR zone: The lowest intensity zone is the closest to the hand, highest is the farthest. From the lowest to the highest intensity, the colors of the stripes changed from black to white, blue, green, orange and red, respectively. Using individual stripes and different colors for each zone was motivated by providing easy perceptual differentiation among zones.

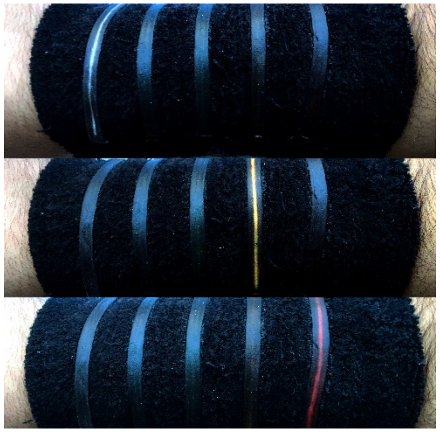

Figure 3: Examples for HR zone representations on the Howel: (Top) 1st HR Zone; (Middle) 4th HR Zone, (Bottom) 5th HR Zone.

Table 2: Backgrounds of the participants

Demographics		*Exercise & Tracker Background*
P1	Female, Age: 24	Owns a wrist-worn HR monitor; Regularly attends the gym.
P2	Female, Age: 20	Owns a wrist-worn HR monitor; Regularly attends the gym.
P3	Male; Age:28	Used smartphone apps for counting steps & calories; Does not conduct any physical activity for two years, but intends to start.

We implemented stripes by layering fabrics with conductive yarns (28 Ohm/ft), tiny thermistors, thermochromic (transparent above 39°C) and regular paints (Fig. 2). All stripes remain black until the user is in the relevant zone. When the wearer enters a zone, the current is sent to the assigned conductive yarn. This heats the thermochromic paint, and the stripe reveals approximately 2 mm line shape in 4-6 seconds (Fig. 3). The heat was isolated from the skin as it was on the outer surface of the band. Tiny thermistors continuously check the temperature of the yarn to ensure a stable value, slightly above the color changing temperature (42°C). Therefore, our software cut the current whenever it is above 42°C. This enabled the efficient use of the battery as well as patterns to turn black faster. Eventually, the stripe fades back in approx. 10-12 seconds, when the zone changes.

The length of the band was 16 cm. The hard electronics on the prototype consisted of an Arduino Nano, a Bluetooth module (HC-05), five MOSFETs (IRL540N N-channel Logic Level), and a battery pack (7,4V, 900 mAh LiPo). The total size of the hard electronics was 13.5 x 6 x 1.3 cm, and they were placed in a pocket on the band (Fig. 2). Arduino Nano was used to control the current that passes through the heating elements by adjusting the voltage of the MOSFETs. Bluetooth module was used for controlling and monitoring the zones remotely by a computer.

4 PRELIMINARY USER STUDIES

We conducted Wizard of Oz [12] trial sessions with three healthy individuals (Table 2) on a volunteer basis at the sports center of Koç University. Upon arrival, we informed participants about the five zone training intensities (Table 1). Afterward, we measured and entered their HRresting & HRmax values to the FITIV Pulse app on the Apple Watch for customizing HR values. This also enabled us to stream HR Zone to an iPhone to control the Howel's display during trials. Then, we asked participants to wear both the Apple Watch and the Howel to their desired arms. The trials were conducted in an exploratory manner that we altered conditions among participants (Table 3). During trials with only the Howel, the screen and notifications of the Apple Watch were disabled. P2 and P3 could check the FITIV Pulse application interface (Fig. 4) by raising their wrist during their trials with the Apple Watch. Only P3 used the FITIV Pulse's vibration notification that warns users on zone changes. At the end of each study, we conducted semi-structured interviews, investigating their overall experience with the Howel, their perception of understandability and intrusiveness. All interviews were audio recorded upon the consent of the participants. Overall, the studies lasted approx. one hour.

5 PRELIMINARY FINDINGS & DISCUSSION

Below, we present the themes that emerged from our interviews that might guide and inspire the design of soft wearables as ambient displays during CT.

