

# Rhythmic Sonic Feedback for Speed Skating by Real-Time Movement Synchronization

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## Abstract

A unique problem associated with the movements of a speed skating athlete inspired this practical work, looking into the question of using interactive auditory feedback to improve sporting movements and sporting movement acquisition. Presented here is a method for synchronizing the periodic movements of a subject against the movements of a model and sonifying that synchronization data in real-time. The sonic feedback is designed to convey information related to how the movements of a subject match against those of a model. A simple, inexpensive sensor system is created to capture speed skating movements and facilitate the sonification. The effectiveness of the system is demonstrated with two case studies. The first case study involves an experienced skater who had developed a significant anomaly in his technique, who uses this system to become aware of and correct his undesired movements. The second case study involves a new and inexperienced speed skating athlete who accelerates the acquisition of speed skating skills by listening and reacting to the relationship between his movements and those of a skilled speed skating athlete. While speed skating is used to demonstrate this sonic feedback technique, the algorithms can be applied to any repetitive movements.

**KEYWORDS:** SONIFICATION, MOTION ANALYSIS, AUDITORY FEEDBACK, AUGMENTED REALITY

## Introduction

Walking, running and skating are all examples of repetitive movements. In therapeutic, sporting and everyday settings people attempt to refine, improve and correct these types of movements. The kinematics associated with a repetitive movement is periodic and so measurements of these movements lead to periodic waveforms (Figure 1). We can compare periodic waveforms to measure how closely they match. A comparison of waveforms produced from measurements of two people performing a repetitive movement will give an indication of how closely the movements of those people match.

We present here a signal processing technique to compare and synchronize relative data taken from multiple people performing a repetitive movement. We use the synchronization data to form the basis of real-time interactive sonic feedback. The sonic feedback comes in a discretized format synchronized to periodic movements. In addition, we show how the comparison information can be used to identify key windows when corrective or instructive sonic feedback can be provided, coaxing or correcting certain behaviors.

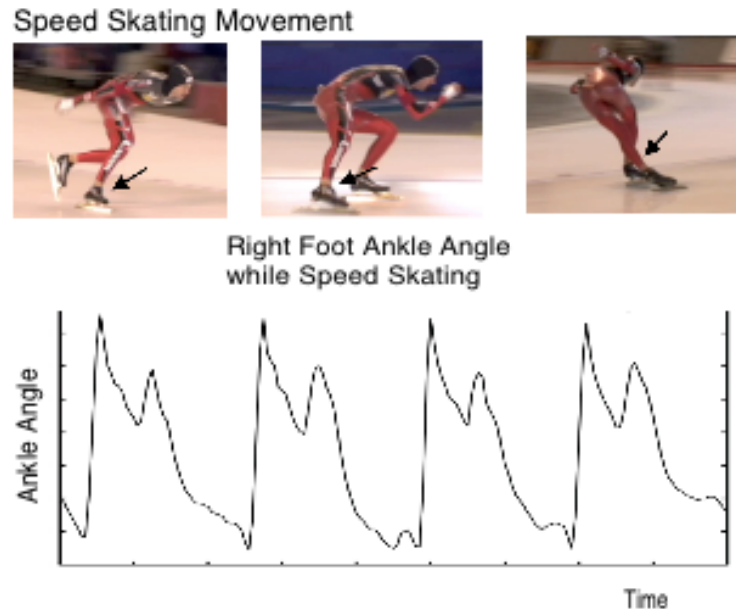


Figure 1. Measuring repetitive motions, produces periodic waveforms.

Our methods are unique in that we create a rhythmic sonic feedback by synchronizing two signals in real-time. We can communicate corrective information regarding a specific movement with little specific knowledge about that movement. The system we demonstrate requires little calibration and makes use of relative data, allowing for simple and cost effective sensors to be employed.

We demonstrate the methods with an economical, custom built sensor system designed to track speed skating movements. We synchronize the movements of a model skater to those of a subject skater in real-time and broadcast rhythmic sonic feedback synchronized to the periodic movements. The sonic feedback is designed to elicit in the subject skater the behaviour of the model skater.

We present results from use of the system on two specific speed skating subjects. Our first subject, hereafter referred to as Subject A, displays a particular anomaly in his stride. We are able to synchronize his movements to our model and use that information to identify the anomaly and broadcast corrective feedback to help him ameliorate his stride. Our second subject, hereafter referred to as Subject B, is new to speed skating and lacks the fluid and relaxed movements of an established skater. We use our system to synchronize his movements to our model, creating a feedback that describes the differences between he and the model.

The following three important aspects of our method should be noted.

