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Audio-Visual Feedback for Self-monitoring Posture in Ballet Training

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Abstract

An application for ballet training is presented that monitors the posture position (straightness of the spine and rotation of the pelvis) deviation from the ideal position in real-time. The human skeletal data is acquired through a Microsoft Kinect v2. The movement of the student is mirrored through an abstract skeletal figure and instructions are provided through a virtual teacher. Posture deviation is measured as torso misalignment, via comparing hip center joint, shoulder center joint and neck joint position with an ideal posture position retrieved through initial calibration, and pelvis deviation, expressed as the xz-rotation of the hip-center joint. The posture deviation is sonified via a varying cut-off frequency of a high-pass filter applied to floating water sound. The posture deviation is visualized via a curve and a rigged skeleton in which the misaligned torso parts are color-coded. In an experiment with 9-12 year-old dance students from a ballet school, comparing the audio-visual feedback modality with no feedback leads to an increase in posture accuracy ($p < 0.001$, Cohen's $d = 1.047$). Reaction card feedback and expert interviews indicate that the feedback is considered fun and useful for training independently from the teacher.

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Keywords

Classical ballet, Interactive application, Unity3D, Kinect v2, Posture correction, Multimodal feedback, User-centered approach

1. INTRODUCTION

Classical ballet is a dance art that follows a strict form. While ballet is easy to learn it is very hard to master, as the movements are of a highly technical and disciplinary nature. The dancers must be able to control their movement with exact precision and must rely on a strong core stability and a good posture [7]. The teaching of ballet also follows a strict form that has been the same for over 400 years. This teaching method is called the demonstration-performance method, where a demonstration is given by an instructor, which is then imitated by the student under close supervision [7]. Feedback is provided to the students after they have imitated the movement performed by the teacher. The efficiency of this feedback relies heavily on the instructor - whether they are able to identify the correct aspects of the movement [14]. In other words; this teaching method relies on repetitive qualitative feedback, which means that the training is of a subjective nature. However, through media technologies, it is possible to provide continuous quantitative feedback, which can help inform the students to which degree their movement is correct or incorrect. Multimodal feedback can be provided based on whether the student's movements follow the strict principles of ballet. Both *concurrent* (real-time) and *terminal* (post) feedback can be utilized but must be designed carefully in order to avoid distraction or demotivation for the student [11].
This paper presents a method for detecting whether a bal-

let dancer's posture is correct while performing one of the basic ballet movements: the plié. A prototype is developed that utilises a Kinect in order to gain information about the user's joint locations and rotation. This data is computed in order to find out if the torso is vertically aligned and the pelvis placement is correctly centered. Unity3D is used to provide multimodal feedback to the user. Through auditory feedback, the user can recognize whether he or she has an incorrect posture. In addition to expressing the degree of an incorrect posture, the visual feedback provides an approach to anatomically localize the error. The system is tested and refined through several iterations. A final experiment is performed, in order to evaluate if our application can be used to assist elementary ballet dancers in improving their fundamental ballet techniques.

2. BALLET

Ballet is an art-form, which can be described by precise dance movements done gracefully. Ballet dancers typically start learning and practicing basic positions and techniques from a young age. After many years of training, ballet dancers are able to execute these techniques correctly, thus ensuring that the movements respect the aesthetics and the fundamental principles of classical ballet [14].

2.1 Fundamental ballet techniques

Rachel E. Ward [14]. defines four key principles when performing classical ballet techniques. These principles consist of; alignment of the torso, placement of the pelvis, turnout of the lower limbs and extension of the lower limbs. The first two principles are used for the scope of this project. These principles are also the two which dramatically affect posture.

Alignment of the torso

An upright and vertical posture of the torso is expected to maintain classical ballet aesthetics. The dancers are required to have a firm grip in their spinal muscles to have the correct body alignment during ballet movements [14]. A common mistake is when the dancers' spine and buttocks are too relaxed, which results in the torso inclining forward as seen in figure 1.

