EMStriker: Potentials of Enhancing the Training Process of Racket-based Sports via Electrical Muscle Stimulation

Sarah Faltaous
University of Duisburg-Essen
Essen, Germany
sarah.faltaous@uni-due.de

Anna Hubert
LMU
Munich, Germany

Jakob Karolus
LMU
Munich, Germany
jakob.karolus@um.ifi.lmu.de

Steeven Villa
LMU
Munich, Germany
steeven.villa@um.ifi.lmu.de

Thomas Kosch
TU Darmstadt
Darmstadt, Germany
kosch@tk.tu-darmstadt.de

Paweł W. Woźniak
Chalmers University of Technology
Gothenburg, Sweden
pawel.wozniak@chalmers.se

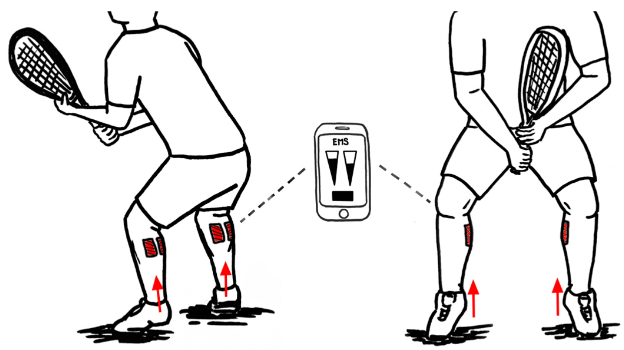


Figure 1: Adjusting the ready position of crossminton players by actuating the calf muscle to modify their feet posture using electrical muscle stimulation.

ABSTRACT

Racket sports offer an enjoyable form of physical activity and are fertile ground for interactive technologies supporting new players. Yet, current research has neglected its potential to support not only active players but also coaches in their training methods. To investigate how interactive technologies can support skill acquisition in training, we designed an Electrical Muscle Stimulation (EMS) system that helps maintain the ready position in crossminton. We compared the system with a vibrotactile solution in a user study, interviewing novice players and experienced coaches about their perception of the system. The system allowed coaches to effectively and immediately guide players to the ready position. An EMS-based feedback system for coaches can potentially reduce delay (physical and cognitive) for trainees, as stated by coaches. Our work contributes insights into designing systems that facilitate learning sports techniques using interactive feedback.

TEI '22, February 13–16, 2022, Daejeon, Republic of Korea

ACM ISBN 978-1-4503-9147-4/22/02.
https://doi.org/10.1145/3490149.3505578

CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

sport, electrical muscle stimulation, vibrotactile, feedback

ACM Reference Format:
Sarah Faltaous, Anna Hubert, Jakob Karolus, Steeven Villa, Thomas Kosch, and Paweł W. Woźniak. 2022. EMStriker: Potentials of Enhancing the Training Process of Racket-based Sports via Electrical Muscle Stimulation. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22), February 13–16, 2022, Daejeon, Republic of Korea.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3490149.3505578

1 INTRODUCTION AND BACKGROUND

Wearable technology increasingly permeates the sports landscape. New sensors are made available every day and athletes see their sport as an increasingly quantified activity. In racket sports, performance sensors such as the Zepp Tennis 2[1] became commonplace, where a vital function is the collection of performance data to improve and augment the athlete's performance post hoc. In this work, we research an alternative design idea and explore how technologies can actively augment performance during sports training,

[1]www.zepplabs.com/en-us/tennis

allowing coaches to provide real-time guidance and thus leading to developing better techniques. In particular, we investigate design qualities of EMS-based feedback systems and their potential in existing training philosophies using crossminton[2] as a use case scenario. Racket sports are of particular interest for feedback systems as they rely on extensive coaching, continuous technique development and complex measures [8].

Practicing sports proficiently can be interpreted as a skilled motor performance that depends on cognitive and motor skills [1]. These skills are usually developed through technique training, most commonly with the participation of a coach who provides verbal guidance [1]. However, when a given sport requires fast or complex movement, verbal feedback may not be efficient enough. Past inquiries investigated how interactive technology can foster technique development in sport. GymSoles [3] showed that interactive feedback could aid users in the complex techniques deadlifts. Subtletee [26] investigate how the rapid movement of a golf swing could be augmented with interactive feedback. While these systems showed that feedback can potentially help users develop sports techniques, they only featured guidance in diverse forms and did not act directly on the user to guide them into correct body positions. Consequently, there is a need to investigate how sports technologies can provide active guidance in developing techniques.

