PaceGuard: Improving Running Cadence by Real-time Auditory Feedback

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Abstract
This paper presents PaceGuard, a mobile phone-based system which supports runners in keeping their cadence by auditory feedback. Experts have reported that maintaining the cadence is a prominent challenge for many running beginners and less experienced runners. However, this is important to make the exercise healthy and effort-saving, and to avoid discomfort like side stitches. PaceGuard automatically determines a suitable target cadence on the basis of the measured accelerometer data of the first 150 seconds of a run. Then this cadence as the guideline is constantly signaled to the runner via rhythmic pulse beats, defined as beats per minute. On the basis of previous studies [5], we assume runners will adapt their cadence to the presented pulse beats and thus will run more consistently compared to running without the auditory feedback of PaceGuard. Our pilot study results encourage this assumption.

Author Keywords
mobile training assistant; running cadence; auditory feedback

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces - Auditory (non-speech) feedback

Introduction

Many people like running for sports. For a healthy, effort-saving and pleasant exercise, running consistently is necessary and avoids discomfort like side stitches. To achieve a healthy and consistent running style, runners should choose an appropriate cadence according to their individual fitness level and – most important – sustain this cadence during each entire running session.

However, especially beginners encounter problems in sustaining a consistent cadence, i.e. in keeping the same time interval between each single contact of the feet with the ground over a given distance. One common problem is that less experienced runners start their runs too fast and then decelerate more and more because they become exhausted too quickly. Beginners typically decelerate by changing their cadence instead of their step length, as experienced runners do. Therefore, beginners often run inefficiently and suffer from discomfort like side stitches.

Previous work has shown that people, when listening to music or to rhythmic percussive sounds, they intuitively try to adapt their footsteps to the corresponding rhythms [5]. In addition, it is well-known, that many people are already accustomed to use their audio channel while running in terms of listening to music. Some current smartphone applications for runners do already make use of this knowledge by trying to motivate the runner to stand the run or to accelerate by playing appropriate music.

As motivated, we take a look beyond that and support the runner's goal to first, find an appropriate and achievable running cadence and second, keep this cadence consistent over a longer period, independent of their running speed. Therefore, we propose the mobile system *PaceGuard* which presents acoustic pulse beats with an individually fitting rhythm while simultaneously collecting data on the user's actual running pace in real-time. This data, among others, is used to choose an individual fitting cadence for the runner at the beginning of a run. In contrast to previous work [4, 1], PaceGuard can be used with a current smartphone with a built-in accelerometer and does not need additional sensors to collect real-time running data.

We evaluated PaceGuard in an initial user study and got the encouraging results, that running beginners – when using PaceGuard – adapted their pace to the rhythm signaled via pulse beats and were able to sustain a consistent cadence for a longer period. Furthermore, participants appreciated the automatic cadence selection as it undertook the choice of an appropriate baseline rhythm to start with.

Related Work

There are several mobile assistants for runners which focus on different aspects like performance feedback, competition, social support, navigation and entertainment. Many of these assistants use audio to display information. O'Brien and Mueller [3] investigated remote jogging to support socializing when running alone. In an experiment they fitted joggers out with headsets connected to their mobile phones and asked them to phone with a jogging partner while running. The results revealed that the system was able to support socializing and was appreciated by the joggers.

MPTrain [4] is a system composed of different physiological sensors wirelessly connected to a mobile phone. The system monitors the runner while running with the aim to help him achieving a specific heart rate over time. During exercise, MPTrain automatically selects

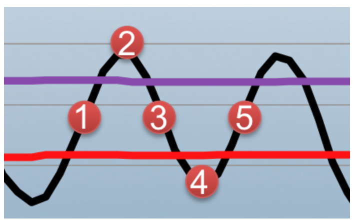

Figure 1: Step detection algorithm

music out of the user's personal music library with specific features like volume, beat and energy according to the measured physiological data and speed of the runner. On the basis of previous studies dealing with the influence of music and rhythmic stimuli on people's gait [5], the played music should encourage runners to run faster, slower or to keep their pace in order to achieve the desired heart rate. Preliminary experimental results indicate that the desired impact can be reached when using MPTrain during running exercises. MPTrain was enhanced to a system called TripleBeat [1] by including additional persuasive features like virtual competition and a re-engineered, easy to-glance-at visual interface. Experiments show that TripleBeat is more effective in supporting runners to achieve their workout goals and leads to a more enjoyable experience than its predecessor MPTrain.

