

# Designing an Interactive System Based on Pose-estimation to Support Rhythmic Gymnastics Basic Coaches in Enhancing Their Learning

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This research aims to explore how to shape technology to enhance the educational learning path of Rhythmic Gymnastics basic coaches. These individuals feel that the formal training path is not enough to enable them to perform safely and professionally. Therefore, they try to compensate for this lack through informal sources. Starting from this background the questions that this exploratory research investigates are: How it is possible to support basic coaches in their learning path with technology, particularly pose estimation? Semi-structured and unstructured interviews with basic coaches and athletes, and user observations were used to frame the context and define the user requirements. Several qualitative surveys with basic coaches and athletes but also experts in different fields helped in defining the system concept. The research process involved the development of a mobile application using pose estimation. The system was then tested to verify its overall usability and to validate the hypotheses that the system could increase coaches' explanation and learning, could increase coaches' level of confidence during the correction and improve athletes' motivation. The results lend validity to these hypotheses and show that this technological approach could become a supportive tool for coaches who perceive its potential. We also discuss the limitations and future implementations of this research.

**Keywords:** *Rhythmic Gymnastics; Pose Estimation; Real Time Feedback; Augmented Feedback*  
**Introduction**

## 1 Introduction.

Coaching is a very complex activity, it is both an individual and social process due to the importance of ongoing human interactions, which characterize sports in general. Among these, the one between coaches and athletes could be considered the main one (Cushion, Armour, and Jones, 2003). This

research focuses on the figure of basic coaches, responsible for athletes' preparation in most of Rhythmic Gymnastics (RG) schools at promotional levels. Rhythmic gymnastics has been a popular sport, it is a discipline under the general umbrella of gymnastics, close to artistic gymnastics and acrobatics. It involves the gymnast performing an exercise on a floor with one apparatus among ball, hoop, clubs, rope, and ribbon. Basic coaches are qualified by the official course provided by the national RG federation to obtain the necessary qualification to coach. Of five planned levels of the Italian qualification pathway, basic coaches hold the first or second title.

According to previous studies (Cushion and Townsend, 2019), the current formal coach education is designed in a linear and fragmented way and does not completely prepare coaches for the context in which they will work (Cushion, Armour, and Jones, 2003). The official educational path is based on the conception of learning as a *wall of bricks* (Moon, 2004), where learning means accumulating knowledge. This approach may not fully describe how coaches learn because it leaves out of the picture some methods such as personal experience and observation of other coaches that are the primary source of knowledge (Cushion, Armour, and Jones, 2003). And most of these basic coaches do not have a specific deep academical formation in motor science or biomechanics[xx]. Due to this gap, many coaches pair formal learning situations with more informal ones, which are also often preferred; this preference also brings them to be increasingly open to using technology to support their learning (Cushion and Townsend, 2019). In fact, social media and the Internet are great examples of common tools used by basic coaches to expand and consolidate their knowledge, so to acquire more competence. These mediums allow them to create *unmediated learning situations*, where “there is no instructor, and the learner takes the initiative and is responsible for choosing what to learn” (Werthner and Trudel, 2006). Today, these opportunities are just accidental and are not getting the attention they deserve. Instead, they should be facilitated and encouraged. In this context, technology enables flexible methods through which coaches can be supported (Cushion and Townsend, 2019). Over the past decades, interaction technology has been developing rapidly and showing great potential in supporting the RG scenarios.

Therefore, in this study, the main research question is:

How could an interactive digital tool be integrated into RG training to support basic coaches in enhancing their learning path?

Based on the main research question, other sub-questions can be identified:

1. How can an interactive digital tool support coaches in demonstrating and assessing the correctness of the training exercises?
2. How can an interactive digital tool support trainees to improve their performance?

From the definition of these questions, the main users for this research will be primarily the basic coaches but also the athletes, in fact, it would be unthinkable to separate these two groups whose interactions are constant and. Above all, fundamental for the purposes of the learning path of both. Furthermore, it is clear from the questions that the context this research focuses on is the training, in particular in the phase of demonstration and assessment of new exercises.

