Strive: exploring assistive haptic feedback on the run

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ABSTRACT[1]

Mobile technologies have become an important part of run training, however, existing technologies focus on performance metrics (e.g., distance and pace), which makes it difficult for runners to improve their running technique. In this paper, we present Strive, a wearable running technology that aims to assist runners in achieving *rhythmic breathing*; a running technique that potentially leads to improved results and lower injury risk. Strive continuously collects physiological data and uses haptic feedback to provide real-time assistance during runs. As communicating technique-related information in the dynamic and complex context of a run is challenging, we present two studies. The first study investigates how runners adapt to two different vibration patterns; and the second study explores the temporality of the assistance through three different approaches: Continuous, periodical, and self-serviced. Based on these studies, we discuss and provide insights on interacting with technologies during runs.

CCS CONCEPTS

• **Human-centered computing** → Empirical studies in ubiquitous and mobile computing • **Human-centered computing** → Haptic devices

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KEYWORDS

Sports, running, wearable technology, haptic interaction.

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1 INTRODUCTION

Running is a popular sport. In 2015, more than 17 million runners participated in and finished a run in the U.S. This indicates that a multitude of runners are enthusiastic about their running activities, which is also evident from the plethora of available running technologies, e.g. GPS-based running watches and smartphone applications. However, as pointed out by Jensen and Mueller [11], these technologies focus primarily on performance metrics, such as time, distance and pace, and to some extent neglects the runner's technique. Furthermore, these technologies often falls short of utilizing data for assisting the runner to improve running style. Nevertheless, a proper running technique (or running style) is important for runners, as it affects their risk of getting injured, their performance results and their running economy, i.e. the energy spend on each stride [1,19]. For example, the runner's bipedal gait cycle, also known as strides, inevitably impacts the overall running performance, and the runners' respiratory system, which provides the body with oxygen for metabolism, is a paramount part of doing exercise.

Even though strides and respiration are coherent, they are rarely performed in coordination. However, such a coordination of strides and respiration is suggested by renowned running coach Budd Coates and Clair Kowalchik in their book *Running on Air* [2], where they argue for the benefits of rhythmically timing respiration with strides in different patterns, matching the intensity and longitude of a run. This technique is described as *rhythmic breathing* and adapting it could help runners reduce

their risk of getting injuries, prevent side stiches and improve overall performance [2].
This paper presents Strive - a wearable running technology that 1) assists to achieve rhythmic breathing during running using a wrist-worn vibration actuator which produces vibration patterns, and 2) detects how the rhythmic breathing is performed in terms of monitoring respiration and strides using chest-worn sensors.
We initiate this paper with an overview of related work on running technologies, and highlight the limited work on helping runners improve their technique. To guide our design process, we initially conducted a survey, asking 97 runners about their use of technologies during runs. Following this survey, we present the design of Strive along with various design considerations. Afterwards, we present two studies eliciting the challenge of communicating information during the complex and dynamic actions of a run. With these studies, we also aim at examining how assisting vibration should be performed. The first study explores how two different vibration patterns affect runners; one pattern assisting the inhalations correlation to strides and another pattern assisting the exhalations. The second study explores the temporality of interacting during a run, and expose runners to three different temporalities; continuous assistance, periodical-based assistance and self-serviced assistance. Finally, based on our findings, we discuss interaction with technologies and highlight why context and skill level are paramount factors when designing appropriate technology-based interactions and assistance, as well as the pros and cons of evaluating run training technologies in controlled and in-situ settings, respectively.

1.1 Rhythmic Breathing

As presented by Coates and Kowalchik in ”*Running on air” [2],* rhythmic breathing deals with the coordination of breathing and strides when running. More specifically it relates to how runners should time their inhalation and exhalation with their feet touching the ground. Furthermore, this should be done in patterns, such as 3:2 where the runner inhales throughout 3 steps and thereafter exhales throughout 2 steps. The reason behind these patterns and why they are odd is because they believe it can enhance ones running performance and reduce proneness to injury. Additionally, they explain in their book that when you exhale your diaphragm relaxes which creates less stability in your core and therefore making you more susceptible to injury. Coates and Kowalchik also propose how to learn to breathe rhythmically, by suggesting that runners should 1) start by lying on their back, make sure to belly-breath and then rehearse the breathing pattern by counting, 2) add foot tapping to mimic steps, 3) take the technique for a walk, and 4) try to apply it during runs. The runners should not advance to the next step before they are confident in the previous one. This is a long and slow process which is one of the reasons we designed Strive. Since the benefits of rhythmic breathing is not yet proved, we aim at experienced runners as our target group as

