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Ballroom Dance Training with Motion Capture and Virtual Reality

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Figure 1: A dancer using the prototype

ABSTRACT

This paper investigates the integration of motion capture and virtual reality (VR) technologies in competitive ballroom dancing (slow walz, tango, slow foxtrott, viennese waltz, quickstep), aiming to analyze posture correctness and provide feedback to dancers for posture enhancement. Through qualitative interviews, the study identifies specific requirements and gathers insights into potentially helpful feedback mechanisms. Using Unity and motion capture technology, we implemented a prototype system featuring real-time visual cues for posture correction and a replay function for analysis. A validation study with competitive ballroom dancers reveals generally positive feedback on the system's usefulness, though challenges like cable obstruction and bad usability of the user interface are noted. Insights from participants inform future refinements, emphasizing the need for precise feedback, cable-free movement, and user-friendly interfaces. While the program is promising for ballroom dance training, further research is needed to evaluate the system's overall efficacy.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Virtual reality**; **Empirical studies in HCI**.

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KEYWORDS

Virtual Reality, Motion Capture, Sport, Ballroom Dance, Dance Teaching, Posture Analysis

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1 INTRODUCTION

Virtual reality (VR) and motion capture technologies have shown effectiveness in various movement-related tasks, including sports and physiotherapy [12]. VR has been extensively studied in the field of sports, as evidenced by research [12]. However, a notable gap exists in the literature concerning skill-based sports [12].

In particular, the domain of skill-based sports presents unique challenges. For instance, dancers often struggle to recognize fundamental errors in their technique. Competitive ballroom dancing, requiring precision and finesse, demands focused and expert-guided training. However, access to skilled trainers can be limited and costly.

To address these challenges, a system utilizing motion capture technology could offer significant benefits. By automatically detecting incorrect postures and movements, such a system could provide feedback to ballroom dancers, facilitating skill improvement in a cost-effective manner. In this project, both immediate visual feedback and a replay mode are implemented, aligning with the findings of previous research and addressing the following research questions:

(1) What are the integral features for a program aiming to enhance ballroom dance posture using motion capture and virtual reality?

(2) How should feedback be presented to ballroom dancers for optimal improvement?

Contribution

We address the research gap concerning skill-based sports through the integration of motion capture and VR technologies, specifically focusing on competitive ballroom dancing. By implementing a system that automatically detects incorrect postures, depicted in Figure 1, we propose a solution to provide feedback to competition dancers, thereby facilitating skill improvement. Through qualitative interviews, a prototype system is developed and tested in a preliminary study, featuring real-time visual feedback and a replay function. The study's findings shed light on the effectiveness and usability of the implemented features, offering insights for future research in the field of VR for skill based sports. Overall, the results provide a first validation of our proposed system and even indicate a broader applicability beyond ballroom dance.

2 THEORETICAL BACKGROUND

Motion capture and VR can be beneficial to sports. The surrounding virtual environment can be specifically designed to yield high training motivation and turn training devices into actual equipment [12], as for example letting athletes sit in a rowing boat when exercising on a rowing machine [1]. Also, a program using motion capture can give objective feedback to the athlete thus helping to find and improve weaknesses [13]. Motion capture is defined as a 'process in which an equipment capable of capturing and determine [sic] the location of points in the body of an actor in a given space of time is used' [13]. Finally, such a computer program could replace an expensive trainer [11].

Only a limited number of studies have explored the integration of motion capture in dancing, yet [3, 4, 6, 9, 10, 17]. One of these studies focused on improving timing in rumba dancing using auditory feedback and projecting the avatar of the participant via a beamer. The performance was calculated based on the student's synchronicity with the music to give individual feedback regarding the timing via recorded speech. The feedback was either given immediately or between training sessions. In general, the system was rated as motivating but no improvement of dancing skills could be found. It shows that immediate feedback outperforms a feedback given in retrospect between training sessions. It also concludes that it is important to give fine-graded feedback [10].

Another study examined dancers who are learning a hip-hop choreography through motion capture. In that research different kinds of feedback were used. For example, errors were visually highlighted in real-time and participants' movements were recorded multiple times. After each recording a playback and statistics were shown to the participant. Since the combination of these feedback types improved the participant's dancing skills [4], these feedback types could also be beneficial to this project.