Electrical Muscle Stimulation (EMS) is a novel feedback modality that offers proactive feedback to their users. EMS uses external electrical impulses to activate muscles. The externally induced impulses imitate the impulses which the brain sends through the nervous system to intramuscular nerve branches. This causes muscle traction resulting in body movements [22, 24]. Researchers and practitioners have initially applied EMS in the medical field, primarily for rehabilitation [6, 11]. In the last decade, research in HCI (Human-Computer Interaction) began to explore the potential of EMS. EMS has been employed for controlling human actions, such as guiding the walking direction [19], increasing reaction time [9], or communicating take-over requests [5]. Furthermore, researchers investigated how EMS could influence human perception by providing haptic feedback. This was studied in the context of interacting with public displays [20], manipulating food textures [16], or communicating physical impact in VR [14]. Here, research showed that EMS is a feedback modality with further potential which needs to be explored further.

EMS also offers potential in enhancing in sports and training, where it has been used since the 1960s when the Russian Olympic team trained using EMS [25]. HCI researchers explored the use of EMS in adjusting the foot angle before landing while running [7] or correcting the putting technique in golf [4]. While the previous work focused mainly on the potentials of EMS technology, there was less focus on establishing the user requirements for EMS technology to be integrated into amateur sports, both for players as well as coaches. In this work, we investigate how players perceive EMS and if they would be willing to make it part of their sport practice. Moreover, past exploration of the use of EMS in sports HCI was primarily targeted at developing a corrective device. In contrast, this work explores the potential role of EMS in developing sports mastery and enhancing existing coaching process.

[2]A racket sport that combines elements of tennis and badminton.

This work investigates the user requirements and opportunities for augmented coaching using EMS in crossminton. To that end, we provide the concept for an EMS-based feedback system (cf., Figure 1) that supports players in maintaining the ready position while playing crossminton. We first contribute a (1) user study, where we compared the effectiveness of EMS feedback at varying intensities to vibrotactile feedback. We subsequently conducted (2) contextual interviews with crossminton players and coaches. Based on the gathered data, we present (3) insights on the integration of EMS into crossminton practices that help users to develop motor skills using EMS.

2 AN EMS-BASED CROSSMINTON ASSISTIVE SYSTEM

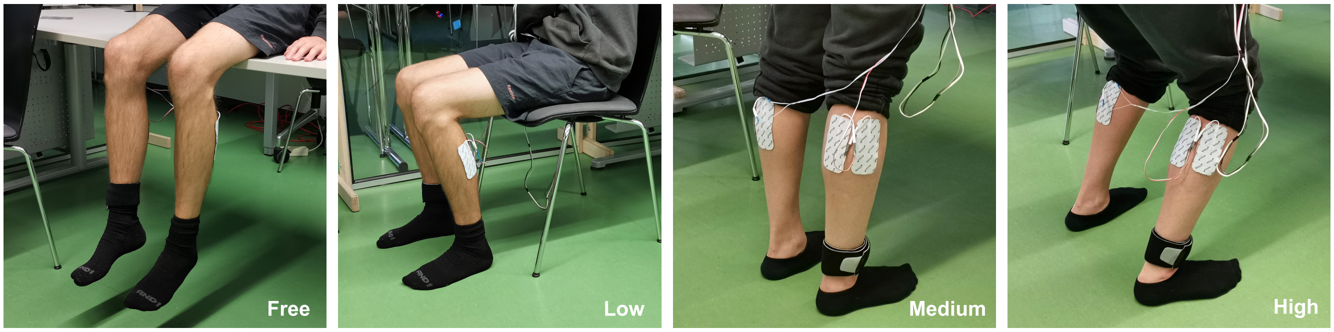
We consider using EMS-based feedback as an assisting modality while playing sports. We focus on crossminton, because it is a sports discipline with a particular focus on training a correct ready position. This ability is key for quick preparation for the opponent's next actions. Informed by related work, we envision EMS as a training tool that subtly actuates the trainee to adjust their ready position, resulting in maintaining correct positions even when no EMS stimulation is present [10]. We describe a user-centric evaluation of the feasibility of using wearable EMS-based feedback in crossminton sports.

