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"Audializing" Human Movements for Motor Skill Learning

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Abstract: People usually make use of visual and somatosensory feedback to perform and learn motor skills. Here, we discuss the possibility that auditory feedback can be also utilized for motor execution and learning by "audializing" one's body movement. To this end, we built a wearable transducer device which modulates sounds according to the user's posture and movement and provides a real-time feedback to the user. In this paper, we explain the principle of auditory feedback and its possible applications, show a preliminary implementation and illustrate how the auditory feedback enhance the motor learning through a simple experiment.

Keywords: auditory feedback, motor learning, sensory feedback, wearable device

1. INTRODUCTION

It is essential to realize our own posture and movement when we try to acquire motor skills (e.g., golf swing and dance performing) through trial and error and/or to imitate good-performers' movements. Although our body is equipped with a number of proprioceptive (i.e., mechanical) sensors on muscles, joints and skin, we can perceive only roughly and unreliably our own posture and movements. Thus, we often watch our body directly (i.e., online visual feedback) or by video-recorded images (i.e., off-line visual feedback), in order to examine and modify our movements. Presumably, however, we cannot make full use of visual information in motor skill learning, because vision is required for other purpose in most tasks (e.g., for looking at the target). Therefore, it is desirable that some additional on-line clues are provided indicating the body movement.

In the present study, we propose to use auditory signal to this purpose. In concrete, we built a wearable transducer system which modulates sounds (i.e., pitch and loudness) according to the user's body posture and movement, and provides a real-time auditory feedback to the user.

Below, we first explain our idea of " audializing body movement" and possible its applications. Next, we show a simple implementation of the wearable device. Then, we illustrate its effect on motor learning through an experiment.

2. "AUDIALIZING" BODY MOVEMENT

Our principal idea is to use auditory feedback to give a new clue to perceiving the body movement. This idea has been inspired by our daily experience that people often make use of the sound in dexterously handling tools. When drilling a hole in a metal object using a boring machine, for example, the worker adjusts the force to the object based on the sound generated from the object and brade. A more familiar example is our own articulation (i.e., vocalization) mechanism. Articulation is a quite complex motor task, and people have obtained this skill by a long training from the infancy. It is well known that auditory feedback plays an essential role in acquiring and maintaining this skill: deaf people have trouble learning the articulation, and even normal people have trouble making a voice unless appropriate auditory feedback is provided.

In some cases, moreover, auditory feedback has already been utilized more intentionally. Bio-feedback is a good example. In a bio-feedback system, some physiological measures (e.g., blood pulsation and brain waves) are fed back to the user through auditory information so that the user can perceive his/her mental state. In medical examination, in addition, audialized EMG signal helps to notice the changing on the response of the patient [1, 2].

Therefore, auditory feedback has been utilized explicitly or implicitly in our daily life. Our idea is to apply this idea to a wider range of motor skill learning.

A prominent merit of using auditory feedback is that it can provide information of the movement in a real-time manner. Our auditory system has precise temporal resolution (that is why we can discriminate complex vocal sounds) and it is expected that people can obtain temporally more precise information on our body movement than visual feedback. A second feature is that auditory feedback does not occupy one's vision: The user can freely move his/her gaze to achieve the motor task. A third point is that, different from the visual information, auditory signal does not have physical correspondence to body movement because the body movement itself does not make any sound. We can design appropriate sounds so that people can perceive most valuable information on their movement.

From a different point of view, our approach is closely related to learning to playing musical instruments. In playing instruments, people try to acquire a movement pattern which brings beautiful sounds: Here, the sound is the major target of the training. In our approach, to the contrary, people try to produce a good sound which brings good motor performance, that is, the movement is

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the major target of the training. Therefore, it can be said that our approach and musical training are two sides of a coin.

3. APPLICATIONS OF AUDITORY FEEDBACK

The proposed idea is potentially applicable to many practical problems. The followings are some examples.

3.1 Comparing one's own movement to model movement

It would be convenient if we can compare the movements of different players by comparing the sounds generated by their movements.

