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# AUFLIP - An Auditory Feedback System Towards Implicit Learning of Advanced Motor Skills

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## ABSTRACT

How can people learn advanced motor skills such as front flips and tennis swings without starting from a young age? The answer, following the work of Masters et. al., we believe, is implicitly. Implicit learning is associated with higher retention and knowledge transfer, but that is unable to be explicitly articulated as a set of rules. To achieve implicit learning is difficult, but may be taught using obscured feedback - that is feedback that provides little enough information such that a user does not overfit a mental model of their target action. We have designed an auditory feedback system - AUFLIP - that describes high level properties of an advanced movement using a simplified and validated physics

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**Figure 1: AUFLIP demonstrates an auditory feedback system that sonifies error between idea peak ballistic trajectory and a user's flip trajectory performance using a wearable ankle sensor, initial takeoff velocity, and detection of body rotation.**



**Figure 2: The AUFLIP sensor is worn on the ankle, purposefully offset from the center of mass; flips that are not ballistic often are the result of a non-stiff body.**

model of the flip. We further detail the implementation of a wearable system, optimized placement procedure, and takeoff capture strategy to realize this model. With an audio cue pattern that conveys this high-level, obscured objective, the system is integrated into a gymnastics-training environment with professional coaches teaching novice adults how to perform front flips. We perform a pilot user study training front flips, evaluating using a matched-pair comparison.

## KEYWORDS

Augmented Motor Learning; Implicit vs. Explicit Learning; Simplified Modeling of Athletic Movement

## INTRODUCTION

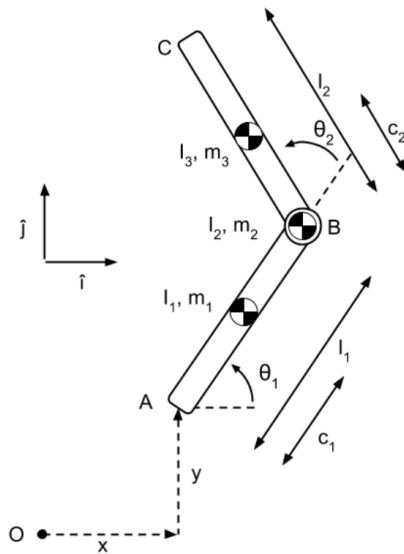
Throughout life, we often desire to learn a variety of exciting motor skills - flipping through the air, hitting a slam dunk, bouncing on a pogo stick. These skills require coaching, a considerable amount of courage, and are often seen as inaccessible to adults due to a lesser physical ability.

Towards this goal, we devised a feedback system that uses implicit learning methods to aid in teaching advanced motion. Implicit learning is characterized by retained motor skill performance ability in a variety of conditions and over an extended period of time and an inability to directly articulate governing rules. It is difficult to execute, and requires teaching via methods such as indirect or "obscured" feedback, association, or distraction. In contrast, explicit knowledge is characterized as knowledge gained from hypothesis testing but low retention. Typically, feedback systems rely upon explicit feedback, sonifying or visualizing direct mappings to position or velocity of body parts. While these systems have been effective for initial learning of rules and corrections of specific skill elements, we are unaware of any feedback systems that make use of obscured feedback to achieve an ingrained learning of advanced skills.

In this paper we put forth one such strategy for teaching the gymnastics salto or "front flip". We develop a simple physics model and sonify the ballistic trajectory as a form of obscured feedback. From this theory we implemented this system and performed a pilot evaluation of our system with six human subjects learning how to front flip.

## RELATED WORK

*Explicit And Implicit Learning.* As defined by Liao and Masters, Explicit Learning is defined by deliberate use of hypothesis testing to develop internal rules. [6] These internal rules are directly able to be articulated. [6] Explicit Learning is typically needed in the early stages of learning to establish some conscious rules but has been shown to decrease ability to perform highly skilled or tasks requiring multiple attention foci.[5] However, expert ability is marked by a less deliberate, more automatic form of knowledge that is difficult to articulate - procedural knowledge. [5] Procedural knowledge is typically imbued using implicit learning.[6] Contrary to Explicit Learning, Implicit Learning is



**Figure 3: Generalized Coordinates for Simplified Front Flip Model**

$x$	horizontal body distance from origin
$y$	vertical body distance from origin
$\theta_1$	relative angle between horizontal and bar 1
$\theta_2$	relative angle between bar 1 and bar 2

**Table 1: Generalized coordinates for simplified 2-D front flipping model**

characterized by learning without accruing more than the basic few rules about the "underlying structure" of the movement or skill being learned.[6] Implicit Learning was demonstrated for motor skills by Masters [8] who showed that motor learning can take place without awareness of what is learned. Masters et al. found that use of minimally perceptible feedback "evokes implicit processes" and enables implicit learning with development of procedural knowledge. For example, when training golf putting, newcomers more robustly maintained and improved when exposed to only partial feedback; when hitting a ball, they were only able to see the approximate square in a 9x9 grid of where the ball landed vs. the precise location. [7]