2.1 Study with Beginner Players

Vibrotactile stimulation was previously applied in sport as it is inexpensive and easy to implement, e.g. [26]. We propose an EMS-based system to support racket sports practitioners in a context in which the use of vibrotactile feedback can be a plausible design alternative. Thus, in our work, we contrast vibrotactile feedback with EMS. By doing so, we (1) evaluate the feasibility of EMS-based systems on racket sports training and (2) contrast the techniques and their advantages/disadvantages in a racket sports context.

2.1.1 Participants and Procedure. Electrical muscle stimulation induces external electric impulses in the muscles to generate a contraction in the muscle, consequently leading to a movement of the body part linked to that muscle (e.g., a calf muscle contraction affecting the foot movement). In the sports context, the muscles of the practitioners are constantly varying the electric charge (i.e, received from the brain) to move from one position to another, making this a relevant factor in our application. Consequently, our study design considers this variable. We conducted a within-subjects study with two factors: (1) Feedback modality, consisting of two levels (EMS, vibrotactile) and (2) calf tension, consisting of four levels (Free, Low, Medium, High).

Tension levels were controlled by changing the participants' position; for *Free* participants seated in a table, in this way their feet were hanging freely without touching the ground, in *Low*, participants seated in a chair, allowing them to rest their feet on the floor, for *Medium* level participants were required to stand straight, and, for *High* participants were instructed to stand in the ready position. Participants experienced all tension levels using one feedback modality and then switched to the remaining one. Feedback modality and calf tension factors were randomized to



(a) (b) (c) (d)

Figure 2: Different tension levels applied to the calf muscles. (a): No tension was applied by seating participants on a table. (b): Low tension was applied by seating the participant on a chair. (c): Medium tension was produced by letting the participant stand on both feet. (d): High tension was applied by putting participants into a ready position.

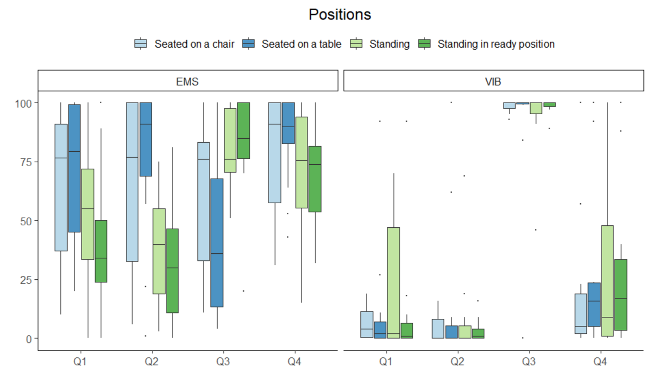


Figure 3: Ratings of feedback quality questionnaire in Table 1) from "Strongly disagree" (0) to "Strongly agree" (100) shows statistically significant differences for EMS and vibrotactile feedback, except for item 1 and 3 in the standing position.

avoid order effects; feedback modality by alternating the starting condition across participants, and calf tension using Latin square.

Our sample consisted of 13 participants (4 female, 9 male) with ages ranging from 19 to 61 years old (M=28, SD=10), seven of them practicing sports regularly (1 to 14 hours per week, M=6.43, SD=4.48). Six participants reported no previous experience with EMS. We used two systems in the experiment: An EMS Wireless system based on the "Let your body move" toolkit reported by Pfeiffer et al. [18], and two wireless vibrotactile bands. The EMS toolkit was powered by a Sanitas SEM 43 Electrical Muscle Stimulation unit and controlled with an Arduino board. We defined a stimulation frequency of 120Hz and a pulse-width of 100 μs based on previously reported studies. The stimulation intensity ranged from 0 to 50 levels. The vibrotactile bands were controlled using ESP32 microcontrollers and four Linear Resonant Actuators (LRA) each. The LRAs were controlled using DRV2605L drivers with resonance tracking, therefore the vibrotactile stimulation frequency was set to the resonant frequency of the LRAs. In both systems, the participants were allowed to set the intensity of the stimulation to a comfortable level.

