The Doppler Effect: Altering Pitch to Materialize Movement Direction in Yoga

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Interactive sonification has made the compelling argument that sound structures are adequate constructs to materialize body movements. In this paper, we explore the alterations of pitch and their effect in body movements when practicing Yoga. Following a user-centered design methodology we designed and developed two sounds structures using the metaphor of ocean waves to represent Yoga cycles. In particular, we designed and implemented a wind and water sound that uses an oscillator to alter it's normal pitch with an ascending and descending one. We explore the correspondence effect of the movement direction in relation to the direction of pitch. The results of a within-subject study with 21 one participants using our sound structures during a Yoga practice show the materialization of movement direction with pitch alterations exhibit a 'Doppler effect', specifically in relation to the displacement and speed of the movement. We conclude with directions for future work.

Additional Key Words and Phrases: Movement Sonification, Sound pitch, Body perception, Yoga

1 INTRODUCTION

Research in interactive sonification has explore the design space of using sound structures and manipulating their sound parameters like pitch, amplitude, or timbre to represent individuals' physical and physiological data [4], or materialize body movement. Moreover, this literature has made the compelling argument that altering sound characteristics can affect how individuals perform their movements [3].This literature also shows that such materialization of movement is very simple to use and understand without needing specialized knowledge in acoustics [2]. However, there are still open questions regarding the study of the relationship of sound characteristics and movement direction or qualities. In this work, we hypothesize that the direction of the movement will concur with the direction of pitch alterations, exhibiting a 'Doppler Effect[1]'. In other words, there is a concordance between the direction of movement and its pitch alteration [6]. We explore this hypothesis through both the design, development and pilot-testing of different sounds structures with pitch alterations in one concrete scenario. An interesting real-life scenario to study movement materialization and its relationship to pitch alterations direction is yoga. Yoga is a physical discipline that focuses on posture control, flexibility, physical awareness, and well-being [1]. Yoga has been reported as an effective, feasible, and accepted alternative to physical exercise [5]. Furthermore, the litearature showcasing the materialization of movement using sound structures in Yoga is currently scarce.

[1]a sound with alterations in pitch controlled by an object motion, toward or away from a source

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2 DESIGN AND DEVELOPMENT OF SOUND STRUCTURES

Following a user-centered design approach we designed a set of sound structures with alterations in pitch appropriate to materialize the body movements conducted by yogis. Our design process involved both interviewing and conducting passive observation of yogis and musicians. We supplemented this data with a set of participatory design sessions with a multidisciplinary team including experts in HCI, Yoga, and Acoustics.

Our results derived in two sound structures inspired by the theme of the ocean to provide feedback during the trajectory of the movement, and/or its initial and ending points. Our experts chose the ocean theme, as the waves from the ocean mimic the Yoga cycles. The idea was to evoke an immersive experience of feeling the wind above yogis' head when practicing upward movements or "reaching up to the sky"; and use water sounds, when conducting downward movements, to evoke the feeling of hitting ocean waves with your feet or sinking your foot or knee in the ocean. For each sound, we proposed two alterations in their pitch by varying the Hz of the sound (see Figure **??**).

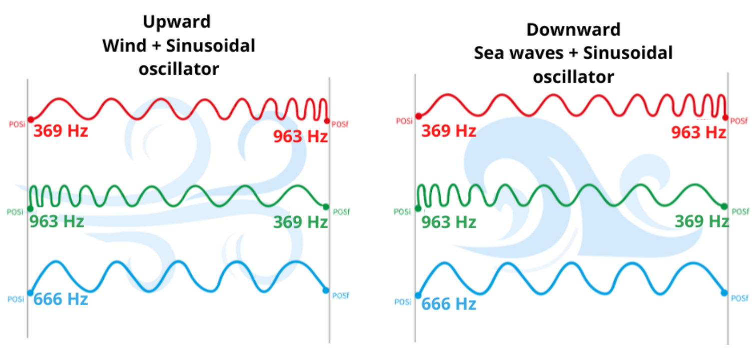

Fig. 1. Sound structures with the TGS in different pitch variations. Pitch variations are the color lines. Ascending pitch (red), Descending (green).

We synthesized sound structures simulating real-life sounds of ocean waves and wind using different values of white noise (water = 0.149, wind = 0.845), LPF filters (water = 86.39 semitones, wind = 78.73 semitones), and polyphonic voices (water = 5 voices, wind = 4 voices). On top of these sounds, we superimposed a sinusoidal oscillator with a normal pitch range established from 369 to 963Hz mimicking the unit of chakras [2]. Two pitch variations were created for each normal range, and each type of sound: sound structures with an ascending pitch were established in the range of 369Hz to 963Hz and sound structures with a descending pitch were established to 963Hz to 369Hz.

The sound structures were developed in Helm [3], and we used the Kinect Sensor to track movements using a set of predefined features and trigonometric functions (see Table 1). We used the Unity Game Engine and developed a Windows GUI to calibrate the range of movement from the Kinect. Such range of movement was mapped to the pitch, to provide the user auditory feedback of the trajectory of the movement.

3 EVALUATION

We conducted a within-subjects study, to evaluate the relationship between movement direction and pitch variation.