An example is to assist a beginner of classic ballet to learn his/her body posture and movement. The beginner should master the basic static forms in classic ballet, but it is generally difficult for the beginners to understand the accurate static forms. In this case, the beginner dancer can recognize the difference between his/her own posture and that of a professional ballet dancer by comparing his/her sound and target sound. This merit can be also applied to sports and any other skills to use various tools (from cocking tools to mechanical tools).

3.2 Improving one's own movement by trial and error

People can utilize the auditory feedback for trial-and-error learning of motor skills. In the process of trial-and-error learning, one might happen to make a good performance by chance, but it is difficult to perceive and memorize the movement of this good trial only with the somatosensory information. However, if the sound information is provided at the trial, one can consciously perceive the movement pattern and get a strong clue to replicate this movement.

3.3 Synchronizing movements of two or more players

Moreover, this system can be applied to the case that two or more people should synchronize their movements. Comparing the sounds (i.e., pitch and rhythm) from their body movements, they can perceive whether their movements are synchronized or not and whether their postures are identical or not.

4. AN IMPLEMENTATION

There are many possible implementations of our proposal. As a simplest implementation, we developed a small device shown in Fig.1. This system consists of an acceleration sensor, a microcomputer, an audio amplifier, a loudspeaker and a battery (see Fig.2). Its size is 5 cm x 5 cm x 4 cm. Though it may be rather large as a truly wearable device, the size can be easily reduced using today's industrial implementation technologies.

Figure 2 shows a block diagram of the signal processing in this device. The acceleration signal is sampled by an AD converter at every 10 ms (i.e., sampling frequency is 100 Hz) and used to modulated the sound pitch, where the acceleration values is smoothed by averaging the 10 samples. To be more specific, the interval of successive

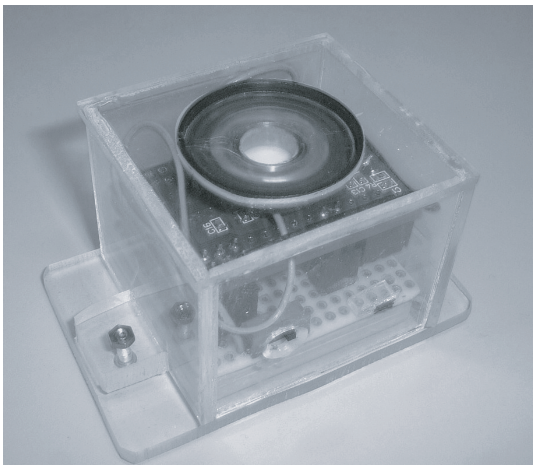

Fig. 1 A sample implementation

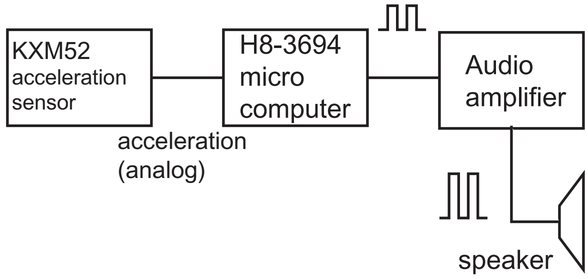

Fig. 2 Block diagram of a simple device

pulses of a square wave is determined by the acceleration value, which enables the immediate reflection of the acceleration to the sound pitch (that is, the delay is shorter than 10 ms). This short response feature is very important to our purpose because only a slight delay gives the users incongruous feeling. The sound pitch is determined so that the logarithm of the pitch is proportional to the magnitude of acceleration.

5. EXPERIMENT

We carried out some preparatory experiments to examine how real-time auditory feedback can assist the motor learning.

5.1 Method

We ran a simple experiment using the device introduced in the previous section. Four subjects participated in this experiment. In this experiment, an experimenter first wore the device on his forearm and made an elbow joint movement (i.e., flexion and extension) within a vertical plane (which will be called a "target movement") and the sound generated by the device was recorded as a "target sound". Then, each subject tried to move his joint so that his sound agreed with the target sound. That is, the task was to generate the elbow joint movement which produced sound similar to the target sound. The start of the movement was specified by the experimenter.

The joint movement was also measured by a 3D position sensing system (Optotrak3020). Three IR markers were attached to the device, the wrist, the elbow and upperarm and the elbow joint angles were estimated from the positions of IR markers.

