Towards Amplified Motor Learning in Sports using EMS

Florian Daiber
German Research Center for Artificial Intelligence (DFKI), Saarland Informatics Campus
Saarbrücken, Germany
florian.daiber@dfki.de

Felix Kosmalla
German Research Center for Artificial Intelligence (DFKI), Saarland Informatics Campus
Saarbrücken, Germany
felix.kosmalla@dfki.de

Mahmoud Hassan
German Research Center for Artificial Intelligence (DFKI), Saarland Informatics Campus
Saarbrücken, Germany
hassan@holmez.net

Frederik Wiehr
German Research Center for Artificial Intelligence (DFKI), Saarland Informatics Campus
Saarbrücken, Germany
frederik.wiehr@dfki.de

Antonio Krüger
German Research Center for Artificial Intelligence (DFKI), Saarland Informatics Campus
Saarbrücken, Germany
kruger@dfki.de

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Abstract
In sports, correctly performed (repetitive) exercises increase efficiency and performance. In cases of incorrect performance, they may lead to injuries. Thus, focusing on correct performance is of high interest for both professional and non-professional athletes. In running, knee-related injuries are very common. The main cause is high impact forces when striking the ground with the heel first. In contrast, mid- or forefoot running is generally known to reduce impact loads and to be a more efficient running style. In this position paper, we introduce a wearable running assistant, consisting of an electrical muscle stimulation (EMS) device and an insole with force sensing resistors. It detects heel striking and actuates the calf muscles during the flight phase to control the foot angle before landing. We discuss how EMS can be used to enable motor learning of complex, repetitive movements.

Author Keywords
Electrical muscle stimulation, wearable devices, wearables, 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 1: A runner wearing the FootStriker prototype.

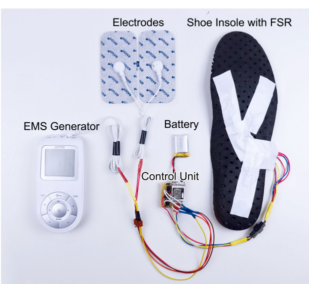

Figure 2: Overview of the hardware components of the prototype.

Motivation

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 [3]. 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 [8]. 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 [5, 9]. 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 chances of injuries but also leads to inefficiency while running and should thus be avoided [10]. Therefore, amateur athletes who want to become faster often need to change their running style to mid- or forefoot running.

Some research on EMS as an interface exists in HCI (e.g. [4, 7]). An approach that is closely related to our work is using EMS for pedestrian navigation [7]. By using EMS-based actuation the system could change their walking direction by applying an EMS signal to the sartorius muscles in the upper legs. In this work, we aim to go beyond steering the user but enable subconscious motor learning by using EMS to directly actuate muscles.

In the following, we present *FootStriker* [2], a wearable system that detects the user's running style using force resistant sensors (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). We further summarize an evaluation of the system and discuss the lessons learned as well as potential applications for amplified motor learning in sports.

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, sends the data to a computer for logging, and controls the EMS signal.

The shoe insole contains three Force Sensing Resistors (FSR), one on the heel area and two on the forefoot area (see Figure 3). 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* [6] toolkit. We implemented a simplified version (Figure 4) which contains only three electronic switches (relays) and a low resistance (470 Ohm). 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.

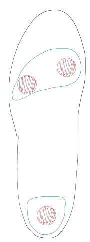

Figure 3: Positions of the FSR on the shoe insole.

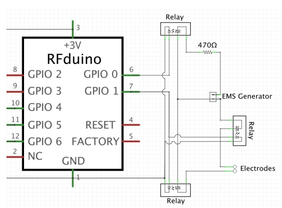

Figure 4: Design of the EMS control circuit.

Evaluation

In a between subject experiment with 18 participants, we compared this novel approach against traditional coaching for running that consists of slow motion videos and verbal instructions, and an EMS alert condition that uses . In the following the main results are summarized and discussed (see [2] for more details).