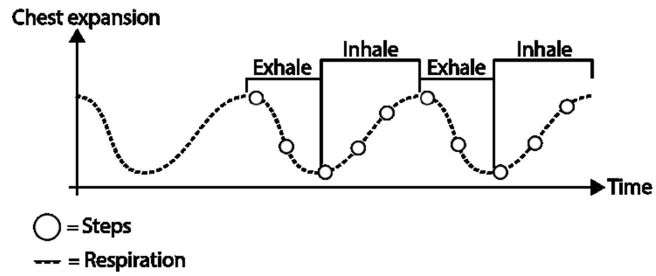

Figure 1: Rhythmic breathing pattern 3:2.

they would perhaps be more inclined to learning this even though an improvement is not guaranteed.

2 RELATED WORK

Since the arrival of the first Garmin Forerunner in 2003, the number of technologies for runners have incremented substantially. Besides the vast amount of advanced running watches, multiple smartphone applications, e.g. Strava [2], Endomondo[3], and RunKeeper[4], have been developed for runners, utilizing the built-in GPS and Bluetooth connectivity to provide the runners with functionality similar to that of running watches. Traditionally, these watches and applications primarily focus on monitoring the performance metrics of the runner, e.g. time, distance and pace, and to some extent neglects the running technique and style. However, recently this has been changing and running technique metrics, such as cadence and vertical oscillation, are now being measured by newer systems, e.g. Garmin Forerunner 620 and Fenix 3[5]. Furthermore, KickStarter projects, such as Sensoria Fitness Socks[6] and Stridalyzer by RetiSence[7], where the runner is augmented with additional hardware (e.g. socks or insoles with embedded sensor components), provide detection of foot strike type (i.e. where on the foot the runner touches down).
Within the academic field of wearable and ubiquitous computing, an interest in measuring different metrics related to running techniques has emerged as well. By using wearable sensors and camera-based motion detection, researchers have developed systems that detect foot strike type [5], cadence [7], ground contact time [27], arm movements [26], vertical oscillation [4], knee flexion-extension angles [10], and significant divergence in running style over time [24,25], making it possible to profile running styles, identify opportunities for improvements and recognize fatigue indicators. However, most of these systems only make the data available to the runners after the run, and therefore, it is difficult for runners to adjust their running style accordingly, as feedback is unavailable

[2] Strava - https://www.strava.com/
[3] Endomondo - https://www.endomondo.com/
[4] RunKeeper - https://runkeeper.com/
[5] Garmin - http://www.garmin.com/en-US
[6] Sensoria Fitness - http://www.sensoriafitness.com/
[7] RetiSense - http://www.retisense.com/

during the actual movements. Despite a few of these systems provide real-time feedback, limited work exists on how to utilize the information to actually assist the runners during the execution of running movements. For example, the system RunBuddy detects rhythmic breathing patterns in real-time using a microphone and a smartphone's built-in accelerometer, however, the system only presents the measurements and analysis to the runner post-run [8]. As pointed out by Jensen and Mueller, there is a gap in both research and commercial products for assistive technique-focused running technologies, and an associated need for investigating how to assist runners in improving their running technique in real-time [11]. Only limited work explores this gap. One example is Hassan et al.'s wearable system FootStriker, which uses electrical muscle stimulation along with an insole with force sensors to correct the runner's foot angle towards a mid- or forefoot landing, thereby improving the running technique [9]. A more autonomy-based part of this gap of assistive technique-based running technologies is explored in this paper through the design, development, and evaluation of Strive.

2.1 Alert-based Running Technologies

Some systems do provide real-time feedback to runners, however, these often merely warn or alert the runner of erroneous movements and falls short of correcting or assisting the runner to actual improvements. For example, Strohrmann and colleagues presented a wearable system, which uses haptic feedback to alert runners if their arms have inexpedient movements, which can affect the running economy [26]. Another example is Eriksson and Bresin's system that uses auditory feedback to alert runners if their vertical displacement is above a predetermined target value [4]. Vertical displacement relates to the upward motion the runner must perform against gravity in each step, meaning that a low vertical displacement should result in an improved running economy, as energy is used to move the runner forward instead of upward. Also, the aforementioned Sensoria Fitness Socks[5] use auditory feedback to alert runners if they diverge from user-determined run characteristics. The presented systems all alert runners if a movement is inexpedient, however, realizing how to correct an erroneous movement and to what extent it needs correction is difficult based on the discrete feedback [23]. Thus, with Strive we aim to assist runners in their movements, rather than solely representing their movements as visual information on a screen post-run or alerting them of their errors.