- We do not require absolute measurements of pose (joint angles and body positions). This reduces the cost and complexity of sensor systems.
- We show that relative data from two repetitive motions is sufficient to synchronize them. While we demonstrate this with speed skating, it can be applied to any repetitive motions.

- We give a framework for how to provide sonic (or other) feedback synchronized to a periodic motion.

### **Relative Data**

A measurement system that can consistently reproduce a measurement under identical conditions is said to be precise, while a sensor that produces a measurement that closely matches the true value is said to be accurate. A measurement that may not be accurate but is precise within a single session we call a relative measurement. Relative measurements preserve the shape of a signal but not the absolute value or scale. Our methods require only signal shape to be preserved and as such relative measurements are sufficient.

### **Background**

We became aware of a speed skating athlete, Subject A, who was previously a national calibre speed skating athlete, but after developing an anomaly in his stride was struggling in the sport. This athlete repeatedly made the same error during the same part of the speed skating cross-over stride. Although rare, instances in which an athlete struggles performing a previously known movement is called *Lost Move Syndrome* (Day et al., 2006). While we were investigating synchronization and sonification, the unique opportunity posed by this skater provided motivation for our work.

### **Speed Skating**

Subject A, displayed his erroneous movements only while executing a speed skating cross-over stride. As such we'll focus specifically on that repetitive periodic movement in this paper. Figure 2 shows a plot of right ankle angle versus time in a cross-over from our model skater. The plot is divided into the three components that make up a cross-over.

- **Right Foot Pushing:** the skate is in contact with the ice as the skater pushes (Figure 2 - A),
- **Right Foot in Air:** the skater lifts his skate off the ice and moves it across the left skate (Figure 2 - B), and
- **Right Foot Prepares to Push:** the skate blade contacts the ice (the set-down) as the skater prepares to push again (Figure 2 - C).

Efficient cross-overs are critical to achieve top performance in speed skating and ankle angle is an important factor in determining the amount of pressure being applied into the ice and subsequently the speed being generated by a skater (Jun et al., 2007).

Figure 3 illustrates the problem associated with the cross-over of Subject A. Described briefly, he plantar flexes immediately before putting his skate onto the ice during Component B of a cross-over. While plantar flexion is a desired movement in certain portions of the speed skating cross-over movement, Subject A is plantar flexing at a time in the stride that causes his skate blade to dig into the ice. This results in instability, loss of speed and risk of crashing. His problem persisted for 14 months and he was unable to correct his problem using traditional coaching methods. During those 14 months our subject describes that he was unable to perform any cross-over strides in a correct manner. Moreover he describes that in each instance he feels surprised when his toe digs into the ice, he perceives that his foot is in a proper

position to execute a correct cross-over.

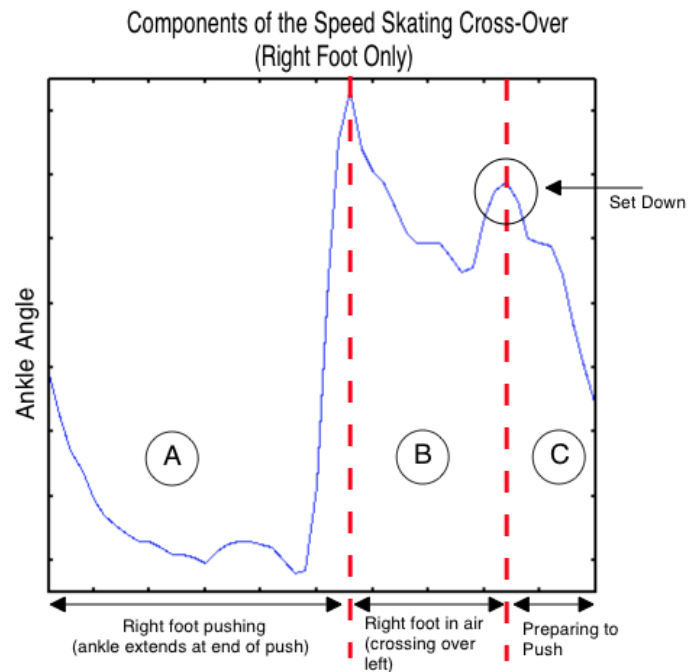


Figure 2. The Speed Skating Cross-over – Ankle angle versus time.

We detail another speed skating subject later in this paper. But it was Subject A who inspired and motivated many of our methods and decisions. Our methods have application on repetitive movements in general but our system was tailored to work with this special case.



Figure 3. Consecutive frames in video of Subject A during Component B of a cross-over. The skate blade is highlighted to show the open clap skate upon set down.