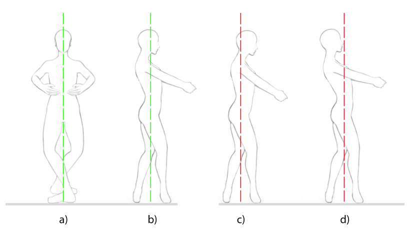

Figure 1: ***Correct posture (a and b), and incorrect posture (c and d).***

The correct alignment is when preservation of the vertical axis passes through the middle of the head and body to the ball of the foot.

Placement of the pelvis

It is important that the dancer finds the correct centered placement of the pelvis. If the pelvis is pushed front, back, left or right the lumbar part of the spine will be bent, and the pelvis will be displaced, as seen in figure 2.

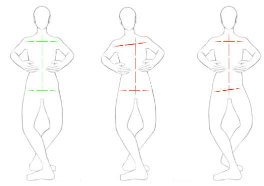

Figure 2: ***Correct alignment to the left and incorrect alignment in the middle and right.***

The pelvis must be kept in balance and completely horizontal, which can be controlled by oblique abdominal muscles on either side of the waist [14].

Five basic ballet positions

In ballet, there are five basic ballet positions. The feet must always move to and from these fundamental positions. A significant characteristic with these positions is that the feet are turned out, pointing towards the lateral sides of the body. This is a necessity in order for the dancers to move sideways on the stage [14].

The plié

Plié, which means 'to bend', is an essential ballet move used both by elementary and professional ballet dancers when practicing ballet. There are two types of plié; demiplié and grandplié. During a demiplié, the dancer has to make a small bend of the knees. A grandplié is a deeper bend of the knees, where the heels are lifted from the ground [1].

3. MULTIMODAL FEEDBACK

Multiple studies have been conducted in the field of uni- and multimodal feedback that investigates the effects it has on performance and learning. By comparing visual-auditory feedback with visual feedback Jennifer Burker et al. [2] found that visual-auditory feedback is the most effective when a single task is being performed and under normal workload conditions. Workload conditions refer to how complex the task(s) is.

Wulf and Shea [15] defines task complexity as to be complex if they generally cannot be mastered in a single session, has several degrees of freedom, and perhaps tend to be ecologically valid. They state that tasks will be judged as simple if they can be mastered in a single practice session, have only one degree of freedom and appear to be artificial [15]. Ballet movements can be seen as a single task (at least at an elementary level) and the workload condition can be argued to be moderate-to-high, as there are several factors that the student has to keep in mind. Thus, visual-auditory feedback could, according to Jennifer Burker et al. [2], help ballet dancers achieve a better performance.

Multimodal stimuli typically are perceived more precisely and faster than unimodal stimuli [11]. This holds true even during active movements. Sigrist et al. [11] investigate the effects multimodal feedback can have on motor learning through a review of other studies. Multimodal feedback has a relatively high effectiveness in both simple and complex tasks, compared to other unimodal feedback strategies [11]. If the workload is high in one modality, augmented feedback should be given in another modality or in a multimodal way. This might prevent cognitive overload and, therefore, might enhance motor learning [11]. As ballet movements can be seen as moderately to high complexity, it is good to provide concurrent visual feedback to the user. Sigrist et al. [11] argue that one reason could be that concurrent feedback attracts an external focus of attention. For the auditory feedback, error sonification and alarms are appropriate, especially when combined with different modalities. Error sonification can supply a ballet dancer with detailed information, as it is possible to sonify the deviation from the ideal posture - letting the dancer hear to what degree their movement is incorrect.

4. SYSTEMS FOR DANCE TRAINING

There has been developed several other systems, that aims to assist dancers and improve their performance, through interactive motion sensing systems.

CAVE is a system that uses real-time capture by utilising virtual reality through the *CAVE* environment, which uses sensors to detect body movement. By a gesture database which is filtering the information into gestures, the CAVE environment provides visual feedback for the dancer, practicing ballet. A score is displayed, which is determined by how well their movement correlates with that from the gesture database [7].

In order to accompany dance teaching and training, a wearable sensor-based system that detects motion and provides real-time sonification, has been developed in [6]. With insole pressure sensors for measuring jumps, goniometers for measuring knee angles, and accelerometers as well as gyroscopes for measuring acceleration and orientation, the sonification is rendered real-time for the dancer [6].