3 METHOD

We conducted a requirement analysis with qualitative interviews. Based on this analysis, a concept is developed and implemented into a prototype. Finally, the prototype was evaluated through a user study and qualitative interviews.

3.1 Description of the requirement analysis

The qualitative interviews consist of the following questions, which were asked in German and when possible accompanied with images from the corresponding papers: Do you think a head-mounted display (HMD) would be helpful? Would it be more helpful than a usual PC screen? Do you think a HMD would be restrictive? Do you think auditive feedback would be helpful [10]? Do you think visual feedback by coloring wrong body parts would be helpful [4]? Do you think a record and replay of the dancer's movements would be helpful [4]? Do you think showing a summary that indicates how well each body part performed would be helpful [4]? What are typical errors when dancing?

3.2 Results of the requirement analysis

The recruited participants (n = 5, m = 3, w = 2) had an average age of M = 41.8 years (SD = 9.73) and all had experience in ballroom competition dancing (since M = 15.4 years, SD = 11.82) or actively participated in a course for competition dancers. Of these participants, two had no prior experience with VR, while the other three participants had at least some experience with VR. One participant had to be excluded due to missing dancing experience.

Visual feedback directly displayed on the avatar was considered as very helpful. However, three participants suggested that merely color-coding specific body parts lacked sufficient detail. They proposed that feedback should offer specific improvement suggestions. *Replay* was also considered as helpful. Three participants requested a function that allows them to pause and rewind the recording multiple times. Opinions regarding *auditory feedback* varied, with three participants finding it useful and two considering it unhelpful. Concerns were raised that spoken feedback would be too short and might lack the necessary complexity. A *post-training analysis* of the movement accuracy of specific body parts was considered as little or no help by all participants, because the numbers alone do not provide enough context. Lastly, participants expressed a desire for a *comprehensive view* of themselves.

The most common posture errors during ballroom dancing, according to all five participants, are the positions of the elbows (should not be too low below the shoulders, as depicted in Figure 2), of the shoulders (they should be at the back and not too high) and the position of the head. Since the ideal position of the head differs between men and women in ballroom dancing, this is not implemented in the prototype. However, the other errors will be checked. These rules apply generally for every movement and figure in ballroom dancing, thereby eliminating the need to restrict dancers to a specific sequence of steps.

In conclusion, our concept shall include a full embodiment that indicates incorrect elbow and shoulder positions with arrows pointing in the right direction to give more helpful feedback. Additionally, a replay feature with the option to rewind shall be implemented. Finally, to provide participants with an outside perspective, small duplicates of the avatar that mirror the movements of the athlete shall be a part of the prototype.

4 CONCEPT AND IMPLEMENTATION

The project utilizes the markerless motion tracking system Captury-Live (version 257a) [2] with eight FLIR Blackfly S BFS-PGE-16S2C

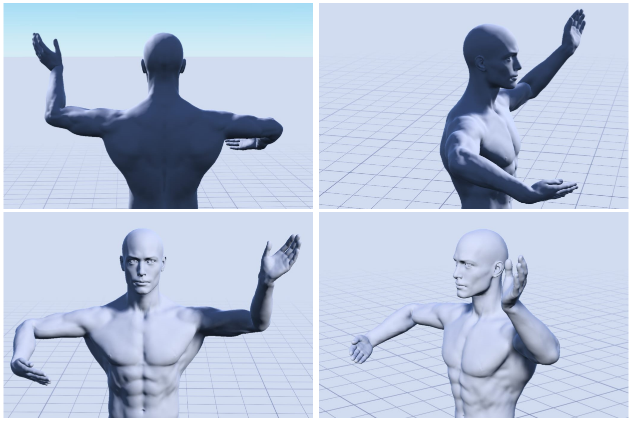

Figure 2: Optimal position of arms and shoulder in ballroom dancing

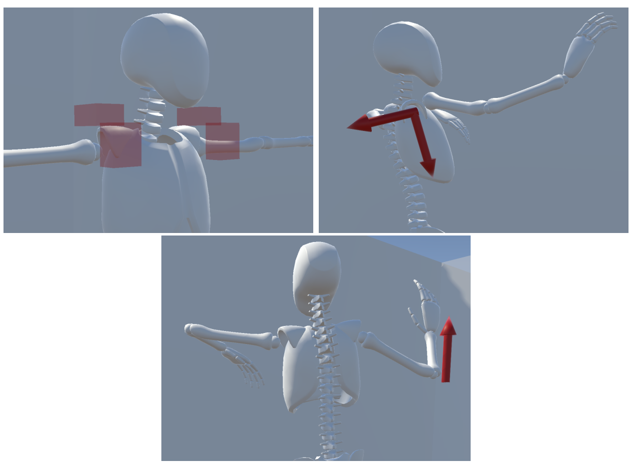

Figure 3: Positioning of the hitboxes (left) and arrows to correct posture (middle and right)