5.1 Organically Integrated Information on Body

P1 and P3 specifically appreciated that the Howel felt like an organic way of receiving information by referring to its softness and non-emissive modality. P1 stated *"Dynamic patterns felt more organic. Screen means solid surfaces. But textile presents a more organic experience"*. P3 also supported his argument by referring to a moment that he noticed the LED of Arduino Nano

Table 3: Trial Conditions Among Participants*

	Trial on	*Trial Conditions*	*Duration*
P1	Treadmill	Only Howel	30 mins
P2	Running Track at Sports Center	Only Apple Watch with the screen interface	15 mins
		Only Howel	15 mins
P3	Treadmill	Both Howel + the Apple Watch (with screen interface and vibration notifications on zone changes.)	30 mins

*After the first trial, as we were also curious about how participants would find our prototype in comparison to a commercially available application, we included trials with the FITIV Pulse application on the Apple Watch. For the same reason, we enabled the FITIV Pulse's vibration notification on zone changes during P3's trial. Different than other participants, P2 preferred to try on the running track at the sports center.

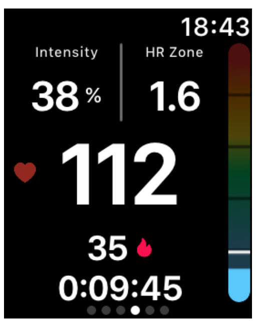

Figure 4: The FITIV Pulse Application Interface on the Apple Watch, displaying HR zones visually with a bar (right bar) that is divided into five. When training intensity increases, the bar rises by revealing different colors for different zones. It also represents numerical data related to training intensity (top left), HR Zone (top right), HR (middle), calories burnt (bottom) and time elapsed (bottom).

through the textile which, in his words, *"disrupted the feeling that it [the Howel] is a part of me"*.

To this end, [8] states the difference between embedding and integrating information on devices: Embedding means attaching display component onto artifacts, whereas integration refers to blending information into the environment. Looking at the comments from this perspective, we argue that the softness and non-emissive modality of the Howel brings it closer to integrating information organically with the body, rather than attaching a display while CT.

5.2 Understandability of Abstracted Information with Dynamic Patterns

All the participants stated that they understood the information on the Howel. They also said that it was fun to receive information visually based on color alterations. For instance, P1 stated, *"I liked the way that it presents visuals based on something real (HR)"*. One explanation for this might be the qualitative graphics letting subjective reflections, instead of observing detailed information [14]. Moreover, P3 commented on the FITIV Pulse interface *"People might not want to receive detailed technical information as it might make them anxious"*. These feedbacks suggest that mapping information with abstract dynamic patterns might advance the comprehension as well as the enjoyment of receiving information by reducing performance anxiety.

On the other hand, besides enjoying the color changes, P2 mentioned that she would rather observe numeric information as she is used to numeric HR data. The other two participants also indicated their desire to know decrease and increase of intensity within a given zone. This might indicate that, although the ambient information favored by users, we need further investigations about precision needs about the HR data. As [6] suggests the hybrid feedback modalities might be implemented depending on the criticality of information during training. For instance, there might be numerical representation on the inner wrist in addition to dynamic patterns with more steps to display the relative proximity to the next or previous zone. This might enable wearers to glance at patterns for understanding the zone, and attending numeric value when it is critical for them.

5.3 Non-intrusive Information via Non-emissive Dynamic Patterns

P3 and P1 highlighted the non-intrusive nature of dynamic patterns by mentioning its non-distracting modality. P3, who used both devices simultaneously, mentioned that *"my rhythm was disturbed when the Watch vibrated ... I checked the information on the Howel whenever I wanted"*. He also stated that *"whenever, the Watch vibrated, I preferred checking the Howel as it requires less effort to look at"*. P1 also mentioned the advantage of non-emissive modality by contrasting it to light modalities: *"Patterns are natural, they do not distract you like the lights"*.

Overall, our results suggest that using non-emissive dynamic patterns might decrease the intrusiveness of in-situ information in terms of both giving the autonomy to glance at information at will without causing distractions and, spending minimal effort for attending to the information.

6 CONCLUSIONS & FUTURE WORK

In summary, we presented an early prototype named as Howel, which is a novel wrist-worn soft wearable that utilizes dynamic textile patterns, to the best of our knowledge for the first time, for conveying real-time performance information during CT. We also presented preliminary design insights that might be of help not only to designers and researchers of wearables but also ambient displays and exertion studies. Briefly, the results suggest new initial clues that that soft wearables with non-emissive dynamic patterns have potential (1) to embed information representations organically on the body, (2) to give easy-to-understand glanceable in-situ intensity information and (3) to keep the attention of the wearer on the exercise instead of performance measures.

Although these initial clues are promising for the HCI field, they demand further examinations with more participants in more structured evaluations. In future work, we plan to conduct a comparative user study that examines the effects of our prototype on understandability, intrusiveness and social issues (i.e. privacy) in comparison to smartwatches. Meanwhile, we plan to explore different forms of information mapping to the patterns for examining the design space of the dynamic patterns in terms of creating ambient surfaces for in-situ data exploration.

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