Saltate! is a sensor-based system, for couples practicing ballroom dancing. With sensors in the shoes, the couple gets real-time auditory feedback, when not dancing in sync with each other [5].

With body-worn active vibrodevices and cameras for a motion capture system, Akio Nakamura et al.[9] has built a system for teaching dance motion. The active devices are composed of vibro-motors and are attached on the dancer to provide haptic feedback [9].

To assist students practicing snowboard, Spelmezan et al. [12] developed a sensor-based system that detects common mistakes by calculating the weight distribution on the board, and gives the student immediate haptic feedback in the shoes, on how to correct their mistakes [12].

5. TECHNICAL COMPONENTS

In this section, we will present the hardware and software used to develop the system.

5.1 Kinect

A *Kinect v2* is a motion sensing device. It provides a robust, relatively accurate and non-intrusive acquisition of the human skeletal points [13]. In this context, this device will be used to identify if the user's posture is correct or not, in relation to the basic principles of ballet (see Section 2.1). The skeletal data from the *Kinect v2* can be extracted real-time via the *Kinect for Windows SDK* [13].
The *Kinect v2* utilises an infrared (IR) emitter and depth sensor to measure distance. It sends out IR beams, which reflect back to the sensor, thus measuring the distance to the object. If the IR beams hit a material that is either reflective or highly absorptive, it can cause unreliable data [8]. Another issue, as reported by Wang et al. [13], is that the orientation of the feet and ankle joints are unreliable. This is due to a problem with time-of-flight artifacts generating large amounts of noise close to planar surfaces, such as the floor.

5.2 Unity3D

Unity3D is a cross-platform game engine for 2D and 3D games. However, the engine is not limited to games and can be used for a wide variety of software development. Since its launch, various assets have been developed that, inter alia, helps interconnectivity with other software. The asset *Kinect v2 Examples with MS-SDK* is used for this project, making it possible to get a visual representation of the data gathered by the *Kinect* in 3D space. The joints are instantiated as *Game Objects* which makes their transform data accessible. Their transform data holds information about their position and rotation. This feature makes it possible, through specific calculations, to check if the joints are oriented and positioned as desired.

6. SYSTEM ARCHITECTURE

A user-centered approach was used for developing the application. Field studies were used to help establish a set of initial design requirements and the design was iterated through several expert reviews. The expert reviews helped shape and refine the visual and auditory feedback and gave valuable insight into the features of the application. The main outcome of the iterations was that the application should be able to assess whether a user's posture is correct by looking at certain joint positions and orientations. One of the later expert reviews revealed that the application also should include a calibration feature due to each individual user being physically different.

The final prototype consisted of a *Kinect v2* which was connected to a computer that makes it possible for the system to identify a user's skeletal points. This data determines both the visual and auditory feedback, provided through a screen and speakers. A virtual teacher is implemented in the upper left corner in order to instruct the user in the movements. For the full setup see Figure 3.

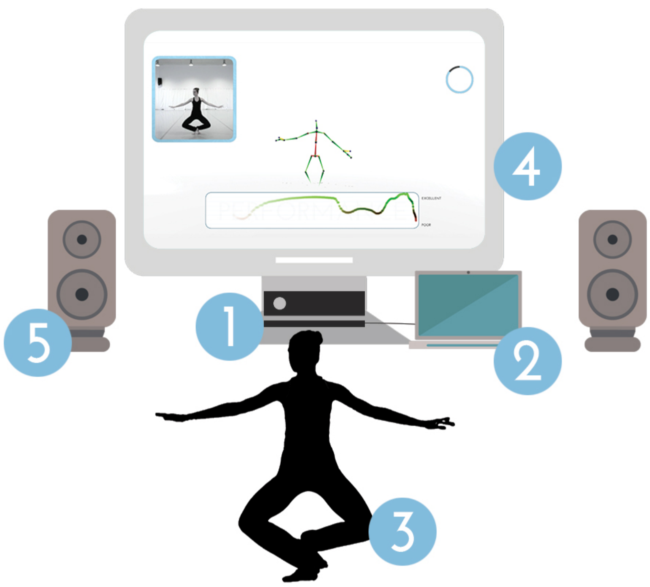

Figure 3: ***The Interactive Ballet Application: 1) a* Kinect v2 *connected to 2) the computer, 3) a dance student, 4) a screen displaying the instructor video (*top left*) and the real-time visual feedback (*center*: skeleton with color coded position deviations,* bottom*: visual performance curve), 5) speakers for auditory feedback.***