### **Sound in Sport**

We focused on sound as our communication medium, sound has the potential to integrate in a non-distracting manner for an athlete that is taxing their visual, tactile and balancing senses. Naturally occurring sounds like a skate blade gliding on ice or a golf club impacting a ball are

common in sport and can influence an athlete (Roberts et al., 2005). In recent years we have seen numerous instances of sporting data being sonified to provide additional information to athletes and coaches. Running pace (Hockman et al., 2009), rowing boat velocity (Schaffert et al., 2009; Schaffert and Mattes, 2011) and karate movements (Takahata et al., 2004) have all been electronically analyzed and used to control or create a sound that is communicated back to the athlete. The ability of a subject to mimic the jumping height of another subject using sonified jumping data (Effenberg, 2005) shows the potential for sound as a teaching tool. Especially for repetitive motions like walking, music and sound have successfully been employed in therapeutic ways for Parkinson's and Tourette's patients (Sacks, 2007). Sonifying the differences between an optimal movement and a subject's movement have been shown to increase abilities with complex motor tasks like shooting (Mononen, 2007; Kontinen et al., 2004).

As noted by Sigrist et al. (2011), when comparing augmented auditory feedback during a rowing task against augmented visual feedback, auditory feedback has the potential to be less distracting but also more powerful as a learning tool. This seems especially true for tasks

related to movement timing (Doody et al., 1985). Staying within the speed skating domain in a recent study by Stienstra et al. (2011), the recordings from sensors attached to a subject's skates were mapped to sound characteristics like sound intensity. This informed the athletes in real-time of quantitative data such as skate orientation, speed and force. Loud or intense sounds were mapped to data relating to powerful speed skating strides and in this way athletes could augment their perception of how much power they were generating in each stride, with what was actually happening.

Humans quickly learn and predict sounds and rhythms. This predictive nature of our brains is often exploited by musicians allowing them to change patterns and create melodies that we perceive as surprising or interesting (Levitin, 2006). While the music world has been exploiting the pattern matching and predictive nature of our brains, the sporting world has lagged behind in taking advantage of our sonic entrainment. We are cautioned however, that as musical complexity increases, our abilities to synchronize to those complex sounds is strained (Chen et al., 2006). We are striving to use simple sounds that allow us to take advantage of both human entrainment and the predictive nature of our brain to teach and correct sporting movements. Sonifying the synchronization of two athletes is what sets our work apart. We do not convert physical data related to one person into sound, we convert the relationship between the movements of two people into sound, thus allowing one athlete to experience and explore that relationship in an interactive auditory-based manner.

## System Description

This section describes the system we created to measure ankle movements of our speed skating subjects along with descriptions of both our synchronization methods and sound generation algorithms.

### *Apparatus*

We use a single variable-resistance elastic, depicted in Figure 4, attached between the toe and shin of a skater to continuously measure ankle angle. As the athlete skates, a netbook computer carried in a backpack measures the elastic's resistance,  $R_s$ , at 30 Hz. The plot in Figure 2 was obtained from this apparatus. At less than \$500, the cost of our entire system is only a fraction of what other options like video based motion capture or motion capture suits cost. The

simplicity of the system and little requirements for calibration or time consuming manual body measurements make this system practical for use with real athletes in the sporting environment.

### **Synchronization**

The most important aspect of our system, is its ability to accurately synchronize a subject's skating stride to that of our model's stride. The following is a description of our brute-force method to estimate the phase of a speed skating stride from a single sensor stream.

Let  $g$  be the model signal of  $n$  samples containing a single cycle of data from the sensor. If  $f$  is an  $n$ -sample segment from the on-line sensor data (we use the most recent  $n$  samples when synchronizing on-line in real-time), we can use a correlation (Gonzalez and Woods 2008) to compare  $f$  to the model signal,  $g$ , i.e.,

$$h = f \otimes g,$$

$$= \sum_{i=0}^{n-1} f(i)g(i)$$

The magnitude of  $h$  is a measure of how well  $f$  matches  $g$ . However,  $f$  is periodic, and there is no guarantee that the phase of  $f$  will match that of  $g$ , so we must consider the set of models given by  $g((i+s) \bmod n)$  where  $0 \leq s < n$  determines the phase shift of the model.

Now consider the correlation

$$h(s) = \sum_{i=0}^{n-1} f(i)g((i+s) \bmod n)$$

Therefore, phase,  $\phi$ , of  $f$  is

$$\phi = \frac{1}{n} \operatorname{argmax}_s h(s)$$

and  $\max_s h(s)$  indicates how well  $f$  matches the model. Note that  $0 \leq \phi < 1$ .

