

Improving Running Mechanics by Use of Interactive Sonification

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ABSTRACT

Running technique has a large effect on running economy in terms of consumed amount of oxygen. Changing the natural running technique, though, is a difficult task. In this paper, a method based on sonification is presented, that will assist the runner in obtaining a more efficient running style. The system is based on an accelerometer sending data to a mobile phone. Thus the system is non-obtrusive and possible to use in the everyday training. Specifically, the feedback given is based on the runner's vertical displacement of the center of mass. As this is the main source of energy expenditure during running, it is conjectured that a reduced vertical displacement should improve running economy.

1. INTRODUCTION

When training to optimize a technique in sports, it is important to receive appropriate feedback on the performed action. Generally, feedback to the brain travels internally through the proprioceptive and vestibular system and externally via our five senses. There are two main categories of feedback – feedback of result (KR) and feedback of performance (KP) [1]. Feedback of result is the most common in sports, simply since it is more straight-forward. For example, a long-jumper can simply measure how far he or she jumped in order to assess the trial. A weight lifter knows how much weight is on the bar and can thus judge the success of the lift accordingly. Feedback of performance on the other hand is based on *how* the result was achieved. For example, a sprinter may want to work on a specific technical detail of the running-cycle such as the height of the knee-lift. In such a situation, he or she does not worry too much about the final result (the speed of the sprint) but more on the technique. By providing live feedback about the technical detail, the athlete then has a chance to immediately adjust the technique in order to comply with the target technique. In almost all sport-like situations, such feedback must be given through means of auditive or haptic feedback. The reason for this is the difficulty in watching and interpreting data visually during a trial. Practically, auditory feedback via sonification is the most appealing approach since sound provides a much richer “vocabulary” than haptics.

Feedback in sports is generally based on the following main categories of parameters:

Physiological parameters. In endurance sports it can be interesting to monitor heart-rate, ventilation and blood-lactate during exercise.

Kinematic parameters. This involves measuring how the athlete moves during the exercise. For example, joint-angles and

accelerations of certain limbs can reveal important cues. This is generally measured by inertial sensors, such as accelerometers and gyroscopes. It can also be interesting to measure the overall motion of the athlete which can be done by for example GPS. This is of particular interest in team-sports, where game strategies can be evaluated in real-time by analyzing the players' position on the field.

Kinetic parameters. Many times it is interesting to measure the forces leading up to, or resulting from, a certain action. For example strain-gauges and force-sensitive resistors (FSR) are frequently used for this purpose. Also, electromyography can be used in order to estimate the internal forces in the athlete's individual muscles.

In order for a sonification system to be useful to the athlete, the sensor-data must be converted into sound that makes sense to the athlete. In this work we will select a rather simple and straight forward technical parameter - mechanical cost of running - and evaluate how important the sonification-schema is in order to enhance learning. The sonification schema will be evaluated based on measuring the distance between a target technique and the technique actually obtained.

2. RUNNING ECONOMY AND FEEDBACK

Running economy is a measure on how efficient a person runs. It is usually assessed by measuring the amount of oxygen required by a person in order to maintain a sub-maximal velocity at steady-state. This is generally referred to as the metabolic cost. The metabolic cost has shown to correlate very well with running performance [e.g. 2, 3]. There are reasons to believe that the metabolic cost is strongly related to the mechanical cost the athlete has to pay in order to move forward [4] [5]. This mechanical cost is primarily due to the work the runner has to do against gravity during each step. Thus, by reducing the height that the runner moves his or her center of gravity, the mechanical cost and, probably, the metabolic cost is reduced. This is supported by the results reported by Heise and Martin [4] who found a negative correlation between vertical force impulse and running economy. Another factor affecting the mechanical cost is the step-frequency. With a high step-frequency, the runner needs to overcome the work against gravity a larger number of times than with a low frequency. Thus, the mechanical work can be estimated by the average vertical displacement of the runner's center of gravity multiplied by the number of steps taken during the run. This means that a runner could reduce the mechanical cost by adjusting these two parameters. In order to accomplish this, we have developed a feedback platform that allows the runner to monitor step-frequency and vertical displacement in real-time

