# Regular Articles

# Body-mind Sonification to Improve Players Actions in Sports

## *Toshitaka Kimura, Takemi Mochida, Tetsuya Ijiri, and Makio Kashino*

## Abstract

It is essential that we recognize both our own physical movements and mental condition if we are to achieve and improve goal-directed actions in sports. However, it is not easy to adequately understand one's own body-mind state during complicated sports actions. A potentially better way to overcome this problem is to use auditory feedback because auditory perception has higher temporal resolution than visual perception, and it interferes very little with the performance of an action. In this article, we propose real-time auditory feedback techniques designed to sonify the temporal coordination of the body and the excessive activation caused by mental pressure when participating in sports based on surface electromyography and acceleration signals. Our aim was to determine *when* and *how* the body-mind behaves. We believe that these techniques will help players learn the skill needed for a desired action and will reveal a player's physical and mental condition when playing sports.

*Keywords: auditory feedback, real time, motor learning*

## 1. Introduction

It is essential that we understand our own movement if we are to achieve and improve goal-directed actions in sports. However, it is not easy to adequately recognize the state of one's own body during complicated movements involving multiple segments of the body, as when a golfer needs to coordinate various movements of the arms, trunk, and legs quickly and correctly when hitting a tee shot. In addition, the body is affected by a person's mental condition; that is, the body and mind are not independent but are closely linked. Even a highly skilled player may not perform well under mental pressure. Therefore, it is very important to understand one's own *body-mind* state during sports actions so as to perform satisfactorily in an actual sports game.

NTT has long researched the neural mechanisms behind motor control, sensory perception, and emotional processing in humans. We have incorporated these findings and know-how into feedback techniques designed to convey certain key features of the body-mind state during actual sports actions. Specifi-cally, we propose using auditory feedback to obtain the temporal structure of segmental motions and muscle activity using synthetic sound. Our aim is to make a player intuitively aware of when and how his/her body-mind behaves.

## 2. Use of auditory feedback

To sense one's own motor state (e.g., posture, motion, and muscle activity) during ongoing movement, we mainly depend on proprioception, which originates in the sensors in muscles and joints. However, proprioception offers only rough spatiotemporal resolution. Thus, many studies have proposed various ways of providing the motor state with a multimodal approach based on, for example, vision, audition, or haptics, to compensate for poor proprioceptive information [1]. Visual feedback has been the most widely used way of displaying body motion (e.g., looking at snapshots and video). However, visual feedback is also assumed to have some limitations. First, we cannot fully use vision during an ongoing action because vision is commonly used for other goals (e.g., looking

at a target). Furthermore, vision is expected to be limited in terms of showing the temporal structure of segmental activities because of the insufficient temporal resolution of human visual perception, even though the very quick coordination of multiple body segments is a key feature in some sports.

A potentially better way to overcome the above problems is to use auditory feedback. One reason for this is that unlike vision, human auditory perception is much less likely to interfere with performing an action, which is a benefit of providing feedback in real time. Auditory perception also has higher temporal resolution than vision. In fact, human beings often utilize auditory feedback to understand the temporal structure of motor behavior in daily life. A very familiar example is speech articulation. It is well known that speech articulators (e.g., the lips and tongue) have a very quick and complicated pattern, and auditory feedback plays a crucial role in controlling speech articulation [2]. We designed techniques for real-time sonification of the body-mind state to extend the human auditory system so that it can utilize motor control in the body in addition to speech.

## 3. Sonification of sports action

Although previous studies have already applied auditory feedback to sports, most of them have sonified behavioral outcomes (e.g., ski displacement [3]) or individual segmental activities (e.g., the timing of wrist and ankle movements in karate [4]). However, these kinds of feedback for individual outcomes and activities may be insufficient to utilize for motor recognition and learning because the spatiotemporal coordination of the body appears to be critical in terms of achieving a skillful movement in most sports. In contrast, our idea is to sonify body coordination, namely when and how a player controls his/her body, based on muscle activity and acceleration signals in multiple target segments. We expect our artificially provided auditory feedback to be integrated with original proprioceptive information during sports actions and that this integration will facilitate improvements in sports skills.