We asked participants to wear the system. We provided them with an instruction manual specifying the steps required to attach and calibrate the system. The study met the ethics regulations of our institution. Participants were required to experience the feedback of the system by sending stimulation using the smartphone app. After every muscle tension level, participants had to fill up a feedback quality questionnaire (see Table 1). Similarly, after every feedback modality, we distributed a modality evaluation questionnaire to compare both systems. The modality evaluation questionnaire featured the Intrinsic Motivation Inventory (IMI) [21] to assess the participants' enjoyment, effort, or usefulness of both systems. Furthermore, we used the Sense of Agency Scale (SoAS) [23] to measure the feeling of control over actions. We concluded the experiment with a short semi-structured interview, which explored the users' perception of the system and their views on skill acquisition in crossminton. The average duration of the study was 65 minutes.

2.1.2 Results. The placement time for the EMS setup ranged between four to seven minutes (M = 11.75, SD = 3.48) and between one to four minutes (M = 2.08, SD = 0.90) for the vibrotactile setup. A Wilcoxon signed-rank test on the feedback quality questionnaire yielded significant differences (p < .05) between EMS and vibrotactile modalities regarding items 1 and 3 (cf., Figure 3) For item 1, participants perceived EMS moving them toward a specific direction. At the same time, vibrotactile feedback made them feel in control of their movements

Table 1: Questions to assess the quality of the feedback.

Item	Question
1	The feedback nudged me in a specific direction.
2	The feedback made my body move on its own.
3	I was in control of my movements.
4	I could associate a movement with the feedback.

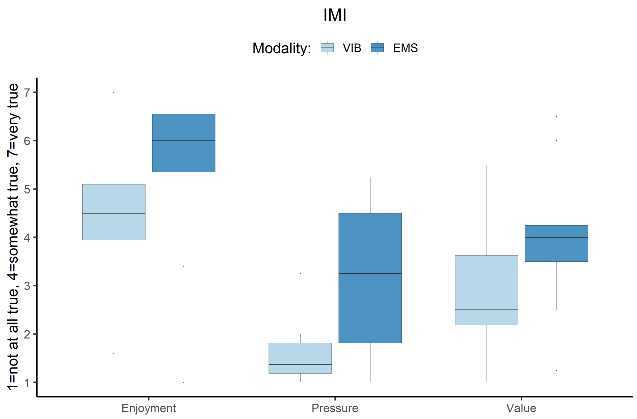


Figure 4: Ratings of IMI Questionnaire. In contrast to enjoyment and value, a significant difference was shown between EMS and vibrotactile feedback for the pressure subscale.

A Wilcoxon signed-rank test showed significant differences ($p < .05$) in the IMI pressure subscale, reflecting less negative feelings towards vibrotactile modality (cf., Figure 4). The SoAS yielded significant differences ($p < .05$) in two of the subscales: Positive Agency (SoPA) and Negative Agency (SoNA). In both cases, participants experienced more agency while using vibrotactile feedback. The complete questionnaire data is available as supplementary material.

2.1.3 Interviews. We used the pragmatic approach for the qualitative data analysis [2] ($1 : 58\,h$, transcribed verbatim). We identified three themes in the data: SENSE OF CONTROL, FEEDBACK CLARITY and NOVELTY EFFECT. The initial code report for both the beginners and coaches interviews (Section 2.2) is available as supplementary material.

Sense of Control. Our participants indicated that in the case of EMS they could actively suppress the movement induced by the EMS as P3 mentioned *"I did not have to do anything that I did not want to actively do"*. P6 further elaborated that *"it's more like I was controlling my legs with my hand"*. This further reflected their sense of control over their own movements as P2 concluded *"I would not have the concern because I have the device in my hand"* and *"I was initiating or stopping what I was doing "* [P13].

Feedback Clarity. When comparing the vibrotactile feedback with the EMS, the participants stated they found the intent of the vibration feedback unclear, highlighting it as a *"passive information modality"* [P7]. The participants further elaborated, that in the case of EMS they felt like it was actually *"doing something to the body"*[P1] as it felt as if it was pushing them *"forward"* [P6]. The participants further highlighted that the EMS feedback was most noticed in the standings position as P2 described it *"I found that in standing you somehow got the impression that it pushed you forward a bit. While sitting, both on the table and on the chair, I hardly had that at all. I even think that normal standing is a little stronger."*

Novelty effect. The participants mentioned that they felt more comfortable using the vibrotactile feedback as it is more familiar On one side they described the feedback related to the vibrotactile as *nothing unfamiliar* [P12], *already known* [P4], and *vibrates like a phone in your pocket*[P6]. On the other side they described EMS as *unknown feeling*[P9] that *one comes into a rare contact with EMS, if at all* [P2]. P11 reflected on the EMS self adjusted intensity that he perceived as comfortable by mentioning that *as soon as you get used to it, you can go beyond it.*

