Enhancing Support for Optimal Muscle Usage in Sports: Coaching and Skill-Improvement Tracking with sEMG

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ABSTRACT

Cardiopulmonary function and power as well as efficient motion skill are extremely important for athletes. Thanks to the latest sensing technology and smart devices, many researchers have focused on sports-skill analysis. Electromyography (EMG), in particular, is gaining attention as a method of understanding the power-generating process in motions. However, most existing applications using EMG have remained being one-time measurement. This is because athletes do not know how to use the results and how to measure their improvement. We propose a sports-skill-training framework with muscle-usage indicators based on EMG and an EMG live visualization system. With this framework, athletes can determine the skill they need to improve by focusing on skills whose indicators are poor, activate their muscles with live feedback to overcome weaknesses, and quantitatively measure their improvement as the improvement of the indicators during the activation training. We also verified the effect of coaching in this framework on cycling athletes. The experimental results quantitatively indicate the effectiveness of continuous skill training with our framework.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**.

KEYWORDS

skill coaching; muscle usage skill; electromyography; muscle activation drills; sports training

ACM Reference Format:
Osamu Saisho, Shingo Tsukada, Hiroshi Nakashima, Hiroshi Imamura, and Kyoichi Takaori. 2019. Enhancing Support for Optimal Muscle Usage in Sports: Coaching and Skill-Improvement Tracking with sEMG. In *Proceedings of the 2019 International Symposium on Wearable Computers (ISWC '19), September 9–13, 2019, London, United Kingdom.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3341163.3347722

ISWC '19, September 9–13, 2019, London, United Kingdom

ACM ISBN 978-1-4503-6870-4/19/09…$15.00
https://doi.org/10.1145/3341163.3347722

1 INTRODUCTION

All athletes want to safely and effectively improve their competition ability based on training theory. What they need are not only muscular power to acquire greater impelling force by each motion and endurance to sustain that power longer but also motion skill to maximize motion efficiency and reduce fatigue. Training methods for basic athletic ability such as power training and endurance training have been investigated [1, 5]. However, training methods for improving motion skills to maximize motion efficiency tend to depend on sense and opinions of professionals.

Thanks to the development of sensing technology, sports skills also have been extensively analyzed. Electromyography (EMG), in particular, is gaining attention for quantitatively understanding the muscle motions in bicycle racing [8], badminton [10], golf [13] and so on. However, EMG analysis has failed to become a common method for usual training. The simple reason is that the effect allowing users to improve their skills has not exceeded the cost to use EMG devices.

Even though surface electromyography (sEMG) sensors can measure EMG without any invasion, it is still much more expensive than other sensing devices such as those for measuring heart rate and acceleration. Moreover, measuring EMG is more difficult because the EMG-measurement position should be exact. EMG can be sensitively affected by positional displacement of electrodes. In recent years devices with sEMG sensors, such as Delsys EMG system [1], Athos [2] and "hitoe" sEMG pants [3], have been developed for practical use. These clothing with sEMG combining sensing and fabric technologies reduce measurement cost in practical training.

In terms of effect for athletes to use EMG devices, there is no application for using the analysis results to training by athletes themselves. Even if they acquire interesting results and visualizations, they would not know how to use them or how to evaluate their improvement. Therefore, they cannot experience their improvement. These problems are common with wearable and smart devices. Many smart devices have quickly lost users' interest [7, 9]. Novel information visualization can only temporarily hold users interest. This means that no matter how low the cost of EMG analysis becomes, EMG devices will follow the same fate as previous smart devices. Useful and simple EMG applications are needed.

Thus, this research goal is to develop a training framework with EMG for athletes to effectively train and improve upon their skills with tracking how and how much their skill improves by the training. Specifically, we use a skill-training method to extract muscle-usage indicators on bicycle racing athletes [11], train muscle-usage feeling based on muscle activation drills with EMG live visualization, and quantitatively evaluate skill improvement as changes of the indicators. The two main contributions of this paper are as follows. First, we construct a coaching framework for improving efficient motion skill through muscle activation drills with muscle-usage indicators based on EMG and an EMG live visualization system. Second, we quantitatively demonstrate the effectiveness of our framework regarding muscle-usage improvement in bicycle racing. These contributions lead to the spread of EMG-analysis applications in usual sports training.