Another mobile training assistant called Mobota includes various functions like navigation, virtual competitions, real-time performance monitoring and entertainment [2]. Mobota combines visual and auditory feedback to inform the runner about his status. By interviews, six different training situations were identified, in which auditory feedback seemed to be especially appropriate: *time/distance unit is covered*, *wrong way is taken*, *a point of interest is being approached*, *competition status changes* and *destination is reached*. A study about the users' preferences in terms of voice or signal as auditory feedback indicated that users prefer e.g. time and distance notifications via voice, and *destination reached* notifications as a combination of voice and signal.

So, while previous work has investigated auditory feedback in running assistants which focus on various purposes, including to achieve a desired heart rate via selected music, it remains unclear whether such auditory systems can also help runners to sustain a consistent cadence.

PaceGuard

PaceGuard is a mobile training assistant, primarily designed for running beginners. It is designed to run on up-to-date smartphones with built-in tri-axial accelerometer and Android 2.2 or higher versions as platform. PaceGuard is configured via a simple GUI screen, on which the name of the user is specified and the acoustic feedback is either en- or disabled. The screen in running mode, that is after completing the configuration screen, shows several parameters for a quick overview, like time elapsed and number of steps.

In running mode, the acceleration sensor of the smartphone permanently retrieves data in minimum time. This data is then transformed into a signal which is irrespective of the position of the smartphone. Afterwards, this signal is denoised and smoothed.

On the basis of this signal, an algorithm detects single steps (see Figure 1). One single step is detected, whenever the undulated signal successively intersects a defined upper threshold twice (purple line; 1-2, 2-3), before it successively intersects a defined lower threshold twice (red line; 3-4, 4-5).

When a run is started, PaceGuard automatically determines a suitable target cadence on the basis of the measured sensor data of the first 30 seconds. After these 30 seconds, PaceGuard's acoustic feedback starts automatically. After the subsequent 120 seconds of running, the target cadence is adjusted according to the measured sensor data during these 120 seconds. This target cadence serves as the runner's guideline for the complete further run. This procedure shall counterbalance

part.	age	rExp.	SoR
1	26	5	5
2	25	4	4
3	21	3	4
4	22	5	3
5	23	4	3
Mean	23.4	4.2	3.8

Table 1: Characteristics of the study participants

a too quick running speed, respectively cadence, which less experienced runners often choose at the beginning of a run.

Experimental Method

To gain insight into the appropriateness and usefulness of PaceGuard, we conducted a pilot study with five participants. Our hypothesis was that runners can sustain a consistent cadence more easily if they are presented an acoustic orientation in terms of rhythmic pulse beats. Thus, we compared the consistency of their cadence with and without the auditory feedback of PaceGuard.

Material

For the study, we used a Samsung Galaxy Ace S5830 smartphone with the installed PaceGuard application running on Android 2.2.1. The smartphone was placed in a belt worn around the hip. The auditory feedback was provided via earphones.

The study took place in Oldenburg, Germany. We used a fixed running course which started in an urban road and continued on a tarred and straightforward footpath.

Participants

Five male students from our university volunteered to take part in the study. Table 1 shows age, running experience (rExp), and sense of rhythm (SoR) of each participant. For quantifying experience and sense of rhythm the participants had to rate two statements (*I am an experienced runner*, and *I have a very good sense of rhythm*) on a five-point Likert scale, ranging from 1 (I disagree) to 5 (I fully agree). Prior to the study, each of them signed an informed consent. None of the participants was paid for taking part in the study.

Design

The auditory feedback of PaceGuard served as independent variable. In the experimental condition, PaceGuard provided auditory feedback. In the control condition, PaceGuard was turned silent.

We used a within-subjects design. All participants contributed to both conditions. We alternated the order of conditions to cancel out sequence effects.

To measure the consistency of the cadence for each condition, we combined a rating of the runner's *subjective consistency* with the objective measure of the *step interval*.

Subjective Consistency For the subjective measure we asked the participants to rate how consistently they had run. Depending on the condition, the participants had to rate on a five-point Likert scale, how much they agree to the following statements: *I made a step at each auditory pulse* (experimental condition) and *I think I ran consistently* (control condition).

Step Interval To analyze the *step interval*, PaceGuard recorded all steps of each run. For each step, we determined the interval to the last step and calculated the standard deviation over all of these values. The more the interval between the steps varies, the higher the standard deviation gets. Thus, the lower the standard deviation, the better the runner keeps his cadence.