6.1 Posture performance measure

Since the ideal posture also includes having a non-displaced pelvis, one value is calculated for each of the two chosen fundamental ballet principles. The two values are compared and the highest is used to represent the physical error. The skeletal joint data is used to determine the degree of both errors but are calculated in seperate ways.
The torso misalignment is measured by calculating the Euclidean distance of the Hip Centre Joint (H) and Shoulder Centre Joint (S), combined with the distance of S and Neck Joint (N), in the xz-plane:

$$PostureScore = \sqrt{((H_x - CH_x) - (S_x - CS_x))^2 + ((H_z - CHz) - (S_z - CS_z))^2} + \sqrt{((H_x - CH_x) - (N_x - CN_x))^2 + ((H_z - CHz) - (N_z - CN_z))^2},$$

where CH, CS, CN represent the averaged calibrated ideal joints and x and z specify both horizontal axes of the respective joints in world space.

The pelvis-displacement is measured by taking the absolute xz-rotation of H. The predefined maximum distance and rotation can either be reduced or increased, in order to change the sensitivity of the audio feedback.

6.1.1 Calibration

The main scenario for which the calibration is intended, is to have a professional teacher adjusting the students to their ideal posture. The student can then use those reference values when no teacher is present to assist them in achieving the ideal posture.
When the calibration scene begins, it asks the user to stand still holding their ideal posture for five seconds while facing the Kinect. Meanwhile, the position of the joints: HipCenterJoint, ShoulderCenterJoint, and NeckJoint, are gathered into a list, as well as the quaternion rotation of HipCenterJoint. These obtained positions and rotations are then averaged into single reference values. These values will then later be used as reference vectors for the ideal posture of the user.

6.2 Auditory feedback

The auditory feedback consisted of a water creek sound representing a misalignment of the user's posture. This sound was chosen based on the qualitative findings in the expert reviews. The chosen audio should not sound stressful or annoying, yet intense enough to be alarming. When the user gradually worsens their posture, the sound intensifies by passing through a high pass filter. The cut-off frequency of the filter is dependent on the user's posture. The sound system only passes the highest frequencies of the water creek sound when the user's posture is slightly misaligned. This process is implemented by converting the misalignment, measured in meters, into a logarithmic scale going from $min = 20$ Hz to $max = 22$ kHz. The following equation splits the frequency range between min and max into logarithmically equal sections:

$$min \cdot \left(\sqrt[i]{\frac{max}{min}}\right)^n$$

where i is the total number of sections and n is the specific section. If i is changed to represent the range between the maximum and minimum misalignment, and n is set to represent the maximum misalignment minus the ideal posture, the equation can be used to calculate the cutoff frequency of the high pass filter.

6.3 Visual feedback

The visual feedback displays the computed score for the user as a GUI element in the scene in Unity3D. This score is represented through a curve due to Sigrist et al. [11] suggesting abstract visualisation as an efficient way of portraying kinematic values. In addition to the curve another important element of the visual feedback is the rigged skeleton. This element mirrors the user's movements, thus making it possible for them to observe every movement in their body. Color is added to alarm the user, when the torso is misaligned or the pelvis is displaced, by changing their respective color from green to red. The threshold is set to 60 which means that when the score for either torso or pelvis is below 60, the lines representing the torso or the pelvis will turn red.

7. EXPERIMENTAL SETUP

The following chapter presents how the implemented application was evaluated. The main objective of the evaluation is to test whether or not our application is able to improve the posture of elementary ballet dancers. Thus, a null and alternative hypothesis have been established:

- **H0:** There is no difference in posture performance, between the group that uses the Interactive Ballet Application and the group who does not.
- **H1:** There is an improved difference in posture performance, between the group that uses the Interactive Ballet Application and the group who does not.