2 RELATED WORK

Sports-Skill Training with EMG

Even though many researchers have been analyzing sports skills by using EMG, most have been focused on fatigue [2] or classification of professional and amateur athletes [6]. These are of course important topics in kinesiology and sport science; however, they are not applicable for individual athlete training because of their difficulty to use and the difference between laboratory and practical environments.

Unless EMG contribute to individual athlete training, they will not be used continuously as with other wearable devices because to wear any devices originally is nothing more than a cost for athletes [9]. What athletes need is only the better

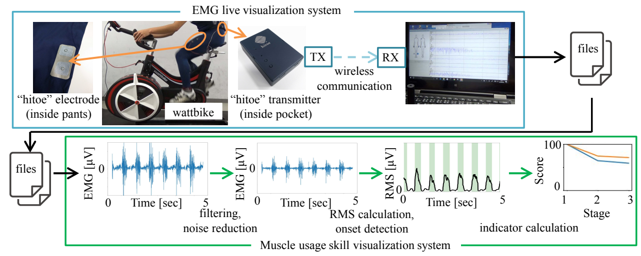

Figure 1: Framework and training support system

competition results such as shortened time or increasing the winning percentage. However, these changes require a long time and must be affected by other environmental changes. Devices should be used to help coach regarding skill improvement and quantitatively visualize the improvement in each motion skill for more immediate results.

Recently, some researchers are shifting to analyzing motion skills in practical environments [11]. Thanks to these analyses, athletes can quantitatively determine their weaknesses such as, "I can not convert muscle power to pedaling torque because my right leg cannot relax", or "His stroke is very smooth and efficient but his muscular strength is insufficient", by using the analyses. Note that the range of existing research is limited to quantitative visualization of sports skills by item as indicators, and there has been no research on evaluating the effect of coaching and improvement through training using such quantitative skill indicators.

Muscle Activation Drill

Muscle activation drill is a training method for solving problems such as a specific a muscle or muscle group can not be well recruited during weight training [4]. Athletes can improve the mobilization strength of the objective muscles through activation drills [12]. This leads to improvement of their athletic ability [3]. However, there has not been sufficient investigation into coaching regarding sports-motion efficiency by using EMG.

3 FRAMEWORK AND SYSTEM

We developed a training framework for coaching athletes on muscle usage. Figure 1 shows the entire process and components of our framework. This framework is based on two systems, a muscle-usage-skill visualization system and an EMG live visualization system. Athletes can find their weaknesses in muscle usage in their sport motion by using the muscle-usage-skill visualization system and conduct muscle activation drills to overcome these weaknesses with training coaches and the EMG live visualization system. During this coaching, they are expected to get a feel for using only the minimum necessary muscles with other muscles relaxed. Muscle-usage-skill visualization system helps athletes find their weak muscle-usage-skill by quantitative evaluation.

[1] http://www.delsys.com
[2] https://www.liveathos.com/product-facility
[3] http://www.hitoe-toray.com/en/

EMG live visualization system helps athletes get an exact feel for using only exact muscles by live showing which muscles are activated. After sufficient self-training period, they can quantitatively evaluate their improvements by item as the improvements of their indicators by using a muscle-usage-skill visualization system again. We developed a training support system for bicycle racing with the existing muscle-usage indicators [11]. Note that the application of this framework is not limited to only bicycle racing.

EMG Live Visualization System

The EMG live visualization system is based on "hitoe" sEMG pants. "hitoe" is a textile bioelectrode coated with a conductive polymer, which was jointly developed by NTT and Toray. The EMG data from all measurement points are sent to a computer via wireless communication and can be visualized live on the computer without obstructing any motions of athletes. Its sampling rate is 500 Hz, even though the standard EMG sampling rate is more than 1000 Hz, because of the practicability of the transmitter. The size, weight and battery lifetime of the transmitter are affected by communication traffic of the multiple channel EMG data. Besides, the sampling somewhat lower frequency exerts no effect on the system because this system does not focus on frequency analysis such as popular fatigue estimation.