Now suppose that we know the shape of each cycle of the signal, but we do not know the frequency. In this case, we need a set of models,  $g_n$ , where the subscript  $n$  indicates the number of samples in  $g_n$ . Assuming constant sampling rates,  $n$ , being the number of samples in one full cycle, determines the period (and therefore the frequency) of the stride. The matching function becomes

$$h(s, n) = \sum_{i=0}^{n-1} f(i)g_n((i+s) \bmod n).$$

We can determine the correct period of the model,  $\hat{n}$  with  $\hat{n} = \operatorname{argmax}_n \max_s h(s, n)$ , and the phase with  $\phi = \frac{1}{\hat{n}} \operatorname{argmax}_s h(s, \hat{n})$ . The absolute measurements from the sensor vary with temperature, length of sensor, and where it is mounted on the toe and shin of the athlete. Given that we cannot control these factors, it is essential to *normalize*  $f$  and  $g$  with a linear transformation such that:

$$\sum_{i=0}^{n-1} g(i) = \sum_{i=0}^{n-1} f(i) = 0$$

$$\sum_{i=0}^{n-1} g(i)^2 = \sum_{i=0}^{n-1} f(i)^2 = 1$$

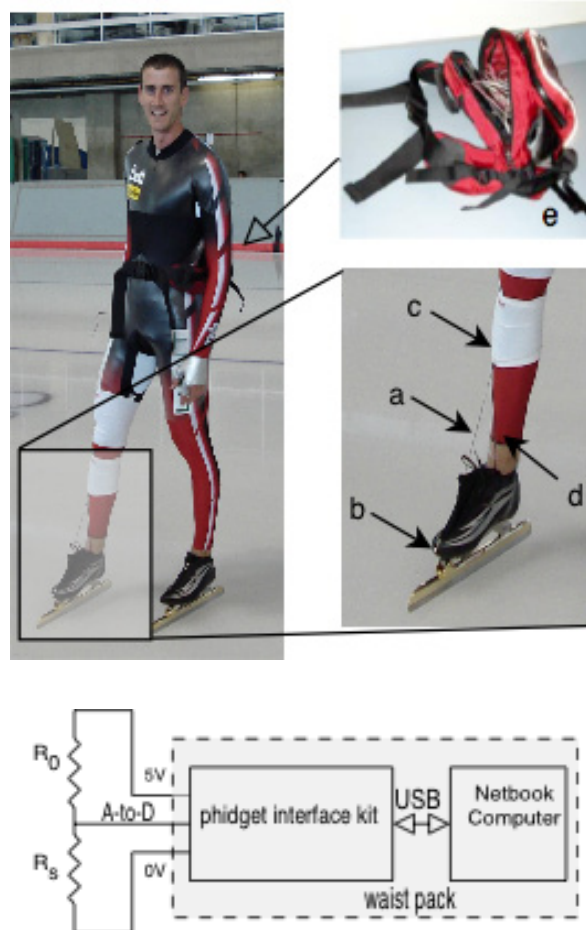


Figure 4. Top: The sensor installed on the model skater: The variable-resistance elastic (a) is connected between a skate lace near the toe (b) and an elastic joint-support band (c) (used only to fasten the sensor). In this configuration,  $R_s$  (and therefore the voltage measured by the interface kit) increases with ankle extension. Leads (d) connect the sensor to the phidget interface kit (<http://www.phidgets.com>) and netbook computer worn by the skater in a waist pack (e). Sound is broadcast using headphones (not shown). Bottom: The sensor circuit.

Note that a perfect match between skater and model yields  $h(s,n)=1$  when  $f$  and  $g$  are normalized this way. Computing the phase match for successive samples  $f$ , results in a ramping from  $\phi = 0$  to  $\phi = 1$ .

## Sonification

### *Rhythmic Arpeggio*

Once the phase is matched successfully the stride cycle can be sonified. We worked within the Pure Data (<http://puredata.info/>) environment to do the sonification. We take advantage of the rhythmic nature of a periodic movement and use that to control the cadence of musical notes we broadcast to a subject. Breaking the speed skating stride into four equally spaced sections, we mark milestones on the boundaries of these sections. We have milestones at:  $\phi = \{0.25, 0.5, 0.75, 1\}$ . We embed musical notes at these milestones, so that as the phase of the stride passes a milestone a musical note is broadcast. We select four sine tones from a C-major chord as the notes. The frequencies of the four tones are: 261.6 Hz, 329.6 Hz, 391.9 Hz, and 523.2 Hz. We assign each note to a corresponding phase milestone in order:

$$\phi = \begin{cases} 0.25 \rightarrow 261.6\text{hz} \\ 0.50 \rightarrow 329.6\text{hz} \\ 0.75 \rightarrow 391.9\text{hz} \\ 1.00 \rightarrow 523.2\text{hz} \end{cases}$$