when running. As the platform is wireless and implemented on a mobile phone, it is possible to use it on a treadmill as well as during over-ground running. By setting target values and providing feedback about the difference between the target and the achieved running-style, it is possible for the runner to continuously alter the running-pattern according to the feedback. The intention of the platform is to serve as a test-bed for different sound-models that can be used to represent the feedback parameters. Inherently, designing a functional sonification schema for enhancing learning of motor tasks involves a number of critical issues such as the frequency and delay of the feedback [6-7]. It has been shown, for example, that the optimal frequency of feedback depends on the complexity of the skill that is to be (re)learned [8]. A simple skill requires less frequent feedback than a complex skill. However, the distinction when a skill becomes complex is somewhat debated upon. Thus, the platform presented in this paper will serve as an asset in optimizing the feedback design and, consequently, the sound model.

The mechanical model that is used to estimate mechanical cost of running adds another dimension of complexity to the feedback-design, as one parameter concerns the *rhythm* of motion (the step-frequency) and the other parameter (vertical displacement) concerns the *magnitude* of motion. When designing a sound-model for running mechanics it must be taken into consideration that it is inherently more difficult to make temporal (rhythmical) adaptations than spatial. This follows from the isochrony principle that has shown to be applicable for various sport skills [9-10].

3. SYSTEM DESIGN

The system consists of four main components, as shown in Fig. 1. These are the sensor module, the communication module, the data-processing module and the feedback module. The sensor module is merely an off-the-shelf unit (Sparkfun Inc.) combining a 3-axis accelerometer and a 3-axis gyro with a Bluetooth chip. The sensor is to be attached to the sacrum of the runner in order to estimate the vertical oscillations (see data-processing unit below). The sensor module streams acceleration data at 92 Hz to a mobile phone, on which the communication module, the data-processing module and the feedback module reside. These modules were all implemented using Java ME.

The *communication module* is responsible for receiving data from multiple sensor-nodes. In the work presented here, only one sensor-node is used. This means that the communication module only has to receive data from the sensor-node and forward it to the data-processing module.

The *data-processing module* is (in this work) responsible for converting accelerometer data into vertical displacement and step-frequency. This is done by estimating the average orientation of the sensor by low-pass filtering the accelerations of each axis with a cut-off frequency of 0.5 Hz, which means that the average values over approximately the past six steps is used. Given this estimated global reference frame, the data is then projected onto the global vertical axis and high-pass filtered in order to remove the DC component due to gravity. Finally, the acceleration along the vertical axis is double-integrated in order to obtain position values. Note that this does not yield absolute position, but merely the oscillations around the mean, which is what is required for this application. Vertical displacement was then computed by locating the peaks and valleys in the position curve. As the sampling frequency is

known, the step-frequency automatically falls out. This method to compute vertical displacement has been validated against a motion capture system [11].

Feedback-module. In order to convert vertical displacement and step frequency into sound, a special module was implemented. The complexity of this module strongly depends on the platform it is implemented on. In this work, a Sony Ericsson 650i was used. This phone has very limited possibilities of sound synthesis. In order to implement a non-trivial sound-model, the sound must be pre-recorded using a stand-alone synthesizer. The sound can then be played on the phone as a ".wav"-file. However, it is possible to have the phone play a given tone for a given period of time, making it possible to, for example, serve as a metronome. It is also a good platform for implementing verbalized feedback, as prerecorded instructions can be used.

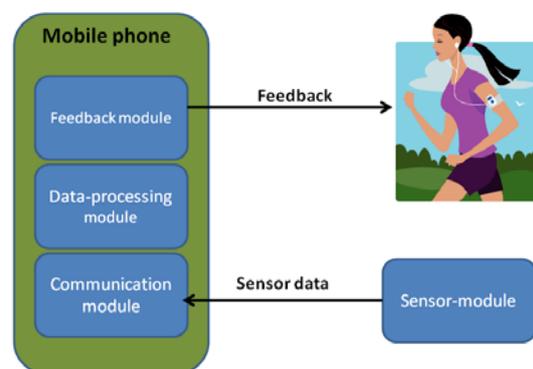


Figure 1. Block diagram of the modules of the platform. The wireless sensor module sends data to the processor (a mobile phone in this work). The communication module handles low-level protocol details and sends the data to the data-processing module. Finally, the extracted data is processed by the feedback module in order to generate an auditory display to the user.