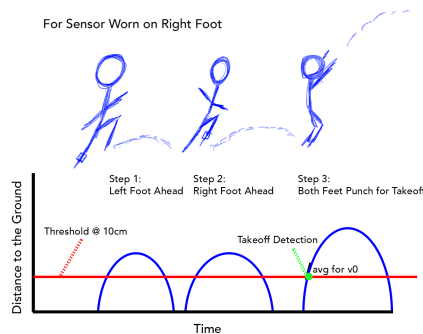
Maxwell et al. describes this phenomenon with working memory, concluding that working memory is saturated when attempting to learn explicitly (Working Memory Dependent), but not when learning conditions are obscured (Working Memory Independent). In WMI conditions, working memory is not saturated, and instead lends itself towards higher rates of retention and forward knowledge transfer[9].

*Forms of Augmented Feedback for Motor Learning.* A prominent early design of sonification was demonstrated and evaluated positively for swimmers practicing the 100m crawl stroke; in 1988, Chollet et al., demonstrated retained improved performance after four days of training with their system that sonified body velocity using hydrodynamic pressure.[4] A series of sonified movements have been demonstrated for a variety of sports, from skiing, to carving, to gymnastics, however many of these systems have not been systematically evaluated. [10]. As a scheme for rehabilitation, Chen et al., demonstrated a concurrent sonification system for controlling an arm in space that makes use of distance to target and harmonic progression with positive results for improving speed, fluidity, and precision of motion. [2] For gymnastics specifically, Baudry et al. successfully demonstrated a system that uses sonification of error to correct body positioning during gymnastics circles, with retained improvements over the control group for a training period of 2 weeks [1]. Chiviacowsky et al. found that augmented auditory feedback for motor learning may inherently provide motivation independent of particular strategy efficacy that may improve outcomes regardless of feedback strategy.[3]

### SIMPLIFIED MODEL OF THE GYMNASTICS FRONT FLIP: BALLISTIC MOTION

Using insight from active collegiate gymnasts, we learned that the body remains stiff, and mostly exerts a stiff downwards motion into the spring floor to initiate height. Consequently, we modeled the body as a two-bar linkage with a spring-damper and motor at the middle hinge. (See Figure 3 and Table 1).

We implemented the model in MATLAB to test these assumptions, using the nonlinear solver fmincon with ode45 and a hybrid model to handle collision dynamics with the floor. We used an objective function of maximum flip height. As optimization parameters, seeded the simulation with



**Figure 4: Strategy for picking up initial takeoff velocity. In order to pick up take-off, the system uses a threshold distance calibrated from sensor turn-on and looks for values rising above this step. Upon the third step, 20 steps are stored in a buffer, and the first and last 5 are averaged with respective timesteps to determine takeoff velocity.**

high body stiffness and low applied torque activation. The results demonstrated two characteristic flip types, 1) A gymnastics-type flip when optimizing for stiffness, and 2) a martial arts-type flip when optimizing for torque.

From Finding 1), we hypothesized that the flipping body could be approximated as a ballistic point mass. By comparing a ballistic point mass of identical mass to the simulated linkage model performing a front flip of identical peak height, we back solved for initial velocity, and found that the flip model matched ballistic trajectories for human-scale masses within 5 percent, thereby enabling us to model the system as ballistic motion if takeoff velocity and time to peak are known.

### GENERATING IMPLICIT FEEDBACK VIA PHYSICS CHARACTERISTICS

By finding the initial vertical velocity at takeoff, we can calculate an ideal time to peak for a well-executed flip. Detecting a rotation event, we can find the difference between rotation event and peak height time via equations  $v_y = v_o + a_y t$  and  $t_{\frac{1}{2}} = \frac{v_o}{g}$ .

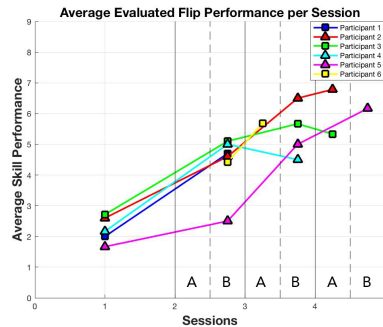
Auditory feedback is generated from the motion as a progression of an F-chord of piano notes playing from takeoff until reaching the rotation event. At takeoff, the ideal time to peak is computed and the chord notes are interpolated from takeoff to user's peak height. If the rotation occurs prematurely, for example before the peak time has been reached, the chordal progression is cut off. This strategy enables users to have a rough measure of better performance without explicitly describing the issue.

### USER STUDY

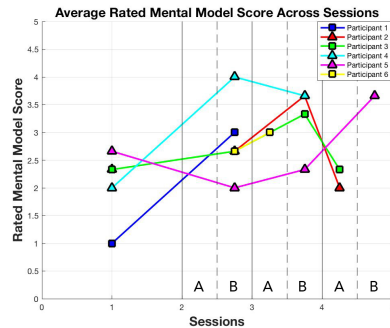
Entering this study, we sought to discern if obscured auditory feedback of ballistic motion aids in implicit motor learning of front flips alongside gymnastics coaching. We expected to see that with the AUFLIP feedback system, participant articulated mental models of declarative rules governing the front flip remain relatively constant, and that the observed performance in executing front flips increases.