The result is that as a subject performs the same movement as a recorded model an arpeggio of musical notes is broadcast. The arpeggio provides both an order and relationship for the information the subject is receiving, allowing him to determine not only which part of the model stride he is currently aligned with but also how long it took him to execute the movements associated with that phase as compared to the model. If the model and subject are perfectly synchronized then the subject will hear equally spaced musical notes, but if the subject slows or speeds up as compared to the model for a given phase window it will be reflected in the time between musical notes. As an example if a subject rushes through movements that fall in the phase window between phases,  $\phi = 0.25$  and  $\phi = 0.50$ , then he will hear musical notes that are closer together in time. The sine tones are improved for asthetic purposes, by adding an attack to the tone using an envelope.

### *Exploiting the Phase Information*

A reliable and accurate phase matching gives us the ability to focus on any part of the stride. We can use this synchronization to identify key phase windows when a subject is likely to perform an erroneous movement or omit a desired movement. The data need not come from the same sensor or body area that is being synchronized against but it is the phase matching from that sensor that allows us to know the phase of the subject. In the case of Subject A, we use this phase information to determine when he is in the key time period when he digs his toe into the ice, that time immediately preceding set-down.

Our system is designed such that the ankle sensor we used to synchronize with is also sufficient to monitor his ankle movements, specifically determining when he is plantar flexing. We use the phase information to tell us when he is in the problematic window of time and then consult the sensor to determine if we think he is exhibiting too much plantar flexion. We can then augment the rhythmic arpeggio feedback the subject is receiving with additional auditory feedback to help the subject correct his movement. Figure 5 shows a graphic representation of how phase information combined with ankle angle data is used to trigger corrective sawtooth tones. We employed three different training methods with Subject A, each making use of the phase matching and rhythmic arpeggio in combination with another auditory feedback.

## Methods

During this section we focus only on Subject A, we use our system to improve his skating. We outline three different ways we used our system to help Subject A. Subject A had the consistent problem of digging the toe of his skate blade into the ice. We worked with him for a period of two months with approximately two one hour training sessions per week. The athlete also conducted his regular training regime and competed in a number of competitions during this time. We aimed to have the athlete use the system for as long a continuous period as was practical during a session. Ultimately we determined that fitting as many 3 - 4 lap repetitions in the one hour ice time was the most practical training method. Four laps last approximately 2.5 minutes total.

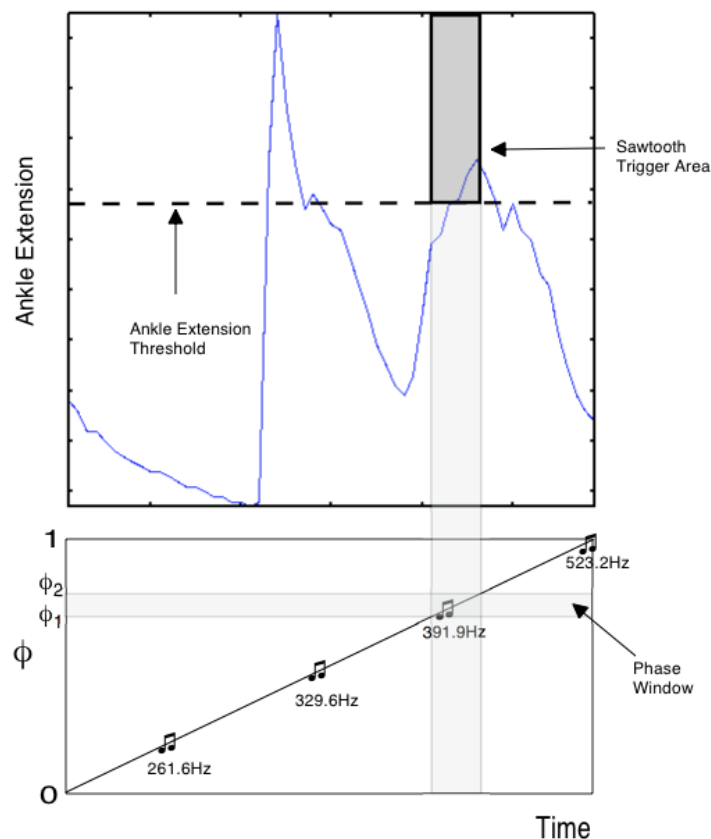


Figure 5. Phase is used to identify the window of time (highlighted rectangle) when we check if the subject is performing an incorrect movement.