RGB cameras attached to the laboratory ceiling to track the participant's movements at a rate of 100 Hz. Captury uses a two-stage process to identify and scale a new person. Initially, all video views are used to generate and scale a skeleton matching the body dimensions of the tracked person. Subsequently, the tracked person is required to move so the Captury system is able to establish bone length more accurately [2]. The project is programmed using Unity 2020.3.42f1 [14], the OpenVR XR Plugin [15] and the HTC Vive Pro 2 headset [8]. The integration of the motion capture system into unity is based on a project from a previous study [5]. The tracking area spans about 2 x 3 meters (if the HMD with cable is used) or 3 x 4 meters without a cable.

To indicate errors during dancing, arrows pointing in the correct direction are displayed on the user's avatar. We embodied a user with a realistic human skeleton. This allows for an ideal movement inspection as it clearly displays the position of the extremities and joint angles important for ballroom dancing. The rules for displaying the arrows are implemented via hitboxes directly attached to the user's avatar, which are triggered when the specific body part makes contact. The hitboxes for the shoulders are depicted in Figure 3. Based on the most common errors, an arrow located at the elbow and pointing upwards will be shown if the elbow is recognized as too low. Similarly, two arrows are implemented for each shoulder, one pointing downwards, if the shoulder is too high, the other one pointing backwards, if the shoulder is too far forward. These arrows are depicted in Figure 3 (middle and right). Hence, as the avatar is scaled to a user's bodily dimensions using the Captury data stream, the dancing performance feedback is also automatically calibrated to each individual user.

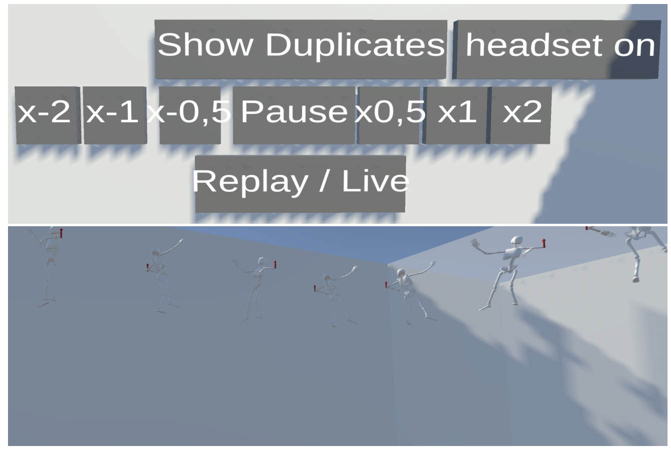

Figure 4: User interface (left) and duplicates (right)

To provide dancers with a view of their current posture at a glance, duplicates that mirror the movements of their avatar are displayed at the walls. These duplicates, as depicted in Figure 4, are smaller than the original avatar and placed on the upper half of the wall, ensuring they remain in the dancers' field of view as they look upwards during dancing. Every other duplicate is rotated by 180 degrees, providing dancers with multiple viewing angles of their posture simultaneously.

The recording as a part of the replay is implemented through a list that records the position and rotation of every body part at specific times. During replay, this recorded positions are applied to each body part of the avatar. The replay can be used in two ways. One option is that the athlete wears the HMD while dancing. The dancer can watch the recording when finished dancing. The second option is to start the recording in VR, then put the HMD aside. This option is suitable for people who do not want to wear a HMD due to reasons of comfort or movement freedom. Once the athlete has finished, they can put the HMD back on to watch the recording in VR. The dancer has to wear the HMD while watching the replay in any case. To navigate the replay, it can be paused, rewound, or fast-forwarded via the user interface displayed at one of the wall as display in Figure 4 (left). This interface further allows users to separately activate or deactivate all implemented assists. To activate one of the buttons, a user merely needs to touch it with the hands of their avatar.