2.2 Smartphone-based Running Technologies

Most current technologies that support or assist runners in real-time are smartphone-based. For example, RunRight [20] uses auditory and visual information on a smartphone to assist runners to reflect upon their posture and stride rhythm during runs. Another system is TripleBeat that assist runners in reaching workout goals in terms of fat burn, cardio, or strength [21], by playing music in a certain tempo that encourages the runner to increase or decrease the pace according to the desired form of workout.

SHFT[8] is a commercial assistive technology that measures technique-related parameters using a wearable sensor and guides the runners' technique and style using auditory voice recordings, which are played to the runner using a smartphone. The Sensoria Fitness Socks and Stridalyzer[7] also both use smartphones for collecting data from the designated hardware and for communicating with the runner. Hence, it seems that the current tendency of interacting with runners during runs is relying on smartphones. While this might be expedient for novice and inexperienced runners, our initial survey (which we will present in the next section) indicated that enthusiastic runners prefer not to bring their smartphones on runs.

2.3 Running and HCI

In the field of HCI, running has become a focal point for interaction design research. For example, Knaving et al. discussed motivational technology for engaged amateur runners and focus on the surroundings of running, e.g. practicalities, supporters and race day [15]. Tholander and Nylander discuss the differences between the measured experience and the lived experience [28]. Further, HeartLink [3] and RUFUS [31] both support the relationship between runners and their supporters, and Mauriello et al. uses wearable E-textile displays to support group running [16]. Mueller et al. proposed a system that allows runners, who are distributed over a distance, to have a shared running experience [18], and Mueller and Muirhead discussed sharing a running experience with a quadcopter as a companion [17]. While these projects touch upon interesting aspects of the running experience (often the sharing of an experience), they do not focus on the training content and the runners' pursuit of improving their results by enhancing their actual skills.

According to the perspectives in Festinger's social comparison theory, all humans have a drive for social comparison, consisting of two coexisting processes: 1) a drive to evaluate one's abilities, and 2) a drive to improve those abilities [6]. This holds true for runners as well as enthusiastic runners, who already have used multiple training hours to improve their results and would be particularly interested in technology that can assist them in doing so. Hence, with Strive we investigate how technology can support and assist these runners to improve their running technique during runs.

2.4 Haptics as Feedback

In modern technology haptics is often used to notify the user when something happens. With smartphones, this occurs when a text or call is received and, as mentioned earlier, with different running technologies when erroneous movements take place. In other occurrences haptics is used assistive as for example with Tsukada and Yasumura who present ActiveBelt, a wearable interface that enables users to obtain multiple directional

[8] SHFT - http://shft.run/

information with haptics [29]. They use different vibration motors evenly distributed inside a belt that the user wears and these vibrators inform the user which direction he/she should take. As with Strive, this technology assists the user with movements though Activebelt focuses more on direction where Strive focuses on rhythmic breathing. Furthermore, Pielot and Oliveira explored the boundaries of the peripheral perception of vibro-tactile stimuli [22]. They did this by exposing subjects to a continual vibration pattern created by a mobile device in the subjects' pants pocket. With Strive it is important that the runners notice the vibration as it assists the runner but at the same time it should not be unpleasant for the runner which is why the studies of Pielot and Oliveira is important even though we do not aim for the runners' peripheral perception. In addition, Warnock et al. explores how multimodal interaction can be used to make home care more effective and appropriate with focus on people with sensory impairments [30]. They research the effect of unwanted disruptive notifications when delivered in different modalities such as textual, pictographic, tactile at home and how they affect the error rate and task success. With Strive, it is important that the success rate is as high as possible which is why we research different temporalities instead of modalities as Warnock et al.

3 DESIGNING ASSISTIVE RUNNING TECHNOLOGIES

Aiming to explore the use of haptic feedback for assisting runners in achieving rhythmic breathing, we initiated the design of Strive. Strive is inspired by Jensen et al.'s design sensitivities for designing interactive technologies for sports training [12] that emphasize a focus on maintaining training context of athletes. Hence, we conducted a small-scale survey to elucidate the context of enthusiastic runners in terms of the equipment they use during runs. In the following, we present the survey and design choices that emerged from it.

3.1 Survey of Runners' Technological Equipment

We used Google Forms as a platform for distributing the survey to online forums for runners. The survey received 96 responses over the course of five weeks. 89% of the respondents stated to run at least three times a week, and as such we consider them enthusiastic runners (or engaged amateur runners). In terms of equipment, 95% of the respondents had a running watch and 83% owned an associated chest-worn heart rate monitor, and 84% responded that they run wearing their watch and heart rate monitor.