We progressed through three main deployments of our system during the two months. We used our observations and feedback from the athlete to make necessary adjustments. Consistent throughout all our work with him, was the rhythmic arpeggio.

### **Corrective Feedback Training**

Corrective feedback is the name we give to the training set-up we described in the Sonification Section. In this training we synchronize the subject against a model producing the rhythmic

arpeggio but we use the synchronization and subsequent knowledge of the phase of the subject to identify the key window when the subject may plantar flex too much and thus dig his toe into the ice. During that key window we monitor the ankle sensor setting a threshold on the amount of plantar flexion we allow and broadcast a sawtooth tone if the threshold is surpassed. The sawtooth tone is scaled in intensity relative to the amount of plantar flexion measured. Figure 7 shows Subject A's skating stride before any training. Subject A was instructed to try to avoid making the sawtooth tone. We began with a modest threshold, slightly less ankle extension than what the subject was already doing. We gradually decreased the threshold allowing less and less ankle extension until we reached a level that would result in a correct cross-over.

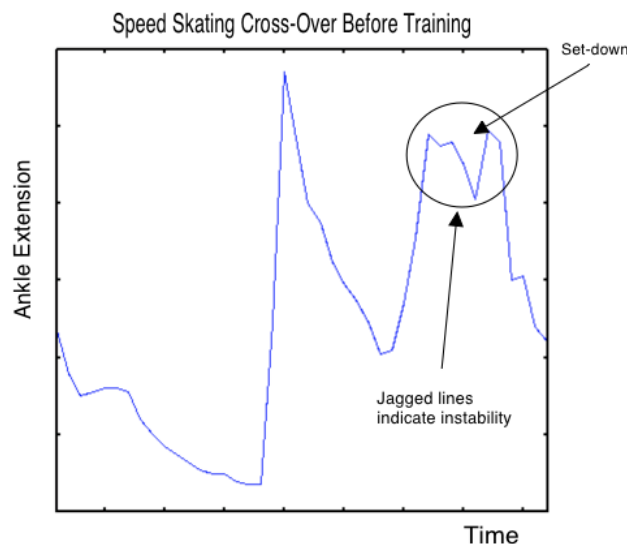


Figure 6: The skating stride of Subject A before training.

### **Awareness Feedback Training**

Awareness feedback training is the name we give to the training we did with Subject A that required him to spend as much time as possible in the key window of time before setting his skate back on the ice. This requires no alterations to the hardware or software that is used in the corrective feedback set-up described above. Here we exploit the system and its ability to remain synchronized to a signal even when the subject is purposely performing non-standard movements. We instruct our subject to purposely create the sawtooth tone during the period before he sets his skate onto the ice. More specifically, we instruct the subject to turn the sawtooth tone on and off as many times as possible before setting his foot back down. The system is robust enough to continue computing phases that are in the key window of time when we want to examine the ankle angle and thus each time the threshold is surpassed the sawtooth is broadcast, and upon ankle angles that retreat below the threshold the sawtooth disappears. We are using the system to create an awareness of the acceptable range of movements. The skater did not skate normally doing this, it was a modified skating stride that allowed him more time with his right skate in the air. The skater went slower and was more upright to allow for this additional movement.

### ***Instruction Based Training***

Instruction based training changes our system from reactive to proactive. Rather than giving feedback after the ankle extension exceeds a threshold, we provide a prompt telling the skater when we predict he should extend his foot to meet the ice. We try to manufacture the set-down point. The aim here is to not allow the athlete enough time to perform his incorrect movement. Instead we prompt the athlete to set-down before he has made the incorrect movement. There no longer is a corrective feedback aspect but rather we use the phase matching information to determine when we think the skater should try to set down his foot.

We produced a bell tone at what we thought was the appropriate moment to start setting the right foot on the ice. The skater was instructed to extend for the ice with his right skate each time he heard the bell. We did not want to allow the skater enough time to extend his ankle pointing his toe to the ice. With enough training the manufactured set-down point might become the athlete's natural movement.

### **Results**

#### ***General Results***

The system was successful at synchronizing the movements of different athletes. Each of Subject A and B received the same rhythmic arpeggio feedback based on the synchronization data. Prior to training with the system each subject displayed a discomfort with the cross-over movement. This discomfort manifest itself in a rushed and hurried movement. Our model skater typically executed a cross-over during a period of 1.5 seconds which in contrast, at similar speeds, our subjects executed the movement in 1.3 seconds. Our model was covering more distance per stride than each of the subjects. Almost immediately upon training with the system each subject modified their cadence to match that of the model. Figure 7 shows a plot of Subject B's skating stride, first the untrained stride and then the stride at the second training session. Although the athletes slowed their cadence, they maintained their skating speed by increasing the distance they covered per stride.

