FootStriker - An EMS-based Assistance System for Real-Time Running Style Correction

Figure 1: Outdoor usage of the FootStriker wearable on a track.

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Abstract

Today, ambitioned amateur athletes often do not have access to professional coaching but still invest great effort in becoming faster runners. Apart from a pure increase in the quantitative training load, a change of the running technique, e.g. transitioning from heel striking to fore- or midfoot running, can be highly effective and usually prevents knee-related injuries.

With this demo, we highlight factors to consider when determining EMS actuation phases for real-time running style correction in an outdoor scenario. During actuation the wearable applies electrical muscle stimulation (EMS) in the flight phase of a stride after having detected a heel-strike with force sensing resistors (FSR) in a sensor insole. To complement the original FootStriker lab prototype, we address the applicability in the field of the aforementioned real-time running style correction system.

Author Keywords

Electrical muscle stimulation, wearable, real-time feedback, motor skills, motor learning, sports training, running, in-situ feedback, online feedback, real-time assistance.

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Figure 2: Overview of the hardware components of the prototype.

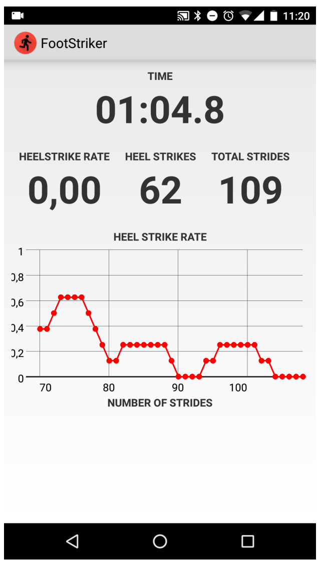

Figure 3: The mobile interface connected via Bluetooth LE to the wearable: it displays total time, total strides, number of heel strikes, and the heel strike rate as percentage in a real-time graph.

Introduction

Today, sports and activity trackers are ubiquitous and widely used by professional and non-professional runners to record and analyze their workouts. However, the currently used measures are mostly quantitative, i.e. assistance and feedback is only provided on running performance (for example distance, elevation, or pace) but not on running technique [4]. For recreational runners, it is often difficult to interpret such numbers, usually displayed on a small screen strapped to a fast moving wrist while running. Numerous factors influence adequate information representation and are not taken into account by current sports technologies [9]. An effective analysis of the running technique can only be provided by professionals or expert coaches using slow motion video analysis.

Due to the fact that many amateur athletes do not have access to a coach, long distance running generally causes a high incidence of repetitive stress injuries per year, including stress fractures and knee problems [6, 10]. In recreational runners, heel striking is prevalent because it was derived from walking and requires less physical effort at slow paces but becomes inefficient when running with increased speed [1]. In comparison to forefoot running, heel strikes generate a more rapid, high-impact peak when the heel initially makes contact with the ground.

Heel striking not only increases the chance of injuries but also leads to inefficiency while running and should thus be avoided [11]. Therefore, amateur athletes who want to become faster often need to change their running style to mid- or forefoot running resulting in a shorter stride length and a higher stride frequency.

An approach that is related to our work is using EMS for pedestrian navigation [8]. By using EMS-based actuation the system is able to change the walking direction by applying an EMS signal to the sartorius muscles in the upper legs. With our system, We aim to go beyond steering the user but enable subconscious motor learning by using EMS to directly actuate muscles. Research that investigates EMS as an interface in HCI exists as well (e.g. [5, 8]).

In the following, we demonstrate a wearable system that detects the user's running style using force sensitive resistors (FSR) in the insole of a running shoe. It uses EMS as a real-time assistant to intuitively aid the runner in adapting a mid- or forefoot stride pattern (see Figure 1). For this demo we extended our original *FootStriker* prototype [**?**] for outdoor usage and discuss training scenarios for real-time running form correction while running outdoors using our device.

FootStriker

The FootStriker system can reliably detect heel strikes and can control the EMS signal on time. The prototype consists of three main parts (see Figure 2): (1) a force-sensitive shoe insole to detect the running strike, (2) a medically approved EMS generator (Beurer Sanitas SEM 43 Digital EMS/TENS), and (3) an Arduino-powered control unit that reads the data from the force sensors, controls the EMS signal, and optionally sends the data to a computer or smart-phone for logging.