Additionally, the survey asked about the runners' use of smartphones during runs. 63% answered that they do not bring nor use their smartphone, which is interesting as most running technologies, both research and commercial products, rely on smartphones as their communication channel.

3.2 Presenting Strive

In addition to the survey, the design of Strive was informed by pilot tests with friends, family, and colleagues. Furthermore, we conducted contextual interviews with 18 runners and one coach, which helped identify two main design requirements: non-intrusiveness and responsiveness. Therefore, Strive is made to be lightweight and convenient for runners, as it is designed to resemble enthusiastic runners' preferred running equipment (watch and heart rate monitor), and thus, Strive consists of two elements: a chest strap, which detects step frequency along with the runners' respiration, and a wristband, which produces the different vibration patterns. Haptic feedback was chosen based on the aforementioned interviews. We asked about different forms of haptic feedback, i.e. vibration and pressure, as well as auditory feedback which is used by many technologies (as presented in Related Work). Hence, it would be interesting to know whether runner prefer these interactions. The result was that haptic feedback was preferred as the respondents considered auditory too distracting, thereby disturbing their running rhythm. Additionally, vibration was chosen as the (haptic) feedback mechanism in Strive, based on the contextual interviews, where our initial testing also showed that vibration could provide runners with rapid feedback in correlation with strides, respiration and speed of the runner.

The Strive chest strap is made up of a MPU-6050 motion sensor, a conductive rubber cord stretch sensor, a coin-cell lithium battery, and an RFDuino microcontroller as depicted in Figure 2. Initially, the stretch sensor is in a 'relaxed' state. In this state, the sensor's resistance is approximately 350 ohms per 24.5 millimeters. When the sensor is stretched, the resistance increases. The breathing pattern of the runner is then calculated based on the change in resistance of the stretch sensor that occurs when the runner either exhales or inhales. The step frequency of the runner is also determined by the RFDuino, based on a step detection algorithm that uses the sensed data from the MPU-6050 sensor.

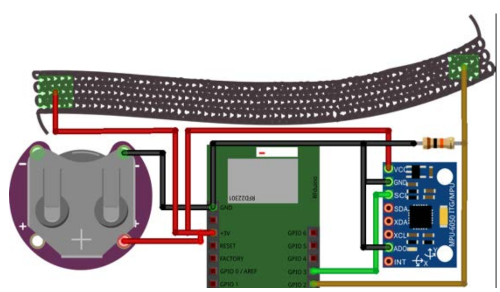

Figure 2: Fritzing diagram of chest strap.

For the Strive wristband, one vibration actuator, a LiPo battery, and an Arduino Mini were used to produce the different vibration patterns. Furthermore, it is embedded with a switch that can turn the vibrations on and off.

As a data gathering tool for conducting user studies, we further developed an associated smartphone application for the researcher to carry around. The application allows the smartphone to collect data from Strive using Bluetooth, and enables real-time annotations of the runner's current state. The change of state revolves around the runner being "in rhythm", meaning that the runner feels he is following the rhythmic breathing pattern, or "out of rhythm", meaning that he cannot get synchronized with the vibration signal. The annotated data is stored locally on the smartphone, hence being available for later analysis.

3.3 Feasibility Study

We conducted a feasibility study to determine the precision of the chest strap's ability to correctly detect respiration and strides during runs. We collected approximately one and a half hour of treadmill running with runners following the 3:2 breathing rhythm, and timestamped inhalation and exhalation using an application with a button to annotate data. Furthermore, we video-recorded the runners while running and counted their steps in order to validate the data from the motion sensor. The feasibility study showed that the chest strap performed with an average accuracy of more than 98% in both step and respiration detection.

4 USER STUDY I: UNDERSTANDING VIBRATION PATTERNS ON THE RUN

This user study investigates how two different vibration patterns work in terms of assisting runners into a rhythmic breathing pattern. We exposed the participants to two different approaches of using vibration to assist the 3:2 rhythmic breathing pattern: An inhale-based and an exhale-based approach. The inhale-based vibration pattern vibrates in synchronization with the runner's strides during inhalation (3 steps) and no vibration when exhaling. Contrary, the exhale-based vibration pattern, only vibrates in synchronization with the runner's strides during exhalation (2 steps). We tried additional vibration patterns, for example, making the wristband vibrate at the beginning of an exhalation and inhalation, however, it became impossible for the runner to differentiate between exhaling and inhaling, and therefore to realize the current phase.

4.1 Participants

For this first study, we recruited six participants, based on the following inclusion criteria:

- The participant runs two or more times per week.
- The participant can complete a 10-km run in 30 to 50 minutes.
- The participant can run 4x2 kilometers (as the studies involves this).