### 3.1 Sonifying segmental coordination

For most sports, it is critical to coordinate multiple body segments sequentially. For instance, when pitching a baseball, a pitcher needs to operate his/her body segments in sequence from the leg to the arm, which is a well-known segmental kinetic chain [5], and a novice pitcher cannot perform this sequence

well. Thus, we attempted to sonify such sequential patterns during pitching using acceleration signals recorded on the pitcher's trunk, and then to apply it to pitching practice for novice participants.

An example of the sonification of the pitching sequence of the trunk in a single novice participant is shown in **Fig. 1**. We attached wireless acceleration sensors (Trigno, Delsys) at three different positions (P1, P2, and P3) on the back of the trunk (Fig. 1(b)) and detected three axes of acceleration signals at a 300-Hz sampling rate. We used analog acceleration signals during pitching to calculate two acceleration components in real time, namely, trunk rotation (A1) and tilting (A2); we calculated A1 and A2 from the P2 minus P1 signals and P3 minus P1 signals, respectively (top two panels in Fig. 1(c)). Then a sound (S) is synthesized as

$$S(t) = A1(t) \, S1 + A2(t) \, S2, \qquad (1)$$

where S1 and S2 indicate band-limited pink noise with peak frequencies of 100 and 500 Hz, respectively. The lowest panel in Fig. 1(c) shows a spectrogram of the generated synthesized sound. Although this spectrogram contains two unclear frequency components, if the player performed a good trunk motion he/she would be able to hear the two components separately (see Fig. 1(d)). Time 0 approximately indicates the ball release timing of pitching.

The above sonification (auditory feedback) was applied while two novice participants engaged in pitching practice that consisted of repeating 100 non-dominant arm pitches with a fixed step length and moderate effort (Fig. 1(a)). In particular, they focused on trunk rotation and tilting, which are targeted in the feedback information, because novices frequently exhibit poor trunk motion [6]. They also performed other practice trials using visual feedback (6-sec.-delayed video streaming) in a separate session for comparison with the effect of auditory feedback. The order of auditory and visual practice sessions was counterbalanced between the two participants. At the beginning of each practice session, either the sound (Fig. 1(d)) or a video of an expert's pitch was provided as a practice target. Before and after each practice session, we measured as a test session the chest, shoulder, and wrist motions in 10 trials without any feedback using a motion capture system (Oqus 300, Qualisys).

The mean velocity waveforms of three segments (chest, shoulder, and wrist) in each test session are shown in **Fig. 2(a)** for each participant. Both auditory (AF) and visual feedback (VF) practices improved the body sequence; namely, the sequential pattern

(a) Pitching practice

(b) Acceleration sensors

P3

P1    P2

(c) Novice's profiles

A1 (Rotation: P2 - P1)

A2 (Tilting: P3 - P1)

Acc. (m/s²)

Synthesized sound

Amplitude

Sound spectrogram

Freq. (kHz)

Time from ball release (sec.)

(d) Expert's sound spectrogram
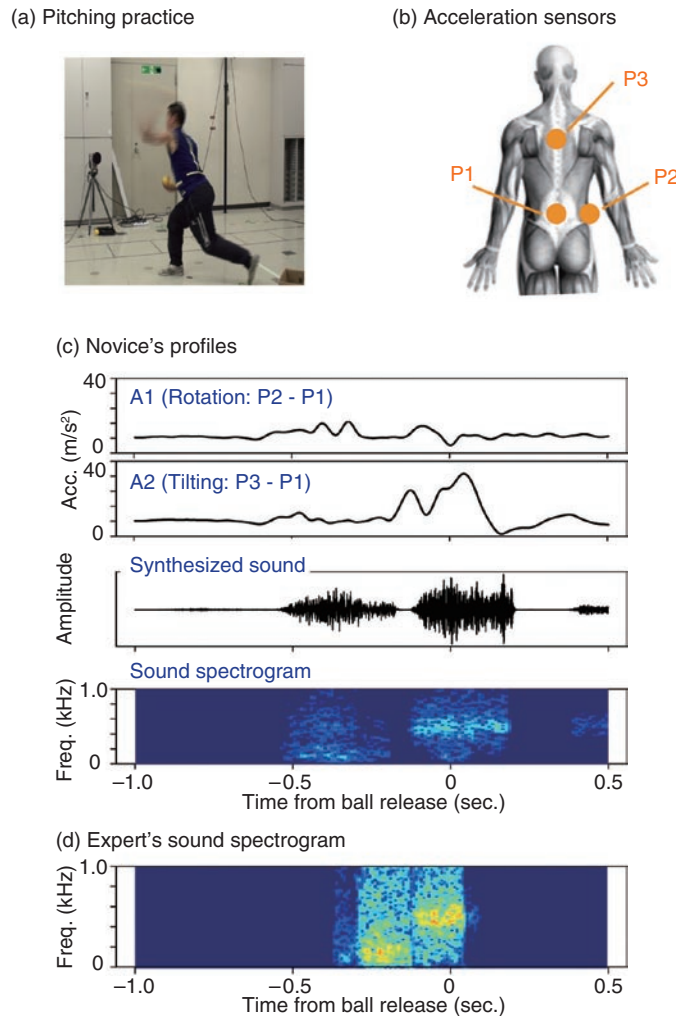
Freq. (kHz)