This study took place in the gymnastics facility of the Dupont Gymnasium on the MIT Campus. Six MIT students (age range: 21-28, mean: 24.8, std: 2.67) were screened and trained for baseline safety. Three out of six trained with the auditory feedback system. For all participants, individual instruction and supervision was provided by a USAG certified instructor. Data collection was performed using questionnaires and recorded video+audio. Performance and mental model ratings were scored by professional instructors following rubrics detailed in MIT COUHES protocol NO. 171217930.

Over the course of four sessions on a Tumbltrak Resimat, participants were taught how to safely dive-roll and how to perform a front flip. Once participants were deemed to be able to safely perform flips, they were provided limited coach feedback (1 comment every 5 turns), and instead trained with either the feedback system + video, or only video.



**Figure 5: Average Skill Performance Scores.** A: user was able to perform evaluation skills throughout an entire session. B: user engaged in training drills during the first half of the session and performed evaluation skills during the second half. Triangle: participant trained with augmented feedback. Square: participant was a control.



**Figure 6: Average Mental Model Scores.** A: user was able to perform evaluation skills throughout an entire session. B: user engaged in training drills during the first half of the session and performed evaluation skills during the second half. Triangle: participant trained with augmented feedback. Square: participant was a control.

## RESULTS & DISCUSSION: MATCHED PAIR COMPARISON

Amongst participants wearing the feedback system, Participant 2 (P2) used the system most extensively. Participant 3 (P3) provides the most direct comparison to P2's performance as a control; both P2 and P3 moved through training at about the same rate, achieving controlled front flips by session 3. For these reasons, this discussion will focus on the matched pairs of feedback-wearing P2 and control P3.

Regarding flip performance, P2 improved across trials, maintaining a near even spread of performance close to  $\pm 1$  rating point. P3's performance rose through session 3 before decreasing in session 4 due to variability of performance. While P3 was able to achieve strong flips in the 7 out of 8 point range, P3 exhibited overall inconsistency in height, form, and apparent control. P3 mentioned that while initiating the flip, "sometimes [they] would feel that no, the jump would be a bad one," giving up right before flipping.

The rated mental model for both participants increased with variance up through session 3, but decreased dramatically after session 4, from 3.33 with a STD of 0.4, to 2 with a STD of 0. Alongside these scores, the themes of P2's commentary also appeared to change. In session 3, P2 insisted that "It [would] be better if the feedback is more clear," "the feedback [did] not specify ... which part I did well and which I didn't." In session 4, they remarked that, "the sound is consistent with my own feeling ... three sounds, felt delayed rotation [,] felt good." Yet, at the same time, they felt that "when [they] did not do well, they did not know what [they] did wrong." They also felt that "With the help of the sensor, I realized that jumping higher is more important and a little bit forward is enough," yet the sensor never explicitly gave them this information. In addition, feeling that the sensor helped them achieve a high jump, when describing their best and worse experiences of the day, they described their best as "Jump[ing] higher," and their worst as "Not knowing how to jump higher." This dichotomy appears similar to observed characteristics of implicit learning, where athletes can achieve a desired performance, but cannot articulate how they managed to achieve that performance.

From commentary, P3 felt, "inconsistent," But felt like they could tell at flip takeoff, "whether my flip would turn out well or not." As with P2, P3 was also observed to have a rise in mental model understanding up until the last session. P3 was also observed to be trying to figure out rules regarding "figuring out the flip," - perhaps in contrast to P2 who received feedback from the AUFLIP system every trial, P3 only received feedback from coaches once every five attempts and may have had less trust in their feeling without affirmation from a knowing source.

Interestingly, in both of these cases, the participants by session four appear to have developed a sense of a flip. However, P2 appeared to have much greater confidence in trusting this feeling than P3. This suggests that P2 may have benefited from the obscured feedback, trusting their feelings formed without significant use of working memory.

## CONCLUDING REMARKS AND FUTURE WORK

Originally, we set out to understand if we could help newcomers to skills learn unfamiliar movements. To do so, we laid out and tested a strategy for implicit learning using auditory feedback driven by high-level goals. We designed, implemented, and demonstrated a system capable of simplifying a complex motion into a high level performance objective. Within a user study, we integrated the system into a gymnastics training procedure alongside coaches for inexperienced participants. Mental Model vs. Performance results from this study anecdotally suggested that the coaching process facilitated implicit learning, and that use of the system resulted in greater consistency and lowered variability in performance improvements over controls. Towards the future, to extend the system beyond front flips, we propose a user flow for using our system to generate useful feedback for general movement types. We believe that this system lays the groundwork for lowering the bar to entry for learning advanced skills, assisted by technology.

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