[2] energetic point correspond to physical, mental, and emotional aspects of humans
[3] an open-source polyphonic subtractive synth with a visual interface

Table 1. Movement features

Direction	Description	Equation	Threshold
Upward	Arm Lift	$\tan^{-1}\frac{hand.y-shoulder.y}{hand.x-shoulder.x}$	$\geq 15°$
	Torso Lift	$\tan^{-1}\frac{shoulder.y-hip.y}{shoulder.x-hip.x}$	$100° < x < 180°$
	Knee stretch	$\tan^{-1}\frac{knee.y-foot.y}{knee.x-foot.x}$	$\geq 90°$
Downward	Arm Descent	$\tan^{-1}\frac{hand.y-shoulder.y}{hand.x-shoulder.x}$	$\leq 165°$
	Torso inclination	$\tan^{-1}\frac{shoulder.y-hip.y}{shoulder.x-hip.x}$	$\leq 100°$
	Bend down	$\tan^{-1}\frac{shoulder.y-hip.y}{shoulder.x-hip.x}\ hand.y > shoulder.y$	$\leq 165°$

3.1 Procedure

We recruited 21 adults (Age = 28.23 years old, SD = 7.90; Women = 12). Each participant used the Windows GUI repeatedly to conclude a Yoga cycle for around 33 minutes using both water and wind sounds and the two variations of pitch. The order of each pitch variation was counterbalanced as the study was within subjects. The session was divided into two sub-blocks, each containing five repetitions of the yoga sequence with one pitch variation.

3.2 Data collection and analysis

We defined the direction of the movement as a binary classification using two potential results either upward or downward. We used the data obtained from the Kinect sensor, to compute its displacement (in *degrees*) and speed (in *degrees/second*). Then we subtracted the difference in the movement displacement with ascending pitch minus the one with descending pitch, and we also extracted this difference for the speed of the movement.

A positive value will indicate the movement direction or speed it's in accordance with the direction of pitch (*ascending – upward* and *descending – downward*), in other words, The Doppler Effect is being observed. In contrast, a negative value will indicate dissimilarity (*ascending – downward* and *descending – upward*). Then, we calculated the mean of the binary scores per type of movement. We analyzed the results for this scale using a binomial statistical test.

4 RESULTS

Our results show the displacement and speed of movements exhibit the Doppler Effect.

The displacement of upward movements of 90.5% of our participants was significantly higher when listening to sounds with an ascending pitch ($\chi^2 = 12.19$, $df = 1$, $p = 0.0004803$; see figure 2); while the displacement in downward movements for 71.42% of our participants was significantly higher when using the descending pitch variation.

Furthermore, our results show the speed of upward movements of 76.2% of our participants was significantly faster using the ascending variation ($\chi^2 = 4.7619$, $df = 1$, $p = 0.0291$; see figure 3); while the speed in downward movements for 90.5% was significantly faster using the descending pitch variation ($\chi^2 = 12.19$, $df = 1$, $p = 0.0004803$).

5 DISCUSSION AND FUTURE WORK

This work emphasizes the importance of the human body as a mediator to materialize sounds that can be translated into an action-oriented meaning at a mental level. Our results show the materialization of movement direction with pitch alterations exhibit a 'Doppler effect'. Although, there was evidence in the literature that pitch alterations improve the execution of movements by taking advantage of pitch alterations; this work extends these findings by also exploring the dimension of the movement's direction and its relationship to such pitch alternations[3]. As future work, we think

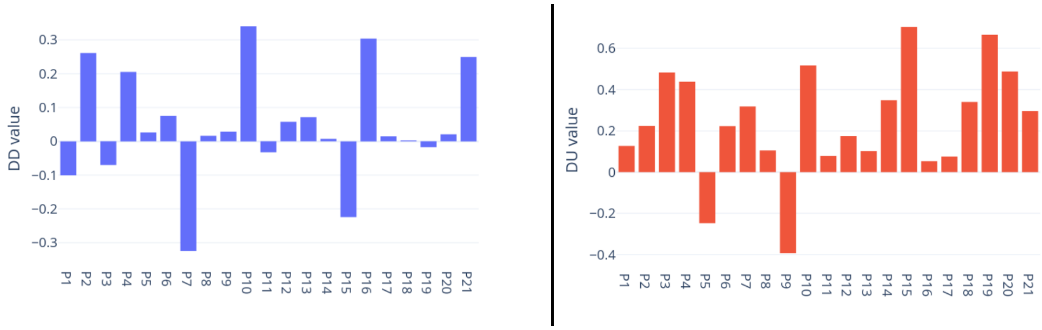

Fig. 2. Displacement of movements in both directions: Downward(Left), and Upward(Right); positive values means higher displacement with concordance between pitch variation and movement direction

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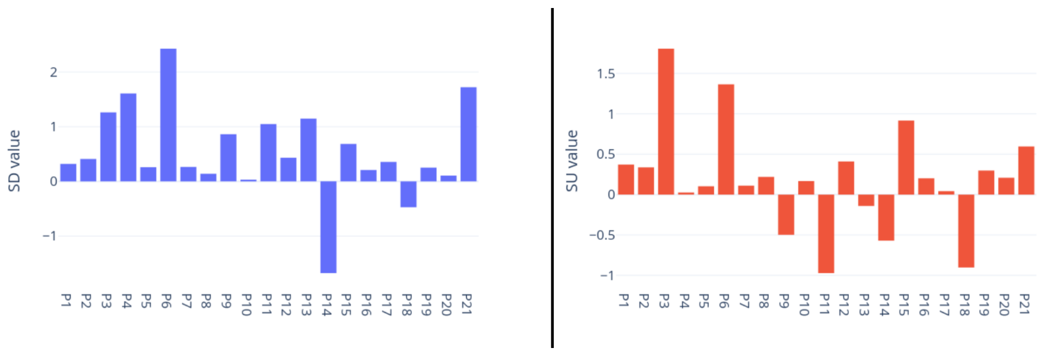

Fig. 3. Speed of movements in both directions: Downward (Left) and Upward (Right); Positive values mean faster movement with concordance between pitch variation and movement direction.

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there is an untapped potential to better understand other movement characteristics that can be materialized and explore their relationship to pitch alterations, for example, the length of the movement.

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