The shoe insole contains three Force Sensing Resistors (FSR), one on the heel area and two on the forefoot area (see Figure 4). The Arduino unit continuously reads the values from the sensors, detects the foot strike, and activates the EMS control circuit in the event of heel striking, during the flight phase of the foot. The control circuit is based on the *Let Your Body Move* [7] toolkit. We implemented a simplified version (Figure 5) which contains only three electronic switches (relays) and a low resistance (470 Ohm).

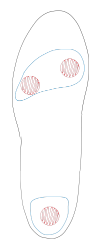

Figure 4: Positions of the FSR on the shoe insole.

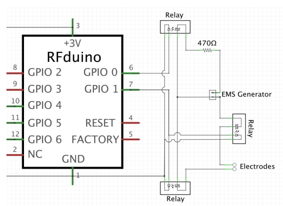

Figure 5: Design of the EMS control circuit.

The circuit will either direct the generated EMS signal to the user or to a small resistance to disconnect the user from the EMS circuit loop.

In a between-subject experiment with 18 participants, we demonstrated that the use of *FootStriker* leads to significantly lower heel strike rates than traditional coaching for running that consists of slow motion videos and verbal instructions, and a second control condition (EMS alert), even after disabling the EMS actuation. The results from the experiment indicate that EMS actuation directly supports motor skill learning (without further instruction) and is thus more effective than the traditional approach. EMS used as feedback alone was also not sufficient to guide the runner towards the error source and to improve her running technique (see [3] for more details).

Outdoor Challenges of EMS-based Assistance

When using the lab prototype for training outdoors, new challenges arise compared to our FootStriker prototype that was initially evaluated on a treadmill. During a workout, the EMS actuation as a whole would need to be enabled and disabled either *manually*, *semi-automatically* via timely generated notifications, or *fully automatically*. Either way, for *safety reasons* the user should be able to trigger an emergency stop of the system at all times. We argue that implementing safety mechanisms in EMS-based assistance systems are relevant and fundamental for all other dimensions stated here as well.

Other challenges will be the elevation profile of the run that has to be considered, since the running style changes significantly when, e.g., running downhill. Additionally the type of underground is likely to affect the running style but could also lead to inaccuracies when sensing heel strikes, for example on loose underground or cobble stones.

Moreover, the state of the runner plays a role when determining the phase of the training in which EMS-based support might help. It is unclear if the runner would benefit from EMS-based support in an increased state of fatigue. In classical coaching, the athletes have the tendency to perform poorly in not internalized newly learned techniques. However, EMS actuation could be beneficial in this very moment as it could act as a reminder to not fall back into old behavior as the results from our initial user study suggest.

Factors Determining EMS Actuation

From our initial lab experiment, we envision a novel approach for EMS-supported training for running that aims to improve the running technique in-situ. In the following we discuss training scenarios for EMS-based real-time running style correction while exercising outdoors. This includes the question of when to enable or disable EMS actuation over long-term in during a single training session. Conceptually, we differentiate these cases as inter- and intra- training treatment.

Inter-training long-term periodical treatment

Mid- and forefoot running requires other muscles groups than heel striking. Some participants in our initial lab study reported muscle sore, which supports this assumption. Furthermore, some physiological adaptation processes in the body generally occur only slowly, e.g. the adaptation of tendon and skeletal muscles. To avoid injuries when using an EMS based running style correction system, we suggest to take the slow body adaptation into account by applying a long-term periodical EMS treatment with per training on- an off-phases and a limited weekly increase in device usage, based on common training principles.

For example, athletes who just started using the system should be slowly guided to this new style of running. A slow

Figure 6: The placement of the two electrodes on the calf muscles.

increase of total duration EMS-actuation over several training sessions can be integrated into the monthly or annual training plan (ATP). We envision that training with EMS-based assistance could be integrated into classical training plans that avoid under- and over training with a variety of different workout types.

We further assume that the average heel strike rate can be monitored continuously over the course of a season. In the process of transitioning to fore- or midfoot running, EMS actuation might become obsolete. At this stage, the average heel strike would be monitored to verify the training goal has been reached and to recognize potential fall-backs.