In the coaching phase, coaches instruct athletes on how to conduct muscle activation drills for each weak point. For example, athletes who cannot recruit their gluteus muscle are recommended to do a hip bridge, and athletes who cannot relax their biceps femoris are recommended to do a stretching hamstrings. Muscle activation drills involve re-educating the nervous system. Until getting a feel for using only specific muscles, athletes must learn muscle usage through trial and error. In case of a hip bridge, athletes who already get an sufficient feel can recruit only their gluteus muscles, on the other hand, athletes who don't get a feel recruit all leg muscles unconsciously. Coaches can instruct and advice detailed motion for muscle activation drill by natural language considering athletes' skeletons and conversation with athletes. EMG live feedback can show which muscles are activated during drills by live visualized information which people cannot see and check by their own. Thus, they need personal instruction by coaches and EMG live feedback; They cannot substitute one another.

Muscle Usage Skill Visualization System

The muscle-usage-skill visualization system is based on the two existing muscle-usage indicators [11] for determining the weaknesses in training each muscle and evaluating the improvement in muscle usage before and after coaching and self-training. Thus athletes can quickly find how and how much this framework contribute to their skill improvement.

pre-trial date post-trial date	26, 27 Sep, 2018 29, 30, 31 Oct, 2018
#, age, gender of participants	11, 19-23 yrs., Male
measurement muscle	vastus lateralis (VL) biceps femoris (BF) gluteus muscle (GM)

Table 1: Overview of experiment

Specifically, the relaxation indicator indicates how well only the necessary muscles are used at the necessary time span and the balance indicator indicates how well avoiding relying on certain muscle or muscle group. We converted these indicators into scores: minimum 0 and maximum 100.

4 EXPERIMENT

We conducted an experiment to quantitatively evaluate the effectiveness of our framework in improving athletes' muscle-usage skills. This experiment was conducted in accordance with the procedures approved by the ethics committee of our organization to guarantee the participants' rights.

Experimental Environment

Table 1 shows the details of the experimental period and participants. The participants belong to one of main university bicycle racing clubs in Japan. Thus, they executes training in the same environment and the differences of their competitive abilities is little. This experiment is composed of pre-trial, coaching phase, self-training period, and post-trial. Evaluation of the effectiveness of coaching is usually conducted by dividing participants into intervention group and control group. In this research, this usual method is unfair for the participants because all of them are active athletes belonging to the same club. Thus, we decided to use only one rule (below) and did not clearly divide them into groups. In accordance with this rule, participants were divided into groups randomly and fairly as a result. We never (encourage/discourage) any participants to perform the training.

rule: Whether you perform the training decided in the coaching phase during the self-training period depends on you, but you must honestly answer the performance frequency of the training during the post-trial.

We used Wattbike PRO [4] for the pre-trial and post-trial with the EMG live visualization system. Wattbike PRO can control the position of the saddle and handle, cadence, and output power, which affect muscle usage. Before the pre-trial, participants recorded their personal optimized positions and functional threshold power (FTP) for conducting two trials under the same settings. FTP, a popular indicator for power training in bicycle racing, is the upper limit of output power to maintain for an hour. In the trial, cadence was fixed to 90 rpm, output power was fixed to FTP × 0.8 during the first

[4] https://wattbike.com/us/product/wattbike

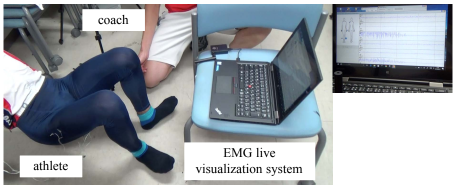

Figure 2: Activation drill

two minutes, FTP × 1.2 after that and the trial finished when participants wanted to stop. The muscle-usage indicators were calculated in three stages, "1": the first two minutes (FTP × 0.8), "2": next two minutes (FTP × 1.2), and "3": after that (FTP × 1.2).