The runners wearing *FootStriker* were not given any further instructions on running style, as opposed to the control group that was instructed in forefoot running. We demonstrated that the use of *FootStriker* leads to significantly lower heel strike rates, even after disabling the EMS actuation. After the warm-up block, all participants started their second block run – when EMS actuation was actually applied – with a very high heel strike rate, but could quickly learn and adopt the new foot striking technique (maximum 6 minutes). However, some heel strikes occurred later in the run. The reason for these heel strikes might be the fatigue effect as in the traditional feedback group. But unlike the traditional feedback group, the issue of falling back to the heel striking is instantly and continuously corrected. Another explanation for the low but existing heel strike rate after the six minutes mark would be a general inaccuracy of the movements as the newly-learned motor skill was not yet completely internalized. In a third group, we removed the actuation effect on the calf muscles and used the EMS signal only to alert the user in the event of a heel strike.In this condition, we did not observe a significant effect. Thus, we conclude that EMS actuation is necessary to achieve the desired running style adaption, while alerting the user was not sufficient.

Qualitative feedback from the participants using the system revealed that all participants developed active knowledge about their newly-learned running technique and could verbally express it only by using the device. This research has been approved by the ethics committee and the subjective feedback regarding the perceived comfort of the device further showed that it did not cause any harm and was not painful to wear. However, using EMS as a training tool also raises ethical questions. While researchers have to deal with ethics boards, practitioners might have to consider ethical aspects and regulations of sports organizations.

Overall, these results indicate that EMS actuation directly supports motor skill learning and is thus more effective than the traditional approach. EMS used as feedback alone (without further instruction) was also not sufficient to guide the runner towards the error source and to improve her running technique.

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 overgrip 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 overgripping.

We envision that athletes who do not have a 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.

References

[1] C. B. Cunningham, N. Schilling, C. Anders, and D. R. Carrier. 2010. The influence of foot posture on the cost of transport in humans. *J Exp Biol* 213, 5 (2010), 790–797.

[2] Mahmoud Hassan, Florian Daiber, Frederik Wiehr, Felix Kosmalla, and Antonio Krüger. 2017. FootStriker: An EMS-based Foot Strike Assistant for Running. *J. IMWUT* 1, 1 (March 2017).

[3] Mads Møller Jensen and Florian'Floyd' Mueller. 2014. Running with technology: Where are we heading?. In *Proc. of OzCHI '14*. ACM, 527–530.

[4] Pedro Lopes, Alexandra Ion, and Patrick Baudisch. 2015. Impacto: Simulating Physical Impact by Combining Tactile Stimulation with Electrical Muscle Stimulation. In *Proc. of UIST '15*. ACM, 11–19.

[5] Tom F Novacheck. 1998. The biomechanics of running. *Gait & posture* 7, 1 (1998), 77–95.

[6] Max Pfeiffer, Tim Duente, and Michael Rohs. 2016. Let your body move: a prototyping toolkit for wearable force feedback with electrical muscle stimulation. In *Proc. of MobileHCI '16*. ACM, 418–427.

[7] Max Pfeiffer, Tim Dünte, Stefan Schneegass, Florian Alt, and Michael Rohs. 2015. Cruise Control for Pedestrians: Controlling Walking Direction using Electrical Muscle Stimulation. In *Proc. of CHI '15*. ACM, 2505–2514.

[8] Jakob Tholander and Stina Nylander. 2015. Snot, Sweat, Pain, Mud, and Snow: Performance and Experience in the Use of Sports Watches. In *Proc. of CHI '15*. ACM, 2913–2922.

[9] R N van Gent, D Siem, M van Middelkoop, A G van Os, S M A Bierma-Zeinstra, and B W Koes. 2007. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med* (2007).

[10] Keith R Williams and Peter R Cavanagh. 1987. Relationship between distance running mechanics, running economy, and performance. *J Appl Physiol* 63, 3 (1987), 1236–1245.