These requirements were chosen to standardize the running level of the participants, so that only enthusiastic runners participated.
We recruited runners from miscellaneous running clubs using word of mouth and social media channels. All participants are shown in Table 1, including their best running results (5 km) from 2016. Only one participant (P4) had tried respiration techniques prior to participating in the study.

Table 1: Participants from User Study I, showing the participants' best 5-kilometer time (in minutes:seconds), their running level, focus and weekly training load.

ID	Age	Best 5 km	Level	Focus	Weekly load
P1	22	17:00	Competitive	Orienteering	6+ runs
P2	22	17:30	Competitive	Orienteering	6+ runs
P3	25	14:55	Competitive	Track & Field	7+ runs
P4	18	19:00	Competitive	Track & Field	4+ runs
P5	42	22:00	Competitive	Ultra running	4+ runs
P6	23	24:00	Leisure	Football prep	3 runs

4.2 Procedure

To explore the impact of different vibration patterns for assisting rhythmic breathing, we used a within-subject study design. The order of which the runners tested the different patterns was decided using a Latin square in order to avoid carry-over effects, such as maturation to the technology and fatigue. The study started with a two-kilometer warm-up run on an athletic track with 400 meter (0.25 miles) laps. Here, the runners got familiar with the vibrations as well as the rhythmic breathing patterns.
After the warm-up, each runner performed two tests of two kilometers, where each test consisted of either the inhale-based pattern or the exhale-based pattern. During each test, we observed the runners by using a bicycle to follow them around the track. By using their hands, the runners signaled if they were in rhythm or out of rhythm, enabling annotation of the collected data with the runner's state. Hand signaling was chosen as it was an unobtrusive method of signaling. Verbal signaling was also considered, however it was deemed too intrusive by runners we interviewed. Afterwards, we conducted semi-structured interviews about their experience of the different patterns and their respiration and stride in general.

4.3 Data Collection and Analysis

For collecting quantitative data from the different participants, we used the built-in Bluetooth of a Huawei Honor 6 smartphone. For the qualitative data collection, we interviewed the participants after each of the different patterns, and took notes during the tests and interviews. These notes were used to produce an affinity diagram, synthesizing our findings.
The data for respiration and strides was processed using a Gauss smoothing algorithm. Afterwards, the smoothed data was analyzed with an algorithm, identifying extremums for strides (i.e. touch downs) and respiration data (i.e. inhalation and exhalation peaks). To check how successful the participants were in following the rhythm, the algorithm checked for the occurrence of five strides between two inhalations, providing a success rate for analysis. The average success rates of the two

different vibration patterns were compared using a paired two-tailed t-test (α = 0.05).

4.4 Results

The collected data indicates that correlating respiration and strides are difficult, even for experienced runners. The quantitative data (see Figure 3) showed that the runners on average followed the inhale-based pattern 17% of the total time and the exhale-based pattern 19% of the total time. When the runners felt, they were in rhythm, their success rates were 22% and 17% for the exhale and inhale-based pattern respectively (see Figure 3). A t-test showed no significant difference between the total average success rate of the two vibration patterns (p = 0.66), nor was there a significant difference when participants felt in rhythm (p = 0.28). The standard deviation (shown with error bars on Figure 3) of the average performances are substantial due to the individual runners' capability of performing rhythmic breathing both with exhale and inhale-based assistance. However, despite the lack of statistical significance, there is a tendency in the data suggesting that the exhale-based pattern is slightly outperforming the inhale-based approach. Even though the quantitative data did not differentiate the two vibration patterns significantly, the quantitative interviews showed that the runners did have common preferences, supporting the data tendency.

4.4.1 *Exhale-based assistance was preferred*

All six participants preferred the exhale-based vibration pattern over the inhale-based. One participant stated, *"It feels natural compared to the inhale rhythm"* (P2). Other runners supported this comment, and phrases, such as "*easier to get in flow*" and "*easier to maintain the rhythm*" were used by the majority of the runners.

4.4.2 *Inhale-based guidance caused staccato breaths*

During the test of the two vibration patterns, a clear tendency occurred for four participants. Three participants' inhalation became staccato, when they tried to synchronize it with the vibration guidance. This means that they only inhaled when the device was vibrating causing short and discontinued breaths, as explained by one participant stating that, "*I breathe with short breaks in the breathing rhythm when the vibrator vibrates*" (P1). Another participant (P5), stated that he was inhaling harder than normal, as he was inexperienced in running with a particular rhythmic breathing pattern.