Time from ball release (sec.)

Fig. 1.   Sonification of segmental coordination of the trunk during pitching.

from the chest to the wrist for peak velocity was clearer than in pre-practice trials. The inter-trial deviation of velocities for each test session is shown in **Fig. 2(b)**. Interestingly, the auditory feedback showed less velocity deviation across test trials than the visual feedback. This result suggests that our real-time sonification for segmental coordination enhances the inter-trial repeatability of movements, compared with standard visual feedback.

### 3.2   Sonifying coordination of muscle activity

The above sonification method expresses the kinematics of movement based on acceleration signals of the body. We propose here another sonification method for body state that describes the dynamics of movement, that is, the muscle activity pattern. Even

if a player is made aware of a difference in motion by the sonification of kinematics, it is probably difficult to understand how to exert a force that will improve the movement because it is a theoretically ill-posed problem. Thus, we attempted to sonify the sequential muscle activity patterns, which more directly reflect the exerted force, based on multiple electromyography (EMG) signals from the trunk and the upper and lower limb muscles.

An example of the sonification of the muscle activity pattern of pitching is shown in **Fig. 3**. The generated sound consisted of multiple sound sources whose fundamental frequencies were different for every muscle and whose amplitudes were varied in proportion to the EMG activity (Fig. 3(a)). An expert (former professional) pitcher almost always exhibited
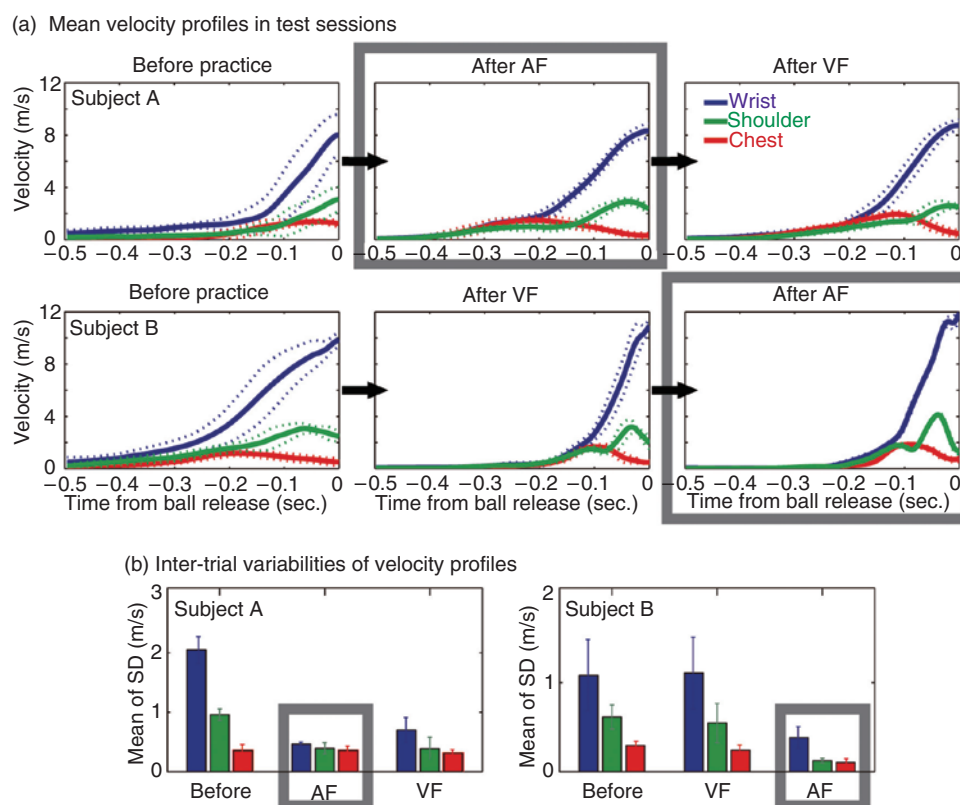
Fig. 2.   Effect of sonification of segmental coordination during pitching.