Figure 2. The sensor (left image) used in this experiment. It is a 6DOF (Sparkfun Inc.) inertial measurement unit with Bluetooth antenna. The telephone (Sony Ericsson 650i) received the data via Bluetooth, computed vertical displacement and step frequency and presents the information visually (right image) and via an auditory display.



Figure 3. The system worn by a runner. The sensor is securely attached to a belt. In this case, the user has an earphone attached to the phone via cable. Of course, a bluetooth headset would work as well. As there is no cable between the sensor and the phone, the user does not need to carry the phone when the running takes place on a treadmill.

4. SOUND MODEL

The feedback module is responsible for providing the components required to convert the sensor data into sound as imposed by the sound model. The focus of the work with this platform has been to maintain an open architecture that is able to adapt to new sensors and new sound models quite swiftly. As the processing power of the mobile telephone we have used is rather limited, the sound cannot be synthesized in real-time, except for pitch and duration of sine-waves. In order to circumvent this problem, the feedback module consists of a number of pre-generated wav-files that are played depending on the sensor-data. Examples of sound-models that we have tried, but not evaluated on a real runner, are short “snippets” of sound imitating wind. The less efficient the running mechanics is the higher frequencies are let through the band-pass of the wind-generating model. Another parameter to elaborate with is of course also the sound level of the sound. This approach gives the runner a “feeling” for running into a headwind when the technique is bad. Another obvious model is to generate a metronome indicating the target step-frequency of the runner. The interesting problem following this scheme is how to generate feedback about the *actually obtained* step frequency. Another more straight-forward model is to use a warning signal when the technique is “bad”. In order to make this approach intuitive to the runner is to simulate a “bouncing ball” sound when the vertical displacement is too big. This signal could be issued after every step that has a vertical displacement above a certain threshold. It could also be issued when the average displacement over a certain amount of steps has been inefficient in terms of vertical displacement. With this “warning-signal” approach there is no need to use pre-recorded sound-files as the tone generator in most mobile phones can handle this.

5. DEMONSTRATOR

In this project, the aim was to use the abovementioned platform to implement a simple sonification schema, facilitating for a runner to improve running mechanics according to a simplistic mechanical model.

In order to evaluate the functionality of the system, one volunteer male runner was asked to perform five trials on a treadmill. The test person was well familiar with treadmill running. After a five-minute warm-up, a base-line measure was performed in order to assess the runner’s natural vertical displacement. The base-line trial was performed at a self-selected pace (11 km·h⁻¹ for this runner). After the baseline measurement, the runner was briefly informed about the relation between mechanical cost of running and vertical displacement. The second trial was performed at the same speed as during the base-line trial – this time with real-time feedback about the magnitude of the vertical displacement. The runner was given two different target-levels of the vertical displacement that he was requested to stay below. The levels were set at 90 and 80 percent of the baseline measurement respectively. The following two different feedback modalities were tested:

1. A warning sound directly after each step where the vertical displacement was above the target level. The sound was intended to associate to the bouncing sound of a ball, which in turn should generate the feeling of being “too heavy”.
2. A warning sound indicating that the *average* vertical displacement computed over the last eight steps exceeded the target level. This sound was designed similar to the bouncing sound in (1) but with a long fade-away period.

Each trial was evaluated on how well the runner could comply with the preset levels of vertical displacement. The average error and standard deviation during each trial was computed. The vertical displacements of each step in each trial are shown in fig.1 and 2 below. Fig. 4 shows the results when feedback was generated as a warning signal after each inefficient step. The graph shows the vertical displacement of the baseline trial and the two controlled trials (90%, 80%) respectively.

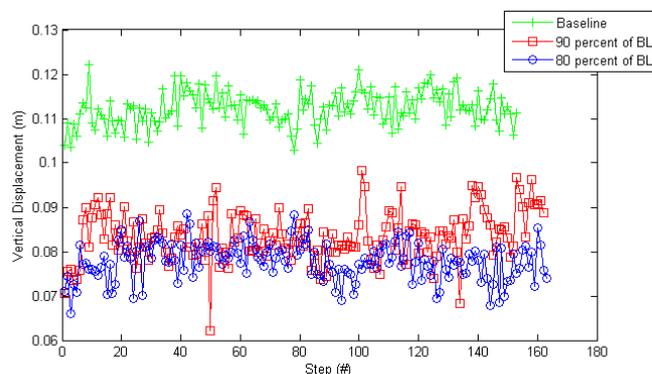


Figure 4. The top curve with +-signs at each vertex indicates the vertical displacement of each step during the baseline trial. The squared curve indicates the result with a target level of 90 percent of the average baseline step. The curve with circles shows the result of a target level of 80 percent.