5 VALIDATION STUDY

The study aimed to validate if the implemented features within the application are helpful for ballroom dancers.

5.1 Design

Participants engaged in both practical use of the application and qualitative interviews. During these interviews, participants answered the following questions: How helpful is the function arrows / duplicates / replay / dancing without HMD? Why? Do you think a specific aspect of the function arrow / duplicates / replay / dancing without HMD could be improved? Are you missing a functionality? Do you think VR is beneficial in this scenario?

The recruited participants were the same as for the requirement analysis. Only the age changed ($M = 42.2$, $SD = 9.39$), since one of the participants celebrated their birthday.

5.2 Results

Results of the validation study revealed both positive and negative aspects concerning the application's functionality and user experience. Although the majority found VR to be beneficial, dancers frequently encountered issues with the HMD cable restricting their movements. Additionally, unintended triggering of the user interface was reported. Despite these challenges, all implemented functions were generally perceived as helpful and the functions were with equal frequently named as the most used function during their test phase.

Feedback specific to individual features provided valuable insights. For the arrows feature, three participants explicitly stated that this feature is helpful, although some suggested improvements to the calibration of rules or user-editable calibration. Similarly, the replay function received positive feedback for its helpfulness from three participants, although suggestions were made to enhance time navigation and address concerns about avatar movements appearing "creepy" when walking through the user. Other studies regarding proxemics in VR showed a similar effect when the personal space of a person is violated [7, 16]. Participants enjoyed increased freedom of movement during the recording phase when using the replay function without a HMD, with four participants explicitly stating that this feature is helpful. Consequently, three participants requested the ability to utilize the entire setup, including watching the replay, without a HMD. The duplicates feature was also well-received, with four participants explicitly noting its usefulness, although two participants desired larger duplicates for improved visibility.

Regarding the appearance of the avatar, opinions were divided, with three participants preferring a skeleton representation over a realistic avatar for its clarity in recognizing relevant joint angles. Two other participants expressed a desire for a customization option to represent their body weight.

6 DISCUSSION

The research question regarding the fundamental requirements of such an application can now be addressed. Overall, both motion capture and head-mounted VR technologies demonstrate suitability for skill-based sports such as dancing. However, it's crucial to ensure that the HMD is cable-free to avoid hindering movement during training or performance.

In regard to exploring the research question about the effectiveness of various feedback mechanisms, several uncertainties persist. While all implemented feedback types were deemed beneficial, their relative importance remains unclear. Moreover, the impact on learning has yet to be thoroughly examined. Based on our results, we derived specific guidelines and insights to inform future research and development in this domain:

- When giving feedback on specific movements: Be precise! Tell the athletes what exactly they can improve - and how they can improve.
- Avoid cables when people have to turn multiple times.
- When using a replay, users should have the opportunity to pause, change the speed, or wind back.
- Mixed settings (e.g. doing sport without HMD and analyzing it with HMD) may not be the best option because the mounting and unmounting of the headset is time-consuming and regarded as annoying.

The study faces several limitations. Firstly, the participant pool was relatively small, potentially limiting the generalizability of the findings. A user study with a bigger sample size still has to be conducted. Additionally, the effectiveness of training was not evaluated. While participant feedback suggests potential benefits, further investigation is needed to ascertain its true impact. VR seems to be quite promising but due to restrictions in the freedom of movement of the users caused by the HMD cable, the study does not provide a definitive answer regarding the superiority of a HMD over a conventional large screen in facilitating training. A validation study that compares VR provided by wireless HMD and a conventional screen still has to be carried out. While the results are promising for ballroom dance, the applicability of the system to other sports remains uncertain, although participant responses suggest potentially broader utility.

7 CONCLUSION

This paper addresses a notable gap in the literature concerning skill-based sports, specifically focusing on competitive ballroom dancing, by proposing a system that integrates motion capture and VR technologies to provide valuable feedback to competition ballroom dancers. The study highlights the importance of precise feedback and the avoidance of movement-restricting cables as well as emphasizing the potential benefits of VR-based training. Through qualitative interviews and user testing, the implemented features, including real-time visual feedback and a replay function, are generally perceived as helpful by participants. While our approach is promising for ballroom dance, its true training capabilities and the broader applicability of the system to other sports warrant further investigation with a bigger sample size.

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