#### ***Discussion***

Each athlete displayed improvements relating to their stride rate within a few training sessions with the system. Given that Subject B was new to the sport, his improvements were not surprising. We were however surprised at the quick progress of Subject A. Subject A had problems with his cross-overs during a continuous 14 month span. During this time he repeatedly executed incorrect cross-overs and that incorrect movement became ingrained into his motor pattern. Knowing that the subject had tried many different possible solutions to this problem without success, we anticipated a slow improvement process.

Regarding Subject B, it is important to note that he was an accomplished athlete in other sports, but he was new to speed skating. We anticipated that he would improve quickly at speed skating regardless of the type of training he received. We were aiming to aid his comfort level on the ice and further accelerate his learning. His racing results improved with each race in a dramatic fashion, however it would be impossible to determine a measure of which training was responsible for his improvements.

We attribute the slowed and controlled movement to an increased comfort level afforded by the rhythmic arpeggio. The athletes were able to maintain their speed while slowing their cadence due to an increase in the duration of the pushing phase of the stride. They were

spending more time on the beneficial portions of the stride, applying the positive attributes of the model's timing to their own stride. In Figure 7, we see less erratic or jagged lines during component A of the cross-over when comparing the second plot to the first. This indicates a more efficient right foot push and thus increased generation of speed.

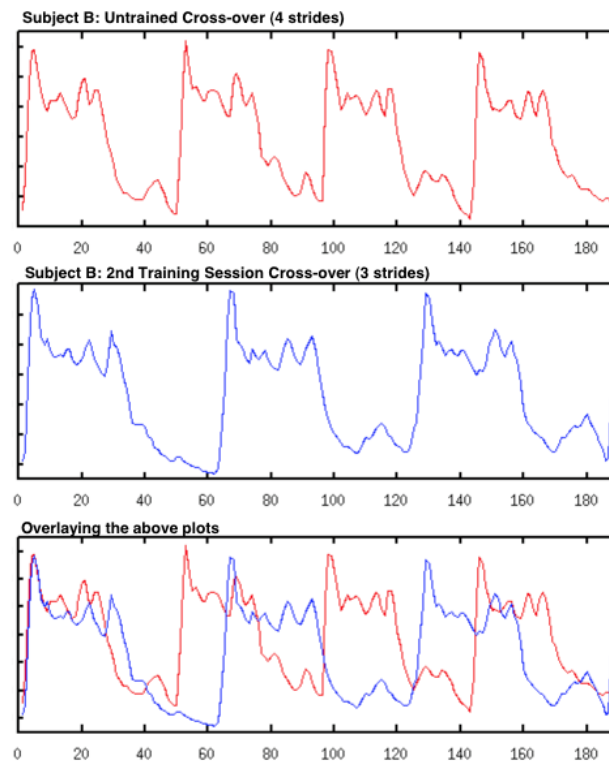


Figure 7. Evolution of Stride for Subject B.

### ***Specific Results Relating to Subject A***

The quick stride amelioration relating to the timing of the movements of Subject A, was not as evident with regards to his ankle angle problem. We trained the athlete with the three methods described changing the method if it became apparent that the training was not effective or if we determined it was not beyond what the subject had achieved with prior traditional training.

During Corrective Feedback Training, he did reduce the severity of the problem by reducing the amount of problematic plantar flexion but was never able to reduce it enough to solve the problem. The subject had achieved similar results during prior traditional training, a reduction but not extermination of the problem.

Awareness feedback training produced promising results. Using this training method the skater achieved flawless set-downs, as seen in Figure 8. The skater could immediately tell that his set-downs were proper and described it as the "first successful set-down in 14 months".

The skater moved at a slower pace and with a more upright posture during this training to allow time for the deliberate ankle extension. Attempts at having him skate at a faster pace while doing these extraneous motions were unsuccessful. We were also not able to replicate the flawless set-down without first doing the purposeful ankle extension. The system proved

extremely robust during this training, maintaining synchronization despite the attempts to alter the skating movement.