7.1 Test Protocol

The final test was conducted in a ballet studio at The Royal Theater in Copenhagen. Three test conductors were present: One facilitating and in charge of the application, one observing, and one interviewing the participants with reaction cards after the test. The testing setup consisted of: One kinect, a computer running the prototype in Unity3D, a screen displaying the visual feedback, speakers for the auditory feedback, a preselected subset of the product reaction cards, and a camera recording the entire experiment. A between-group method was used, with one control group and one experimental. Each group followed the ballet teacher in the video instructions, performing three simple plie sessions. The sessions consisted of simple movements such as demi and grand plie. One short session lasting 47 seconds for the 1st and 3rd, and one long session lasting 82 seconds for the 2nd. The deviation of the subject's individual actual from their ideal posture is measured in centimeters, during the 1st and 3rd attempt. By subtracting the average of 3rd attempt from the average of the 1st session, it is possible to evaluate whether the subject has improved (a positive value) or decreased (a negative value) after interacting with the application. The result is then compared with the control group, which have only been exposed to the video instructions in the all three sessions. This mean difference was used to reject or accept the alternative hypothesis.

7.2 Participants

A total of 42 elementary ballet dancers with two to fives years classical ballet experience from the Royal Danish Ballet Academy, participated in the experiment. Their age ranged from nine to twelve years and consisted of 69% females and 31% males.

7.3 Evaluation

Posture performance for the control and the experimental group is compared used a statistical test. Reaction cards were used to discuss the experimental groups' reflection on the three main features of the application: the skeleton, the visual curve and the auditory feedback. Each subject could choose three out of 20 reaction cards. The options were positive and negative words (e.g. fun, boring, simple, complicated, helpful, unhelpful etc.). After the test, a content analysis was performed to sort the participants' answers into general statements about each feature.

8. RESULTS

In the statistical test, the control group consisted of 21 subjects (mean = -0.0026, std = 0.0049, se = 0.0011) and the experimental group using the Interactive Ballet Application consisted of 21 subjects (mean = 0.0030, std = 0.0057, se = 0.0012). The Anderson-Darling test for the control (p = 0.3567) and the experimental group (p = 0.0765) leads us to assume that both groups come from a normal distribution, with equal variances, since the 2-sample F-test yields p = 0.5102. A 2-sample t-test was performed. Although the actual training between the two control measurements lasted only 82 s, the change in posture performance for the group that uses the Interactive Ballet Application compared to the control group was highly significant (p=0.0008) with a large effect size of 1.047 (Cohen's d) and a statistical power of 0.9100, which is well above the 0.8000 recommended by Cohen [4] as a minimum requirement.

Qualitative data was gathered through the use of product reaction cards to discuss the experimental groups' reflection on the audio-visual feedback modalities. The most frequently chosen words were *fun* (n = 27), *useful* (n = 27), *helpful* (n = 28), *easy to use* (n = 18) and *exciting* (n = 16). Other words chosen were, *Pretty*, *Relaxing*, *HHelpful*, *Too technical*, *Simple* (positive), *Annoying*, *Unhelpful*, *Motivating*, *Entertaining*, *Boring*, *Ugly*, *Unmotivating*, *Hard to use*.

After the test, a content analysis was performed to sort the participants' answers into general statements about each feature, as seen below.

Generalised statements: Skeleton

- The users found the skeleton helpful for practicing their posture, without a teacher, as they are able to see if their back is straight or not.
- The users generally enjoyed the skeleton and found it both funny to look at and control.
- The lower limbs of the skeleton did not follow the participant's exact movements, which for them was not seen as frustrating, but rather silly and funny.
- The users generally enjoyed the skeleton and found it both funny to look at and control.

Generalised statements: Visual curve

- The curve is utilised to distinguish between doing a correct or incorrect movement.
- The users had different opinions about the visual curve. Some of them found it easy to read and motivating while other found it too technical and difficult to understand.
- The curve is visually aesthetic and is interesting as it can change color based on your posture

Generalised statements: Auditory feedback

- The water sound was the most utilised feature of the three, and is used to tell if you are making an error or not.
- The water sound received different reactions. For some, the sound was relaxing, pleasant and funny while for others it was annoying, stressful and boring.
- The water sound is a distinct feedback which the users understand and find useful.