a clear kinetic chain of muscle activity from the leg to the arm muscle (upper-left panel in Fig. 3(b)), while an amateur pitcher did not (lower-left panel in Fig. 3(b)), indicating unnecessary muscle activation. Therefore, the expert's sound is very rhythmical (upper-right panel in Fig. 3(b)), while the amateur's is slurred (lower-right panel in Fig. 3(b)). This sonification can be described as an *instrument* type of sonification, and a player can hear the difference in the muscle activity pattern as a melody. Using this sonification, a player can move so as to make as purposeful a sound as possible.

### 3.3   Sonification of excessive muscle activation

Some sports players cannot perform well because they try too hard, such as when putting while playing golf. This corresponds to the unintentional excessive activation of the muscles probably caused by mental pressure. That is, such excessive muscle activation reflects the state of mind. This phenomenon is very common and very serious in an actual sports match, but it is often hard to notice it. Therefore, it would be useful to make a player aware of this potential for

excessive muscle activation.

An example of the sonification of overflow of muscle activity in the initial stages (address and take back) of putting in golf is shown in **Fig. 4**, based on EMG and acceleration signals of the wrist extensor muscles. The sound signal (S) consisted of a periodic waveform whose amplitude and fundamental frequency were varied in proportion to the short-term power of the EMG activity (E) divided by the acceleration (A) as follows.

$$S(t) = E(t) / A(t). \qquad (2)$$

The sound mainly reflects the EMG activity when the acceleration was kept at almost zero. Therefore, the golfer could hear annoying sounds during the preparation (address) period when the muscle was activated more than necessary while the wrist moved less (lower panels in Fig. 4). Conversely, the golfer could not hear these sounds when the muscle was relaxed during preparation (upper panels in Fig. 4). Little sound was produced when the wrist was moving (take-back period) because the muscle activity and motion were coupled. This is a *warning* type of sonification, unlike the above sonification, and the
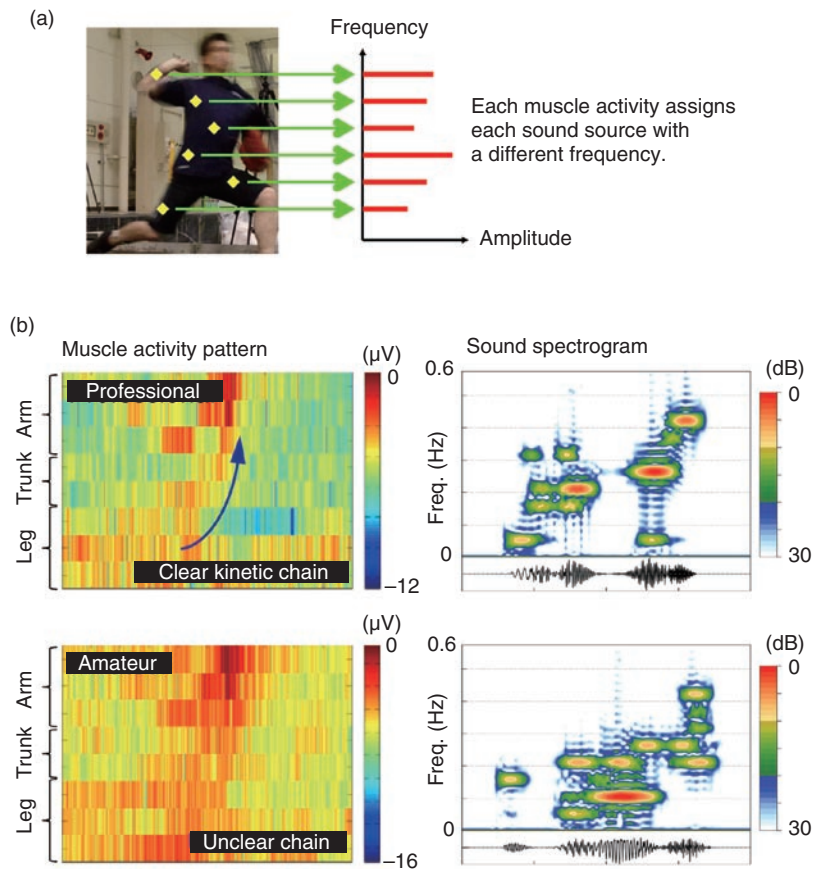
Fig. 3.   Sonification of muscle activity pattern during pitching.