2.2 Interviews with Coaches

To further identify requirements and opportunities for EMS-based assistance systems, we conducted interviews with coaches, in particular addressing example use case scenarios and probing their expertise with regard to integrating such systems in existing training schemes. We recruited a total of six coaches (5 males, 1 female), all teaching crossminton for multiple years ($M = 13.7\,y$, $SD = 14.0\,y$). All interviews were guided by three example training scenarios[3] illustrated by storyboards. Two interviews were conducted face-to-face with experts (E2,E4) testing the EMS system personally, while the rest were conducted via an online video call presenting an introduction to the system. We applied the same thematic analysis procedure as in the first study interviews ($2 : 28\,h$, transcribed verbatim). Our analysis produced three themes, which address integrating EMS-based feedback in racket sports: SYSTEM EFFICACY, PRACTICE INTEGRATION, LEARNING EFFECT. We shortly highlight each theme and its importance for EMS-based feedback systems below.

System Efficacy. The experts identified the potential of EMS-based feedback based on it being punctual, precise and clear. The most commonly used vocal instructions[4] are prone to misinterpretation by students. Here, the experts emphasized that EMS can directly trigger relevant muscle groups (push-to-action), which is especially beneficial in complex scenarios and deep concentration phases.

> "(...) it means that the focus is much higher on the relevant part and thus the implementation [of feedback] is easier because it does not pull you out of 20 factors, but you can really concentrate on one factor." [E4]

Further value was placed on the unobtrusiveness of such a system. No other players are disturbed and social stigma can be prevented.

Practice Integration. Our experts confirmed that the three presented example scenarios were highly relevant in everyday crossminton exercises and commented that the unambiguous definition of this position is advantageous as it leads to clear design requirements on how and when to actuate EMS. Particularly in highly-focused scenarios like a match, where *"(...) you're thinking about something else and you're focused on every point but you're not focused on this [ready] position"* [E5].

Overall, the experts identified basic movement training as a suitable use case for EMS-based feedback, making it a suitable addition for any practice routine.

[3] Standard training routines: agility training, practicing rallies, training match. Storyboards are in the supplementary material.
[4] A coach shouting from the sideline.

Learning Effect. Coaches commented that such feedback can effectively notify the players about posture mistakes, allowing players to reflect on the feedback and learn when to take up the ready position. Compared to other feedback modalities, coaches especially highlighted the ability of EMS to guide players into the correct position as E3 said *"(...) you will notice, "Aha, that's how I feel then, okay." I think that could only be positive."*

In the eyes of the coaches, the reminder effect and the immediate reflection on mistakes is a key element to stimulate proper learning:

> "The idea is that [the student], who actually knows [the ready position], should be reminded "now I haven't done it". They do not even notice [the mistake] and are notified at the moment when the mistake happens. And I think that's where the learning effect actually comes into play." [E2]

3 DISCUSSION

Communicated Information Clarity. Both the trainees and the coaches highlighted the advantage of using EMS over vibrotactile. Here, participants remarked that feedback via EMS is more explicit as the direction of movement is communicated as well. On contrary, vibrotactile communicated feedback was perceived more alarm-like rather than guiding towards the correct action as was the case with EMS. The coaches further elaborated the benefit of this point, as they implied that using the EMS to directly actuate the players would prevent inducing more cognitive workload. Vibrotactile feedback is an option when the user's priority is a simple notification to bring themselves into specific positions. Our results show that EMS communicates clear information that guides the players to correct their ready-posture in racket based sports.

Experience and Agency. Our results indicate that the participants favored the vibrotactile over EMS, due to two main aspects. The first one is the familiarity with the feedback type, which they consider a motivating aspect to them. As one of the concerns they had is not having enough experience with the EMS. The second aspect is the sense of agency [17]. While the participants understood clearly the communicated feedback via EMS, they perceived it as a controlling system rather than a guiding one. Previous work has suggested manipulating the EMS signal attributes to overcome this challenge [13, 15]. In our work, the participants had the control to adjust attributes (e.g., signal intensity) of the induced EMS signal and the intensity of the vibrotactile feedback. The participants' rating of their sense of agency was better in the case of vibrotactile feedback. Furthermore, the control would be handed to the coaches in future real-life training scenarios, where the initial triggering of the signal would be done by the coaches. The need for negotiating agency remains an open question in HCI for sports. Our work shows that more comparisons between prescriptive (e.g., EMS-based) and reflective (i.e. feedback-based) systems are needed to better understand how we can effectively guide users to better sports techniques without building a dependency on technology. We conclude that negotiating agency is an open challenge with EMS, which is not limited to previous experience or self-calibration.