Based on these results the exhale-based vibration pattern was used for a second user study, exploring the temporality of assistive feedback during runs.

5 USER STUDY II: UNDERSTANDING VIBRATION PATTERNS ON THE RUN

This user study examines how the temporality of the assisting vibration patterns affect runners in their pursuit of rhythmic

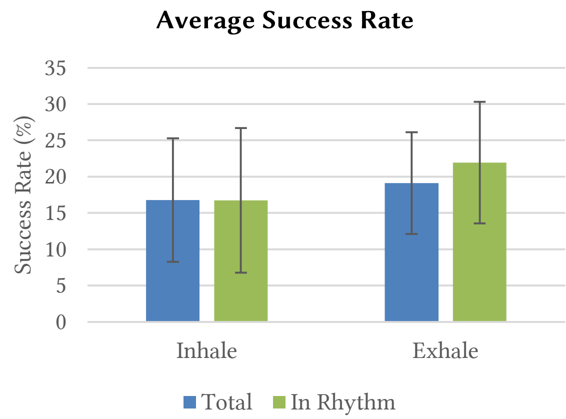

Figure 3: Success rate for each of the participants respectively for the two different patterns.

breathing. In this study three temporalities of the vibration assistance were evaluated; a continuous, a periodical, and a self-serviced assistance. All three approaches built upon the exhale-based vibration pattern that was preferred by the runners in our first study.

In the following, *the continuous temporality* refers to Strive constantly giving the runner feedback during every exhalation. Hence, the runner would constantly be assisted in the rhythmic breathing pattern.
The periodical temporality refers to Strive periodically presenting the runner with assistance. Hence, the wristband would vibrate with the exhale-based vibration pattern for one minute and then turn off the vibrations for two minutes. We based this division on preliminary pilot tests, where the runners in general took less than a minute to adjust to the rhythmic breathing. With the periodical temporality, we investigate whether the runners can maintain the rhythmic breathing when only getting occasional assistive feedback.
The self-serviced temporality refers to Strive enabling the runners to turn the assistance on and off using a switch mounted on the wrist band thereby providing them with autonomy in the interaction.

5.1 Participants

We recruited 12 runners (see Table 2) using the same terms as the first user study. Three participants, P11, P14 and P15, also participated in the first user study. This could have a minor impact on their individual results as they were more familiar with the technology, however, we viewed this impact as insignificant.

5.2 Procedure

To investigate the experience of the different temporalities, we conducted a within-subject study, again randomizing the orders of activities. This study also began with a two-kilometer warm-up. Afterwards, a two-kilometer run was executed for each of three different vibration temporalities. After each test, a semi-structured interview was conducted with questions aiming to elucidate the experience of the different temporalities and how the runners perceived their own performance.

Table 2: Participants from User Study II.

ID	Age	Best 5km	Level	Focus	Weekly load
P7	29	16:40	Competitive	Road races	5+ runs
P8	32	21:30	Leisure	Stay in shape	3+ runs
P9	21	23:30	Leisure	Stay in shape	2+ runs
P10	26	24:00	Leisure	Stay in shape	2+ runs
P11	22	17:00	Competitive	Orienteering	6+ runs
P12	20	19:30	Leisure	Football prep	2+ runs
P13	23	14:40	Competitive	Track & Field	6+ runs
P14	23	24:00	Leisure	Football prep	3 runs
P15	25	14:55	Competitive	Track & Field	7+ runs
P16	26	17:50	Competitive	Road races	4+ runs
P17	25	23:00	Leisure	Stay in shape	2+ runs
P18	27	24:00	Leisure	Football prep	3 runs

5.3 Data Collection and Analysis

All interviews were recorded for later analysis and all data was logged as in the previous user study. Based on the logged data, differences between the different temporalities were analyzed using a one-way repeated measures ANOVA (α = 0.05). We analyzed the participants' total success rates as well as their success rates when feeling in rhythm (see Figure 4).

5.4 Results

In the following, we present the findings from the study, including qualitative and quantitative analysis, highlighting the qualities as well as the drawbacks of the different temporalities.

5.4.1 Quantitative analysis showed no significant differences

The ANOVA showed no significant difference between the different temporalities, neither for the total success rate (p = 0.68) nor for the success rate when participants felt in rhythm (p = 0.75). Thus, based on our study it is inconclusive which temporality is the optimal for supporting runners in real-time. However, there seems to be a tendency that the average success rate of the continuous approach is slightly higher (26 %) than that of the periodic (21 %) and self-serviced approached (23 %). This suggests that the continuous approach could potentially be superior, which is expected as the runners have constant assistance. However, it is interesting that the two other approaches perform almost equally well. This possibly makes the potentially tiresome and monotone feedback from a continuous signal avoidable in training systems.