Fig. 5 shows the same data when the feedback was given at every four-second interval based on the average of the last eight steps. The average vertical displacement of the baseline trial was 0.112m. Thus, the target levels for the controlled trials were set at 0.101m and 0.090m respectively. The average obtained vertical displacements during the first feedback modality were 0.084m and 0.078m respectively. During the

second feedback modality the runner obtained average vertical displacements of 0.088m and 0.080m respectively. Note the number of steps during each one-minute trial increased when the running posture was controlled. Previous unpublished studies that we have conducted have actually shown that a reduction in vertical displacement almost always causes an increased step-frequency.

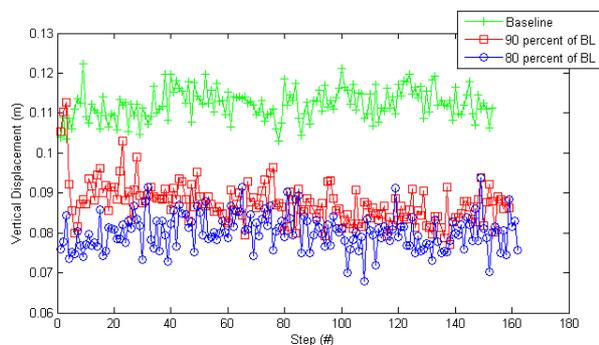


Figure 5. Results from feedback given once each four-second interval. Again, the topmost curve shows the vertical displacement of the baseline-trial. The squared curve show the vertical displacement with a target level of 90 percent and the curve with circles at each vertex show the results from a target level of 80 percent.

6. CONCLUSIONS

This pilot study shows that we have successfully developed a non-obtrusive portable system for improving running posture based on feedback from a mobile telephone. One test person could successfully adapt the running mechanics based on a very simple sound model. From one test person it is of course impossible to draw any conclusion about the behavior of the population at large. However, we have laid the foundation for further studies in this area. The most interesting step ahead is how we can improve and evaluate the sound models.

7. ACKNOWLEDGMENTS

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8. REFERENCES

- [1] Schmidt, R. and Lee, T., *Motor control and learning*. 4 ed. 2005: Human Kinetics.
- [2] Conley, D.L. and G.S. Krahenbuhl, *Running economy and distance running performance of highly trained athletes*. *Medicine and Science in Sports and Exercise*, 1980. **12**(5): p. 357-360.
- [3] Di Prampero, P.E., et al., *Energetics of best performances in middle-distance running*. *Journal of Applied Physiology*, 1993. **74**(5): p. 2318-2324.
- [4] Heise, G.D. and P.E. Martin, *Are variations in running economy in humans associated with ground reaction force characteristics?* *European Journal of Applied Physiology*, 2001. **84**(5): p. 438-442.
- [5] Williams, K.R. and P.R. Cavanagh, *A model for the calculation of mechanical power during distance running*. *Journal of Biomechanics*, 1983. **16**(2): p. 115-128.
- [6] Magill, R., *The influence of augmented feedback on skill learning depends on characteristics of the skill and the learner*. *QUEST*, 1994. **46**: p. 314-327.
- [7] Salmoni, A.W., R.A. Schmidt, and C.B. Walter, *Knowledge of Results and Motor Learning: A Review and Critical Reappraisal*. *Psychological Bulletin*, 1984. **95**(3): p. 355-386.
- [8] Wulf, G. and C.H. Shea, *Principles derived from the study of simple skills do not generalize to complex skill learning*. *Psychonomic Bulletin & Review*, 2002. **9**(2): p. 185-211.
- [9] Delay, D., et al., *Movement control in golf putting*. *Human Movement Science*, 1997. **16**(5): p. 597-619.
- [10] Hay, L. and P. Schoebel, *Spatio-temporal invariants in hurdle racing patterns*. *Human Movement Science*, 1990. **9**(1): p. 37-54.
- [11] Gullstrand, L., et al., *Measurements of vertical displacement in running, a methodological comparison*. *Gait and Posture*, 2009. **30**(1): p. 71-75.