Practical Integration. The coaches indicated that the system is practical for guiding the players to adjust their *ready* posture in racket-based sports. However, they highlighted that the system is not a standalone technology that could replace the coach's instructions, but rather an active reminder of what the correct actions should be. These findings echo past work in HCI for sports where users preferred devices integrated into existing equipment over adding new devices [12]. Therefore, EMS showed a potential for supporting posture correction during the training process, however it should not be accounted as training replacement.

4 LIMITATIONS AND FUTURE WORK

We acknowledge the following limitations to our work. Participants experienced the EMS in a lab setting and not while actually playing , which would need to be further explored in real-life setting. Moreover, two out of six coaches that we interviewed have experience with EMS. Therefore, as future work, we plan test the system in a real coach-and-student sessions, where both the coaches and the students get to experience the EMS actuation while playing. Furthermore, we would focus on examining the reaction time yielded by the different postures.

5 CONCLUSION

In this work, we present an EMS-based system that guides the ready position execution in crossminton. We evaluated the system through two user studies. In the first study, we explored the differences between EMS and vibrotactile feedback as experienced by trainees. In the second study, we interviewed professional trainers, who provided more insights into the EMS feedback communication. From the two studies, we found that EMS has a higher potential of communicating the correct action to be executed in comparison to vibrotactile feedback. However, the communicated feedback is subject to design constraints, as detailed in our findings. For future work, we recommend testing the system in real training sessions to investigate long-term learning effects.

ACKNOWLEDGMENTS

This work is funded by the German Federal Ministry of Education and Research (16SV8368).

REFERENCES

[1] Fran Allard and Janet L Starkes. 1991. Motor-skill experts in sports, dance, and other domains. (1991).
[2] Ann Blandford, Dominic Furniss, and Stephann Makri. 2016. Qualitative HCI research: Going behind the scenes. *Synthesis lectures on human-centered informatics* 9, 1 (2016), 1–115.
[3] Don Samitha Elvitigala, Denys J.C. Matthies, Löic David, Chamod Weerasinghe, and Suranga Nanayakkara. 2019. *GymSoles: Improving Squats and Dead-Lifts by Visualizing the User's Center of Pressure.* Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300404
[4] Sarah Faltaous, Aya Abdulmaksoud, Markus Kempe, Florian Alt, and Stefan Schneegass. 2021. GeniePutt: Augmenting Human Motor Skills through Electrical Muscle Stimulation. In *Special issue "Physiological Computing" at it - Information Technology.* https://doi.org/10.1515/ITIT-2020-0035
[5] Sarah Faltaous, Chris Schönherr, Henrik Detjen, and Stefan Schneegass. 2019. Exploring proprioceptive take-over requests for highly automated vehicles. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia.* 1–6.
[6] Vasiliki Gerovasili, Konstantinos Stefanidis, Konstantinos Vitzilaios, Eleftherios Karatzanos, Panagiotis Politis, Apostolos Koroneos, Aikaterini Chatzimichail, Christina Routsi, Charis Roussos, and Serafim Nanas. 2009. Electrical muscle stimulation preserves the muscle mass of critically ill patients: a randomized study. *Critical care* 13, 5 (2009), R161.

[7] Mahmoud Hassan, Florian Daiber, Frederik Wiehr, Felix Kosmalla, and Antonio Kr¨uger. 2017. Footstriker: An EMS-based foot strike assistant for running. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 1 (2017), 1–18.

[8] Mike Hughes and Ian M Franks. 2004. *Notational analysis of sport: Systems for better coaching and performance in sport.* Psychology Press.

[9] Shunichi Kasahara, Jun Nishida, and Pedro Lopes. 2019. Preemptive Action: Accelerating Human Reaction using Electrical Muscle Stimulation Without Compromising Agency. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* 1–15.