Intra-training actuation phases
Once inter-training long-term periodical treatment of EMS-support has been set, the system would still need to decide when to enable/offer EMS-actuation within a single workout session. We think that a measure of fatigue (e.g. [2]) might serve as a basis besides the training intensity and other existing measures for running style, such as cadence and left-right balance. The surface type or elevation profile can additionally be considered as *environmental factors*. If the terrain is recognized to be suited for EMS-based running (flat, even surface, etc.) EMS-support is automatically or semi-automatically activated for an interval. This workout could be seen as a special form of Fartlek intervals that focus less on an improvement of speed but running form.

The initial lab study further indicates a fatigue effect in participants who got video feedback. Participants started running relatively good with lower heel strike rates but then heel striking increased. This is supported by the subjective feedback, which was gathered after the experiment.

In a second running form exercise for advanced mid- and forefoot runners EMS is used only when the athletes are

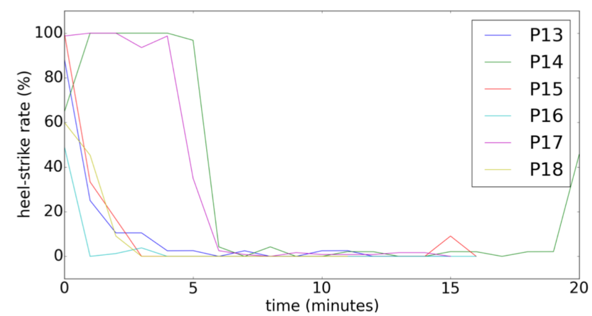

Figure 7: Heel strike rate over time during EMS actuation.

falling back into heel striking due to fatigue. Here the runner is equipped with the wearable that constantly tracks and monitors her running form and in case of wrong technique automatically or semi-automatically activates the EMS-support similar to an E-bike that gives support to a cyclist while climbing up a hill.

Demo Procedure

Based on the results of the EMS condition in the main study [3], we hypothesize that we can generate similar results with a short indoor run. More specifically, most of the participants of the lab study decreased their heel strike rate in less than five minutes (see Figure 7). For the demo, we will provide two fully functional wearable devices. We will wear one unit ourselves for short demonstration and illustration purposes. Thereby, the attendee can look at the interface of the mobile application (see Figure 3) during or after a short run to see the recognized heel strikes and an in- or decrease of the heel strike rate over time in a graph.

Optionally, if an attendee is interested in an actual in-depth experience of the EMS actuation, she can wear our second prototype and take it for a short run for which we expect a similar effect as in our lab study [3]. After the run, we will explain the difference of the running styles, in which phase of the stride the device triggered the EMS signal, and individually analyze the attendee's results. Of course, we will carefully consider any medical requirements and possible risks in a written consent/disclaimer before any self-application of EMS. In terms of insoles, we will provide several sizes with already attached FSR sensors that can quickly be exchanged with a connector and worn in the shoes of the attendees. The demo does neither require Internet connection nor a second person to be carried out.

Conclusion

With *FootStriker* we demonstrated the potential of using EMS-based assistance to trigger an unconscious motor learning process at the time of physical exercise. *FootStriker* detects the user's running stride pattern and provides real-time feedback via EMS to intuitively assist the runner in adapting to mid- or forefoot running.

With a significant improvement over the traditional coaching technique, showing technical feasibility and effectiveness in terms of motor skill learning, we laid the foundation for novel assistive wearable devices for sports. Still, running professionals and coaches cannot be replaced by our system as their expert knowledge is required for the externalization of domain knowledge at the time of building or reprogramming the system. Actuating more complex movements require accurate and timely orchestration of the muscles.

However, we think that our approach is generalizable to other areas and EMS-based assistants for learning new motor skills that can be beneficial especially for amateur athletes. Another possible application might be improving the cadence in cycling. Assisting cyclists towards a more efficient pedal stroke could be especially helpful for beginners. Another potential sport for EMS-based learning support is rowing. In rowing the end phase of a rowing stroke is a very critical performance indicator that requires complex motor skills. In climbing beginners tend to over-grip since they climb with extreme physical tension. High physical tension and over-gripping increase fatigue and may lead to injuries. An EMS-based climbing assistant can be used in training to force muscle relaxation when over-gripping.

We envision that athletes who do not have constant access to professional coaches can in future use the proposed class of wearable devices as an inner feedback loop to communicate with experts to receive qualitative feedback about their personal technique advancements.

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