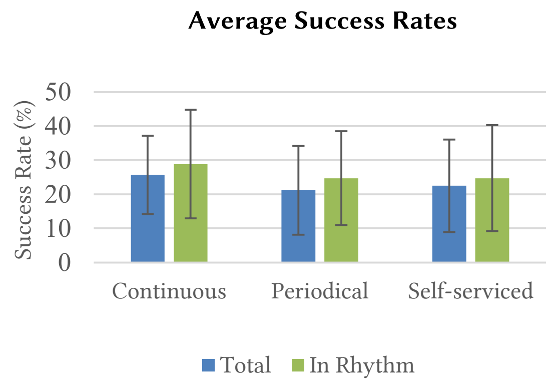

Figure 4: Success rate for each of the participants respectively for the three different modes.

5.4.2 Appreciated non-intrusiveness of self-serviced temporality

Nine participants stated that the self-serviced temporality was more comfortable than the other two temporalities. To the question whether the autonomy of the temporality was pleasant or too much responsibility, one participant responded, *"You were still focused on the respiration but it gave you more freedom"* (P1). This statement was supported by other runners, who thought the autonomy demanded less concentration and focus. One participant stated, *"I zoned out in the last round just to stop thinking about it and then I timed it precisely on the vibration"* (P10). The participant turned off the vibrations and tried to maintain the rhythm, which he felt was a success. The self-serviced temporality was preferred by six participants, making it the favorite of the study. Three participants preferred the continuous temporality and two found the periodical temporality to be most preferable. One participant found all the temporalities acceptable and stated that the different temporalities could be used in different contexts.

5.4.3 The continuous temporality was annoying

In our quantitative analysis, the runners in average performed best with the continuous temporality and only second best with the self-serviced in terms of success rate. One participant said, *"Constant: annoying on a long run"* (P11), illustrating that a continuous vibration would be intrusive and annoying with any run further than two kilometers. If Strive was used on longer runs, the participant would prefer it to be self-serviced. Another participant noted, *"It was more pleasant to run when it was turned off. It stresses me even more when it is on"* (P13), and he also found the continuous vibration to be too stressing and preferred the periodic and the self-serviced as these was more relaxing.

5.4.4 The rhythmic breathing was difficult to maintain

Maintaining the rhythmic breathing pattern proved difficult for multiple runners, due to external sensory inputs, e.g. wind, noise and other runners were influential factors. This is supported by a participant saying, *"It was often when I was overtaken by other runners. I changed focus and lost the rhythm"* (P18). In this case, six other runners overtook the participant on the track, which shows how minor context changes can disturb the runners' focus and cause them to lose the rhythm. Even smaller disturbances as gusts of wind was an annoyance for runners, as noted by a runner, *"I could feel headwind on the last 100 meters and it made it very difficult"* (P12). Several of the runners stated that maintaining a steady rhythmic breathing pattern as 3:2 demanded all their focus and concentration. One participant stated, *"You cannot look at something else while doing it. It demands 95% of one's conscience"* (P13). Because of this extreme amount of concentration, this runner also preferred the self-serviced.

5.4.5 Timing of intervals in periodic temporality is challenging

The periodical temporality surprised some of the runners, exemplified by one runner stating that, *"There was one time where I was not in the rhythm and then it stopped and it was difficult to achieve the rhythm again so I just tried my best to do so"* (P18). Another runner even stopped as the assistance stopped, and explained, *"I was just being inattentive and of course it turned off because it was interval"* (P10). This also supports the claim that maintaining a rhythmic breathing requires concentration and that it is easy for runners to incidentally diverge from the pattern, if they are disturbed.

6 DISCUSSION

In this section, we discuss findings from the two user studies in relation to interacting with technology during runs and learning a new running technique through an assistive technology. Even though the runners' success rates in terms of following a rhythmic breathing pattern were relatively low, they stated to enjoy the exercise. The low success rates are also caused by the difficulty of learning the technique, as described in the introduction. The relatively low success rates are not surprising given the difficulty of the task.

6.1 Different Temporalities for Different Contexts

On a run that exceeds two kilometers the periodical or self-serviced temporality was preferred by the runners. Both temporalities provide the runners with the opportunity of maintaining a rhythm themselves. Contrary, the continuous temporality was more intrusive, and constantly pushing the runners to a rhythmic breathing with vibrations is frustrating over time. That being said, the runners performed best with the continuous temporality. This indicates that the continuous temporality would be preferable for training, e.g. in intervals, and to practice the rhythmic breathing pattern for shorter periods. The self-serviced and the periodical temporality would be preferable for long runs, as they provide more freedom and relaxation.