player aims to produce as little sound as possible.

## 4.   Future developments

This article explained some novel examples of sonification of the body-mind state in sports actions. This sonification has the potential benefit of making a player aware of the coordination of movements and of his/her condition under mental pressure. However, the information regarding the body-mind state and auditory ways to provide them will vary according to the objectives and the skill level of the player. For example, the sonification of a segmental sequence (Fig. 1) would be more useful in helping a novice player to acquire the basic temporal pattern of a target action, while an instrument type of sonification of muscle activity (Fig. 3) may be more useful in helping an intermediate player to improve, rather than acquire, a given movement. Furthermore, it is likely that the sonification of excessive muscle activation

(Fig. 4) is beneficial in terms of recognizing one's own mental state in an actual sports game.

We should pay attention to other elements of sonification. For instance, it is critical to determine what to provide in sonification, namely, the key essence or the *knack* of a target action, before applying our sonification. It is also important to combine it with other techniques to effectively improve a player's performance. It would be useful, for example, to combine it with visual feedback to characterize the spatial structure of an action, such as the form, while it seems more appropriate to combine it with auditory feedback to characterize the temporal structure of an action. Additionally, a wearable device such as the *hitoe* fabric bioelectrode developed by Toray and NTT would make the sonification application easy to use for players and could potentially record EMG signals during the sports action. Further research is needed to develop effective ways to enable a player to learn the skills needed for a desired action and to
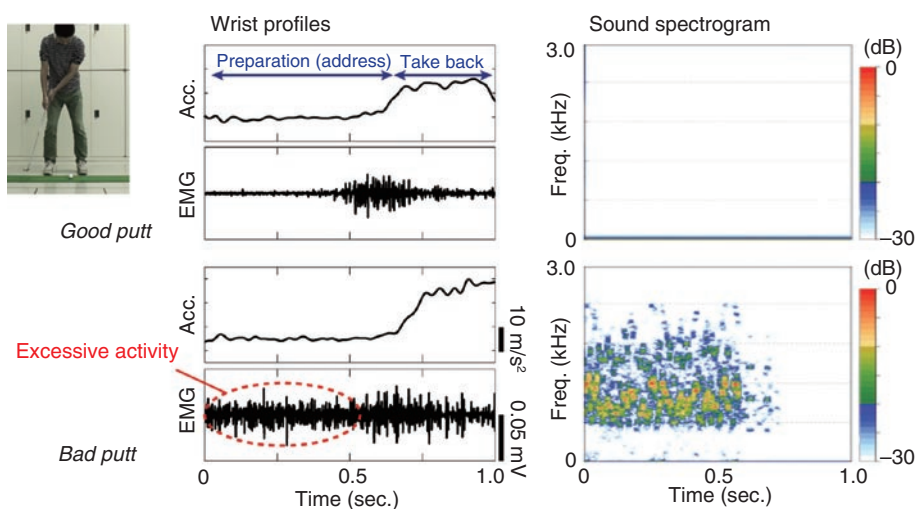
Fig. 4.   Sonification of excessive muscle activation during golf putting.

reveal a player's condition when playing sports.