After the pre-trial, coaching professionals instructed participants to perform personalized muscle activation drills to focus on their weaknesses as the coaching phase. The main drill selections were hip bridge, reverse lunge, clamshell, romanian deadlift, side plunk, and stretching. The professional coaches selected two or three drills for each participant to perform during the self-training period, about one month, after the instruction (Figure 2). At the post-trial, participants conducted the same test as the pre-trial and comparing the indicators between pre-trial and post-trial for evaluating their skill improvements. Also, we asked participants about their performance frequency of the training and divided them into three groups, "Always" (performed always or almost always), "Half", and "No" (performed few times or never).

Experimental Results

Figure 3 shows all groups' average scores. In according with the above rule, five participants were placed in "Always", three in "Half", and three in "No" group. For simplicity, the relaxation indicator score is calculated as an average score of the right and left sides of each muscle. For quantitative verification, Table 2 shows the average and the standard deviation of score improvements, i.e., post-trial score (blue line in Figure 3) – pre-trial score (orange line in Figure 3), of each group without distinction of three test stages. The higher the training performance frequency is, the higher the improvement of almost all of muscle-usage skills is and the "No" group's score changed little. These results indicate the effectiveness of coaching in our framework for skill training and quantitative expressiveness of indicators. These results also indicate the experiment reliability. It is true that the "No" group athletes did not perform the drills selected by the professional coaches, but they continued their usual training, so their score did not change either for the better or worse.

Focusing on the result of each muscle, the improvement in BF and GM is larger than that in VL among groups. BF and GM are said to be difficult to use consciously because they are located on the back-side of legs but important for competitive ability because they contain more slow muscles and more energy. Thus, these results will contribute to athletes' competitiveness.

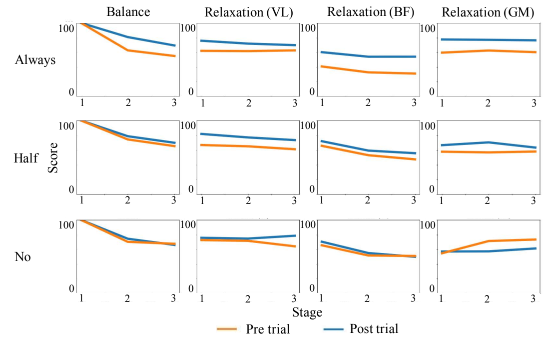

Figure 3: Experimental results

	Always	Half	No
balance	**16.2** ± 8.2	4.4 ± 4.8	1.3 ± 6.9
relaxation (VL)	10.4 ± 5.1	**13.1** ± 7.9	6.9 ± 8.4
relaxation (BF)	**21.3** ± 12.6	6.9 ± 3.4	2.4 ± 4.8
relaxation (GM)	**16.2** ± 10.1	9.3 ± 8.4	-7.9 ± 14.3

Table 2: average of score improvement

By using our framework, athletes can determine their weaknesses and improvements in muscle usage quantitatively as the effect of their muscle-usage training. Existing training frameworks cannot achieve this.

There are some limitations left in our framework and the experiment. First, our systems can not instruct athletes how to train. Athletes need both of our systems and their coaches for training. This is why we call our systems training "support" systems. Second, this framework does not consider individual differences in competitive styles. We believe that targeted muscle usage skills are common factors for all competitive styles, but there is no impact analysis of the differences in competitive styles and skeletons. As regards the experiment, the number of participants is not so large and the dividing method was not completely random. For strict verification, much more participants who execute training in the same environment and can be divided into groups randomly, even though it means unfair, are needed.

5 CONCLUSION

We proposed and evaluated a training framework for athletes to determine, overcome their weaknesses in muscle usage and measure their improvement quantitatively. With this framework, EMG live feed-back and muscle-usage coaching based on muscle activation drills help athletes improve their weaknesses. Moreover, quantitative expressions of their improvement by the changes of skill indicators help athletes experience their skill improvements. The experimental results indicate the effectiveness of our framework on cycling athletes. Thus, our framework can save EMG devices from the same fate as previous smart devices. For future work, we will implement and evaluate this training framework for other types of sports for longer periods and on a larger scale.

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