6.2 Gradually Changing Temporality to Adapt Skill Level

As pointed out by Jensen and Mueller, alerting the runner of erroneous movements is not optimal for learning new techniques, as the runner is only informed about what is wrong and not how to correct it [11]. Furthermore, always being notified about errors or inexpediencies possibly leads to a discouraging user experience. In our studies, when runners felt they were following the rhythm, they were still off in many of the 3:2 cycles, and being alerted about this would be frustrating. However, using the number of erroneous cycles to decide the temporality could be beneficial, for example, the number of errors could be used to decide the duration of the different states in the periodical temporality, so that multiple errors would cause a longer period of assistance and vice versa. This way, alerts will be subtler, as it can be difficult to recognize how long these periods are during a run. Another example could be to extensively assist novices trying rhythmic breathing for the first time, and subsequently change to a less frequent periodic or self-serviced approach after apparent improvements. In other words, technique-training systems should consider using different temporalities for different runners and possibly apply a dynamic and tailored approach.

6.3 Conducting Studies with Runners: Lab or Field?

In both studies, the participants were affected by the surrounding elements, such as other runners, wind gusts, and bystanders, which made it difficult for them to maintain a rhythmic breathing pattern. This shows that testing in-situ provides a more realistic view on the runners' situation. Conducting studies using a treadmill would probably have caused higher success rates from the participants, however, it would not reflect the actual context of a run. This feeds into Kjeldskov et al.'s discussion about whether field studies are *worth the hassle* compared to lab studies, when evaluating mobile interactions and devices [13,14]. In their 2014 paper, they conclude that neither is a superior method, but we should consider when and how to use which approach [13]. Our work is situated somewhere between the two approaches. Runners are kept in their usual context, as they run outside and wear their regular equipment, and as such the study differs significantly from a restricted lab study using a treadmill. We found that external features play a substantial part in the runners' ability to follow the vibration pattern and learn new techniques, and this would not have been apparent in a restricted indoor environment. On the other hand, our study was conducted on an athletic track providing some restriction in contrast to running on a trail. Even though some of the participants use the track as part of their training, the deselection of a more varied route, containing hills and different surfaces, means that our studies are placed somewhere between a lab study and a field study, referring to Kjeldskov et al.'s discussion about *what is the field*? [13]. We argue that for evaluating running technologies, it is important to respect the context of a run, and, as a minimum, studies should be conducted in a context that enables runners to use and wear regular equipment and where locomotive actions have the same effects, as they do under regular training conditions, namely moving the runners forward.

7 CONCLUSION

In this paper, we presented Strive, a wearable running technology that provides real-time assistance of rhythmic breathing. A survey showed that enthusiastic runners prefer to run with a running watch and an associated heart rate monitor and not a smartphone. Thus, Strive is built to accommodate the regular context of runners, and therefore consists of a wristband and a chest belt. In this paper, we explored how to provide runners with assistive feedback during runs through two studies. The first study compared inhale-based vibration patterns to exhale-based, and found a unanimous preference for getting assistance during exhalation. The second study explored the temporality of the assistance, namely continuous, periodical, and self-serviced. This study found that the choice of temporality should depend on factors such as duration of runs and the runner's capability to follow a rhythmic breathing pattern. We further discussed the use of technologies during runs, and argued that the context of a run is important to consider, as runners are easily affected by their surroundings. Learning a new running technique can be troublesome and requires focus from the runner, and we argue that designers and evaluators of running technologies should take this into account. With our work, we believe that it is possible to design and develop technique-focused assistive technologies for runners, based on integrated wearable sensors and haptic feedback.

8 LIMITATIONS

The focus in this paper is on studying different ways of assisting runners using haptic feedback. Hence, we have not compared learning rhythmic breathing from Strive to learning it without technology. A comparison would add to the strength of the technology, however, we still argue that our qualitative findings on exploring haptic assistance in running technologies are valid. Furthermore, there is no statistical evidence that the rhythmic breathing technique suggested by Coates and Kowalchik is superior to others, however, it is a known technique in running communities, and thus an interesting outset and case for exploring haptic assistance.

9 FUTURE WORK

This paper has presented an initial study of using haptic feedback for technique-related assistance in running, e.g. rhythmic breathing. To establish these initial findings with statistical significance more studies are needed with more runners. Further, the longitudinal effect of training with haptic assistive feedback and how well runners can incorporate the assistance in their locomotive nature are yet to be explored.

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