The experiment had two blocks: visual feedback block and no visual feedback block. In a visual feedback block, subjects could see the arm movement during the experiment while in a no visual feedback block they could not see the arm movement. The order of these two types of blocks was counterbalanced among the subjects.

An experimental session consisted of a practice phase and a test phase. In a practice phase, the subject listened to the target sound, and then moved his joint with the auditory feedback. Therefore, the subject could perceive his own movement by the sound in the practice phase. In a test phase, to the contrary, no target sound was provided and the subject moved his joint without the auditory feedback. That is, he should perform the movement by himself, without relying on the auditory feedback.

The practice phase had 20 trials. We divided this phase into four sub-phases (phase 1 to phase 4) each which had 5 trials. On the other hand, the test phase had three trials.

5.2 Result

Figure 3 shows that the movement trajectory in the practice phase of one subject (Subj. D). The upper and lower panels show the trajectories of five trials in the first and fourth sub-phases (thin curves), respectively, together with the target trajectory (a thick curve). We can see some characteristic tendency from this figure. First, the timings of the major epochs (i.e., start, end and inflection) of the subject movement well agreed with those of the target movement, though the absolute angle at these epochs did not agree. This good agreement of the movement timing was observed in both the first and fourth phases, suggesting that people can easily obtain the timing of the movement epochs from the early phase of training.

Second, the movement in the fourth phase was closer to the target movement compared to the first phase. Moreover, variance of the trajectories in the fourth phase was much smaller than in the first phase. This shows that the subject movement was surely improved by the practice with the auditory feedback. To be more specific, the subject movement got closer to the target movement together with getting more stable.

In order to examine the stability of the movement in a quantitative manner, we calculated the standard deviation (SD) of the joint angle at each time step, and averaged it over the movement time. Figure 4 shows this average SD in four sub-phases in the practice phase. The upper and lower panels shows the results for two different target movements. in . Although there are some inter-subject differences, we can see a trend that the variance decreased with the phase.

Finally, Figure 5 shows the joint trajectory of three trials in the test phase of one subject, together with the target trajectory. The overall shapes of the subjectfs trajectories are similar to the target trajectory. However, the stability and the accuracy of the trajectory is apparently degraded compared to the fourth sub-phase in the practice phase (see the lower panel of Fig. 3).

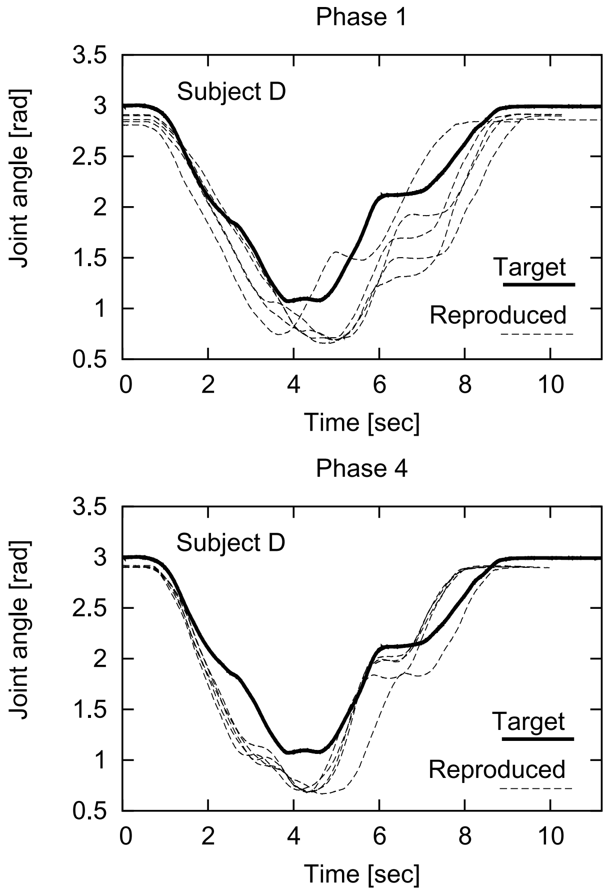

Fig. 3 Joint trajectories of the practice phase

Therefore, it can be said that the subjects acquired the target movement through the practice with auditory feedback, but they failed to reproduce the movement by themselves, in other words, without the on-line auditory feedback. However, this result does not necessarily deny the possibility that people can reproduce the movement without the on-line auditory feedback. It shows that after 20-times practice, the subjects reproduce the target movement superior with the on-line auditory feedback.