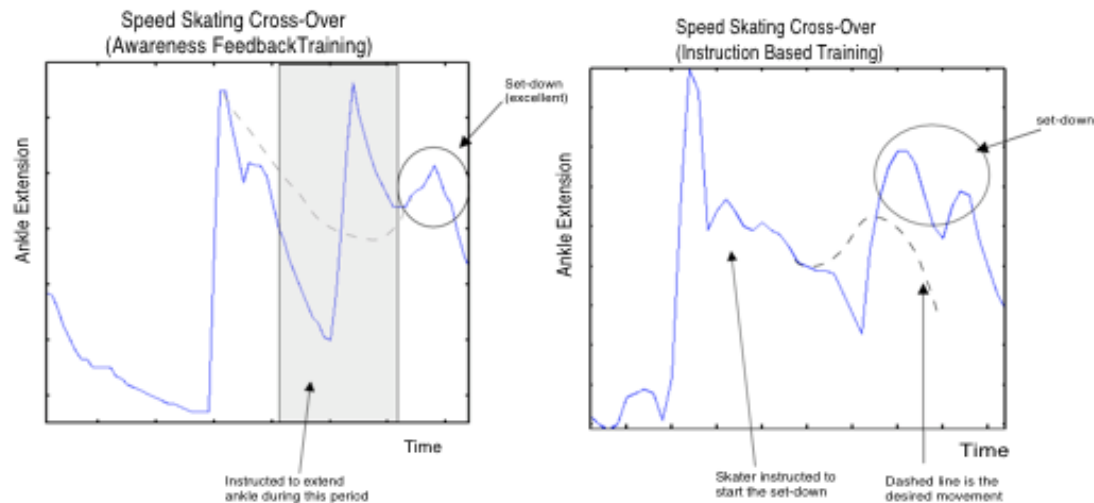


Figure 8. The skating stride of Subject A during training.

During Instruction Based Training we attempted to manufacture a right foot set-down for the subject. Upon hearing a bell tone the subject is instructed to begin setting his blade back onto the ice. We want the subject to avoid the chain of events that produce a flawed set-down. The struggles associated with modifying a previously learned movement are shown in Figure 6. Our subject attempts to override his ingrained movement upon hearing the bell tone, and while his initial movements look promising, he ends up reverting back to his old movement enduring similar results. Our subject achieved strong set-downs using this training method, however was unable to replicate the flawless set-down previously produced.

## Discussion

With respect to our corrective feedback training our subject was able to mitigate but not solve the problem. In prior, traditional training our subject often attempted to pull his toes up as much as he could but was unable to avoid digging his toe into the ice. The fact that we broadcast a sawtooth tone predicting that his toe was going to dig into the ice, did not change the abilities of the skater to flex his ankle to a larger degree. He was not able to have a clean set-down but only mitigate the problem. Given that we did not observe results beyond what we knew the subject had achieved with traditional training methods we moved on, using the system in another manner.

The introduction of changes into the middle of the cross-over (the purposeful ankle extension), provided awareness to the athlete about proper ankle extension. These additional movements being new to the athlete were hard for him to control. It became obvious that we would need more training time for him to become more comfortable with the extra movement and to eventually eliminate it. During this training two things became clear:

- this training method fixed the problems occurring at the set-down point, and

- reducing the amount of purposeful ankle extension while maintaining a flawless set-down required a long training period.

We got to a point during this training, where the subject was able to avoid digging his toe into the ice. Unfortunately the manner in which he was skating to facilitate the extra movements were not conducive to efficient speed skating. Ideally we would have continued to pursue these promising results, and slowly reduced the extraneous purposeful ankle extension, but the time requirements for this did not fit the training schedule of the athlete.

Instruction based training was a challenging movement for the athlete, as we were asking him to execute a critical part of the cross-over earlier than he was accustomed to doing it. We were asking him to execute the set-down before he felt he was ready to do it. This placed a large stress on the athlete to try to execute the movement when the system wanted but also to make adjustments so that he was able to execute the movement without crashing.

We did observe some strong set-downs during this training, however on the whole the skating was unpredictable. It was clear that like awareness feedback training we required more than the two month window of training time to fully evaluate the effectiveness of this type of training.

## Conclusions

A promising outcome from this research is the successful synchronization and sonification of the speed skating movement. While we attempted to aid specific skaters with their training, we were also exercising and demonstrating the capabilities of our augmented audio feedback system. We used case studies to evaluate the potential of real-time sonic feedback and to demonstrate the system with a real world problem.

With that said, we are encouraged by the progress we witnessed with each of the subjects. About his progress Subject A commented, "The device was the only thing that was able to improve my skating." We only worked with Subject A during a two month period (after 14 months with the problem) as he was preparing for a race at the end of that time. After that race the athlete retired from the sport. We are confident that had we continued to work with him we would have continued to see improvements in his form.

Subject B, demonstrated the potential for using a system like this for people learning a new movement. The system allows a trainee to experience the timing of an experienced athlete in an interactive manner. This facilitates comfort with the movement and subsequently improves their movement.

We are encouraged by the potential for this type of feedback and plan to continue developing the algorithms to work on different movements and applications.

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