## References

[1]   R. Sigrist, G. Rauter, R. Riener, and P. Wolf, "Augmented Visual, Auditory, Haptic, and Multimodal Feedback in Motor Learning: a Review," Psychon. Bull. Rev., Vol. 20, pp. 21–53, 2013.

[2]   J. Sasisekaran, "Effects of Delayed Auditory Feedback on Speech Kinematics in Fluent Speakers," Percept. Mot. Skills, Vol. 115, No. 3, pp. 845–864, 2012.

[3]   R. Kirby, "Development of a Real-time Performance Measurement and Feedback System for Alpine Skiers," Sports Technology, Vol. 2, No. 1–2, pp. 43–52, 2009.

[4]   G. Yamamoto, K. Shiraki, M. Takahata, Y. Sakane, and Y. Takebayashi, "Multimodal Knowledge for Designing New Sound Environments," Proc. of the 6th International Conference on Human Computer Interaction with Mobile Devices and Services, Citeseer, Glasgow, UK, 2004.

[5]   M. E. Feltner, "Three-dimensional Interactions in a Two-segment Kinetic Chain. Part II. Application to the Throwing Arm in Baseball Pitching," Int. J. Sport Biomech., Vol. 5, No. 4, pp. 420–450, 1989.

[6]   S. Oyama, B. Yu, J. T. Blackburn, D. A. Padua, L. Li, and J. B. Myers, "Improper Trunk Rotation Sequence is Associated with Increased Maximal Shoulder External Rotation Angle and Shoulder Joint Force in High School Baseball Pitchers," Am. J. Sports Med., Vol. 42, No. 9, pp. 2089–2094, 2014.

**Toshitaka Kimura**
Senior Research Scientist, Human Information Science Laboratory, NTT Communication Science Laboratories.
He received his Ph.D. in human neuroscience from the Graduate School of Arts and Sciences, the University of Tokyo, in 2003. He joined NTT Communication Science Labs in 2003. He has been engaged in research on sensorimotor control and action-perception interaction in humans. He has recently been focusing on brain functions in athletes and the use of ICT in sports. He is a member of the Society for Neuroscience (SfN), the Japan Neuroscience Society (JNS), and the Institute of Electronics, Information and Communication Engineers (IEICE).

**Takemi Mochida**
Research Scientist, Human Information Science Laboratory, NTT Communication Science Laboratories.
He received a B.E. and M.E. in electrical engineering from Waseda University, Tokyo, in 1992 and 1994 and a Ph.D. in systems information science from Future University-Hakodate, Hokkaido, in 2011. He joined NTT in 1994 and has been conducting research on speech science. He was involved in JST-CREST projects from 1998 to 2003 and again from 2014 to present. His research interests include sensorimotor mechanisms of speech. He is a member of SfN, the Acoustical Society of America, JNS, the Acoustical Society of Japan, and IEICE.

**Tetsuya Ijiri**
Research associate, Human Information Science Laboratory, NTT Communication Science Laboratories.
He received a B.S. in environmental engineering from the University of Tokyo in 2009 and an M.S. and Ph.D. in human neuroscience in 2011 and 2014. He joined NTT Communication Science Laboratories in 2014 as a research associate. His research interests include the relationship between mental state and sensorimotor control. He is a member of SfN, the European College of Sports Science, and the Japanese Neural Network Society.

**Makio Kashino**
Senior Distinguished Scientist/Executive Manager of Human Information Science Laboratory, NTT Communication Science Laboratories.
He received his B.A., M.A., and Ph.D. in psychophysics from the University of Tokyo in 1987, 1989, and 2000. He joined NTT in 1989. From 1992 to 1993, he was a Visiting Scientist at the University of Wisconsin. Currently, he is a Visiting Professor in the Department of Information Processing, Tokyo Institute of Technology (2006–). He has been conducting psychophysical experiments and using neuroimaging, physiological recordings, and computational modeling to investigate the functional and neural mechanisms of human cognition, especially auditory perception, crossmodal and sensorimotor interaction, and interpersonal communication. His other recent interests include sports, music, and autism.