6. CONCLUDING REMARKS

In this paper, we have described the possibility of the auditory feedback as a novel clue to motor skill learning and showed the result of an experiment to examine its effectiveness using a simple "audializing" device.

The results of the experiment supported that sound clue and auditory feedback is useful for perceiving the timing (or rhythm) of the body movement.

One future topic is how we represent more complex movements via a sound. In the present experiment, we picked up the flexion and extension movement of a single joint, where the movement was easily associated with the change in sound pitch because the variable is a single joint angle.

However, our daily movement is achieved by combinations of movements of many joints and links. In order

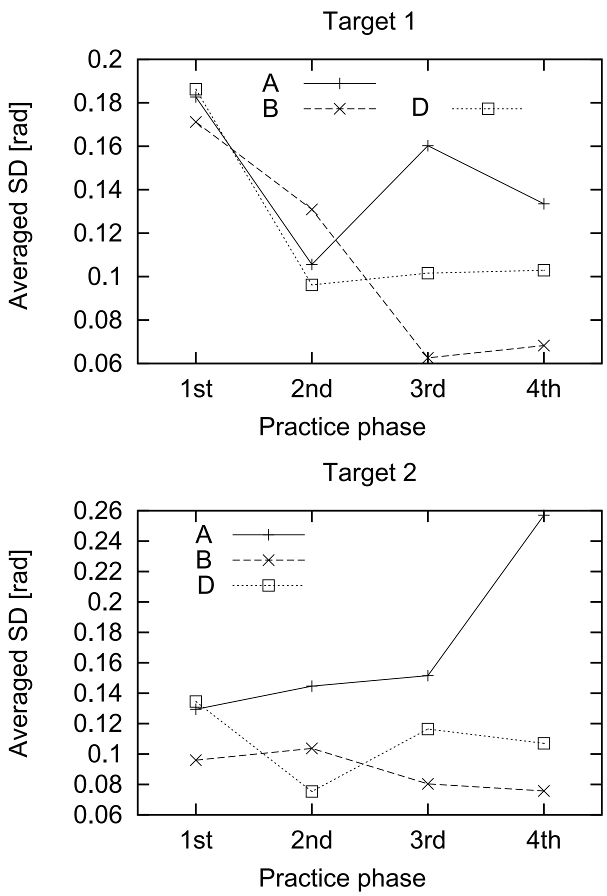

Fig. 4 Averaged SD of joint trajectories

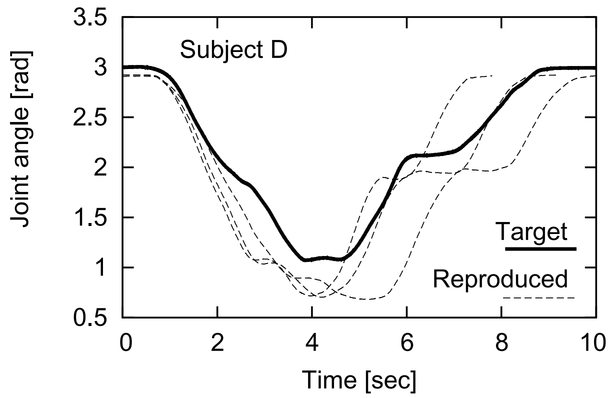

Fig. 5 Joint trajectory in the test phase

to "audialize" such complex movements, we have to code many variables in the sound.

One possible solution to this problem is to attach the sensor devices to every part of the body and to generate a complex sound reflecting the all information. Though this idea may seem unrealistic, we cannot necessarily deny this possibility because people can discriminate many different voices generated by different persons (and the voice is generated by the combination of many muscles in our articulation system). A second solution is to extract an essential movement parameter (such as center of the gravity) from the complex movement and to generate the sound reflecting such important variables. Of course, we have to investigate what parameters are essentials for a given motor skill.

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