Procedure

Participants took individually part in the study. Each study session included a short introduction, a training run (about 2 minutes) and the two actual trials (2x10

Figure 2: Introducing a participant to the study

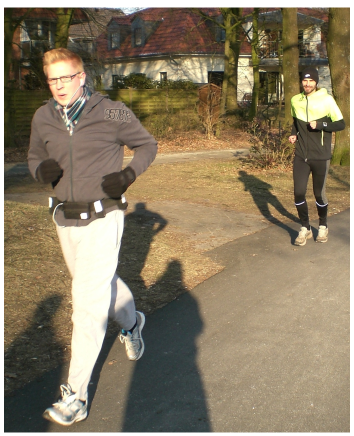

Figure 3: A participant during the run

minutes). The study was concluded with a post-hoc questionnaire.

During the introduction, the participant learned about the procedure of the study (see Figure 2). After the participant signed an informed consent, he was equipped with our system, placed in the belt. Furthermore, we showed the route on a map and explained the functionality of PaceGuard (see Figure 2). Afterwards, the participants warmed up for two minutes, while using PaceGuard in acoustic feedback mode. We used this period to test if the system ran correctly and to allow the participant to familiarize themselves with the system.

Then, the participants started the two trial runs in which their pace was measured. Figure 3 shows a participant during one of these runs. Three of the participants started in the control condition, two in the experimental condition. We stopped the runs when ten minutes were over. We concluded the experiment with a post-hoc interview, asking about the *subjective consistency* of the running cadence.

Results

In this section, we report on the results of the pilot study. None of the participants had trouble with PaceGuard's auditory feedback. Two participants stated that the auditory feedback required a lot of concentration (P1, P5). In general, the auditory feedback was found to be to pleasant (P2, P3) and motivating (P4).

The mean *step interval* was 364 ms over all runs. Since our step-detection algorithm did not detect 100% of all steps, we filtered out all *step intervals* which were detected as being larger than 500 ms. In total, 3.67% of all steps were removed. In the experimental condition, the *step interval* varied less (SD = 22.3) than in the control condition (SD = 23.7). However, the difference was not statistically significant ($p = .14$). In the experimental condition, the distribution of the *step interval* improved by 1.45 ms in average compared to the control condition. The higher the sense of rhythm of the participant, the higher the level of improvement was ($r = .73$, large effect).

In the experimental condition, the *subjective consistency* was higher (M = 4.2, SD = .8) than in the control condition (M = 3.6, SD = 1.5). However, the difference was not statistically significant ($p = .21$).

In general, the participants judged well how consistently they had run. There was a strong correlation between *subjective consistency* and *step interval* (control: $r = -.64$, experimental: $r = -.56$, both large effects), which means the higher the *subjective consistency*, the lower the distribution of the *step interval*.

Further, we found correlations between the sense of rhythm and *step interval*. The higher their sense of rhythm, the more consistently they ran (control: $r = -.50$, experimental: $r = -.66$, both large effects).

Discussion

In summary, the results indicate PaceGuard's auditory feedback might help to improve the running cadence. The level of improvement was the higher, the better the runner's sense of rhythm. The results also suggest that runners with a better sense of rhythm run, in general, more consistently.

Our results support our hypothesis that runner can keep a more consistent running cadence. In the experimental condition, the average distribution of the *step interval* was lower and the participants rated their cadence to be more consistently. The sense of rhythm was strongly correlated with these results, which means that in our study runners with a better sense of rhythm improved their running cadence more with PaceGuard than those with a bad sense of rhythm. Thus, it might be possible that a good sense of rhythm is required in the first place to effectively make use of PaceGuard. Hence, it might be possible that only runners with a good sense of rhythm benefit from PaceGuard.

Running experience was not notably correlated to the results. Therefore, we do not know yet how helpful PaceGuard is for runners with different levels of experience.

However, this study is only a pilot. Due to the small sample size, none of the findings are statistically significant. Thus, we cannot rule out that the differences between the conditions are due to chance. Still, the findings of this pilot study indicate that significant effects might exist and that repeating this study with a larger sample is worth the effort.

Conclusions

In this paper we have explored whether a constant auditory pulse helps runners to keep their cadence. Our pilot study with 5 runners provided encouraging results. However, regarding the small sample, we need to confirm this in a larger study.

Our pilot study revealed interesting research questions to be addressed in such a study. In particular, the question remains to what extend the success of PaceGuard depends on the runner's sense of rhythm. Furthermore, we need to analyze long-term effects, i.e. if PaceGuard's positive effect will remain even if the system is not used any longer after a specified period. Moreover, future research should investigate whether accurate acoustic signals like pulse beats can achieve better improvements than music, used by other running assistants.

Acknowledgements

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