The reaction cards were a great tool to facilitate discussion about the participant's experience with the application. Our application was well received and there was a general consensus among the participants that the application was usable as a potential aid for their training at home.

The skeleton has inconsistent lower limbs however it was not reported as being frustrating. On the contrary, it was reported as silly and funny, which may be a result of having children as participants. This could indicate that the skeleton was used for entertainment rather than keeping a straight posture. However, the participants acknowledge the potential of the skeleton to help correct their posture. Due to the skeleton being *funny* it could also be a motivational factor for the usage of the application.

The visual curve received mixed reactions. For some, it was easy to use and understand while others found it unintuitive and difficult to interpret. This is possibly due to the participant's performance while interacting with the application. Those who had difficulties keeping their ideal posture and experienced a lot of deviation on the curve, were more prone to choose negative reaction cards. Some expressed frustration relating to the speed of the curve increasing and decreasing too fast. This could indicate that the curve may be too sensitive, which makes it difficult to understand the extent of their error.

The auditory feedback was reported to be the most informative of the three features to help participants keep a correct posture, due to its ease of use and distinguishable nature. However, the auditory feedback also received critique similar to those of the visual curve; not all participants were equally fond of it. The participants who performed the exercise, while keeping a good vertical alignment, described it as relaxing, pleasant and helpful when they made a mistake. Those who did not perform as well found it annoying and stressful. To help overcome this problem, making it possible to change the difficulty level could be integrated into the application. The difficulty levels should have different sensitivity as it will accommodate a wide array of users.

Some concerning factors that might have affected our test unintentionally include: (1) The initial learning barrier of the new system, and (2) loose clothing interfering with the acquisition of the skeletal data.

9. CONCLUSION

This project set out to investigate whether an interactive application could assist elementary ballet students train and practice ballet. The traditional learning method in ballet follows a strict form, where the teacher provides repetitive qualitative feedback. Due to variation in ballet experience and knowledge, teachers does not always accurately identify incorrect movements [14]. Thus, a more objective learning method was thought to be beneficial.

A prototype was developed using a user-centered approach, and refined through several iterations. A Kinect v2 was used to gather skeletal data from a user, which then was computed in Unity3D. The final prototype focused on assessing whether a user's posture was correct, according to the fundamental theories of ballet. Visual-auditory feedback was provided to the user, that aimed to inform them whether their posture was correct during the basic ballet movement, plié. An experiment was conducted with 42 elementary ballet students. The experiment evaluated how much our application improved a user's posture alignment, in a single session.

The test indicated that the application had a large effect (Cohen's d = 1.047) on the performance level, with an acceptable statistical power (power = 91%). The qualitative results also suggested that the application had great potential to become a beneficial product. Both the experts and the participants showed great interest in the project and could see themselves using the application as an aid in the ballet training sessions.

9.1 System limitations and future work

Several elements regarding the system architecture should be considered for future development of the application. It should be able to track the entire body, in order to provide feedback for all the fundamental ballet principles [14]. The turnout is an important feature in all five positions. This is a key-feature to track, however it would require using another motion sensing system, due to the Kinect tracking lower limbs inaccurately [13]. Although it might be seen as intrusive, further sensors such as accelerometers, gyroscopes and goniometers can be used to more accurately track leg movement. Other approaches include motion capture (MOCAP) systems such as the Perception Neuron [10].

Another element that needs further work is gesture recognition. The current prototype does not recognise when the user performs a plié - meaning that they can be standing still and receive a perfect score. This is due to the application only tracking posture. Methods for detecting and classifying motion includes machine learning algorithms, that compares the user's gesture trajectories with a library of gestural components [7] [3].

Finally, the visual-auditory feedback could be designed to map several variables. The current prototype utilises cross-modal enhancement as both the visual and the auditory feedback represents the same variable (the posture score). Future development could have the auditory feedback convey information about the user's posture, while the visual feedback could convey information about the user's turn-out, balance or rhythm.

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