[10] Shunichi Kasahara, Kazuma Takada, Jun Nishida, Kazuhisa Shibata, Shinsuke Shimojo, and Pedro Lopes. 2021. Preserving Agency During Electrical Muscle Stimulation Training Speeds up Reaction Time Directly After Removing EMS. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* 1–9. https://doi.org/10.1145/3411764.3445147

[11] T Keller, M Lawrence, and A Kuhn. 2007. Selective finger and wrist activation using multi-channel transcutaneous electrical stimulation electrodes. In *Proceedings of the 11th Ann Conf Intern Func Elec Stim Soc (IFESS).* 2–5.

[12] Francisco Kiss, Paweł W. Woundefinedniak, Felix Scheerer, Julia Dominiak, Andrzej Romanowski, and Albrecht Schmidt. 2019. *Clairbuoyance: Improving Directional Perception for Swimmers.* Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300467

[13] J. Knibbe, A. Alsmith, and K. Hornbæk. 2018. Experiencing Electrical Muscle Stimulation. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 3, Article 118 (Sept. 2018), 14 pages. https://doi.org/10.1145/3264928

[14] Pedro Lopes, Alexandra Ion, and Patrick Baudisch. 2015. Impacto: Simulating physical impact by combining tactile stimulation with electrical muscle stimulation. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology.* 11–19.

[15] Seito Matsubara, Sohei Wakisaka, Kazuma Aoyama, Katie Seaborn, Atsushi Hiyama, and Masahiko Inami. 2020. Perceptual simultaneity and its modulation during EMG-triggered motion induction with electrical muscle stimulation. *PloS one* 15, 8 (2020), e0236497.

[16] Arinobu Niijima and Takefumi Ogawa. 2016. Virtual food texture by electrical muscle stimulation. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers.* 48–49.

[17] Elisabeth Pacherie. 2007. The sense of control and the sense of agency. *Psyche* 13, 1 (2007), 1–30.

[18] Max Pfeiffer, Tim Duente, and Michael Rohs. 2016. Let Your Body Move: A Prototyping Toolkit for Wearable Force Feedback with Electrical Muscle Stimulation. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Florence, Italy) *(MobileHCI '16).* Association for Computing Machinery, New York, NY, USA, 418–427. https://doi.org/10.1145/2935334.2935348

[19] Max Pfeiffer, Tim D¨unte, Stefan Schneegass, Florian Alt, and Michael Rohs. 2015. Cruise control for pedestrians: Controlling walking direction using electrical muscle stimulation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems.* 2505–2514.

[20] Max Pfeiffer, Stefan Schneegass, Florian Alt, and Michael Rohs. 2014. Let me grab this: a comparison of EMS and vibration for haptic feedback in free-hand interaction. In *Proceedings of the 5th augmented human international conference.* 1–8.

[21] Richard M Ryan and Edward L Deci. 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist* 55, 1 (2000), 68.

[22] Nicolas Stifani. 2014. Motor neurons and the generation of spinal motor neurons diversity. *Frontiers in cellular neuroscience* 8 (2014), 293.

[23] Adam Tapal, Ela Oren, Reuven Dar, and Baruch Eitam. 2017. The Sense of Agency Scale: A Measure of Consciously Perceived Control over One's Mind, Body, and the Immediate Environment. *Frontiers in Psychology* 8 (2017), 1552. https://doi.org/10.3389/fpsyg.2017.01552

[24] Wondimu W Teka, Khaldoun C Hamade, William H Barnett, Taegyo Kim, Sergey N Markin, Ilya A Rybak, and Yaroslav I Molkov. 2017. From the motor cortex to the movement and back again. *PloS one* 12, 6 (2017), e0179288.

[25] Alex R Ward and Nataliya Shkuratova. 2002. Russian electrical stimulation: the early experiments. *Physical therapy* 82, 10 (2002), 1019–1030.

[26] Mikołaj P. Woźniak, Julia Dominiak, Michał Pieprzowski, Piotr undefinedadoński, Krzysztof Grudzień, Lars Lischke, Andrzej Romanowski, and Paweł W. Wouźniak. 2020. Subtletee: Augmenting Posture Awareness for Beginner Golfers. *Proc. ACM Hum.-Comput. Interact.* 4, ISS, Article 204 (Nov. 2020), 24 pages. https://doi.org/10.1145/3427332