## **2 Related Work**

### **2.1 Different conceptions of coaches' learning**

Research on coaching knowledge is complex due to its social, relative, and dynamic nature. Researchers have proposed various theoretical paradigms to understand how coaches acquire knowledge, often drawing on general theories of teaching and learning. For example, Schulman's "knowledge base for teaching" model (Schulman, 1987) has been applied to sport pedagogy. Werthner and Trudel (2006) elaborated a new theoretical perspective to understand how trainers learn to coach. They adopt Moon's generic view of learning (Moon, 2004), where she distinguishes two ways to look at learning: the "building a brick wall" view and the "network" view. Comparing to learner has a passive attitude of assimilation, and collects the various bricks that correspond to different learning modules in the conception of learning as a *wall of bricks*, the second conception sees learning as a network of ideas, knowledge, and emotions. Though it is important to consider the two visions of learning, the former emphasizes the accumulation of knowledge through formal instruction, while the latter involves personal experiences, observation of other coaches, and self-reflection.

### **2.2 Augmented feedback for motor learning and coach-athlete relationship**

The literature on feedback in gymnastics and sports in general reflects on the use of intrinsic and extrinsic (augmented) feedback (Park and Lee, 2016) for performance improvement. Extrinsic feedback also known as augmented feedback is information from external sources (Park and Lee, 2016), and most of the research on this topic aim to understand how to use feedback to make training more effective, reflecting on the frequency, modalities, timing, and content. Technical displays are commonly used to provide augmented feedback (Sigrist, Rauter, Riener and Wolf, 2013), through different modalities, like vision (screens, visors), hearing (speakers, headphones), haptic (vibrotactile actuators). While Vidal, Zhu, and Delgado (2020) mentioned that technology an assessing role with automating instructions and feedback may consequently limiting the role of the trainer. They propose a different approach where technology provides open-ended augmented feedback, thanks to which the coach keeps its central role as a mediator.

Besides, coaching is both an individual and social process. The coach-athlete relationship is recognized as a pivotal factor in sports coaching, with specific emphasis on its significance in rhythmic gymnastics. Existing literature highlights the crucial role of this relationship in optimizing training processes and improving athletes' performance (Jowett, 2004). Trust, emotions, and communication are central components of the coach-athlete relationship, with moments of spontaneous dialogues and opportunities for feedback playing a key role. The social context, including ongoing interactions, is fundamental in shaping the research scenario. Also, Park and others (Park and Lee, 2016) explore a way to use feedback in a non-interpretative way. They agree that it is possible to enhance communication by creating a new channel through augmented feedback. The use of a digital tool in coaching aims to motivate gymnasts and foster communication among coaches and athletes during training, to keep the central role of the coach as a mediator, and to use feedback as a bridge between the coach and athletes.

### **2.3 Pose estimation technologies in sports**

Pose estimation technologies are developing rapidly and technology's potential in coaching and training garners increasing attention. Wilson's (2008) analysis discusses video tools' role in coaching, while Wang et al. (2019) highlight artificial intelligence and computer vision's potential in sports video processing. While the incorporation of technology in Rhythmic Gymnastics (RG) remains limited, one of the works is that Díaz-Pereira and Gómez-Conde (2014) introduced a novel method using computer vision to enhance objectivity in competition scoring. Besides, HCI research in this context is nascent offering unexplored avenues for innovative interaction techniques and enriched sports experiences. Amidst the challenges posed by Wilson, designers play a pivotal role in shaping technology's impact. This approach compares athletes' movements against standardized references, resulting in accurate scores. Some wearable devices and computer vision technologies were considered. The use of cameras, such as that of the smartphone is already present in the normal flows by the basic coaches as a tool to analyze, correct, and comment with the athlete on their movements. While precise algorithms matter, optimizing the interaction system takes precedence. The purpose of this research is to explore an interactive digital tool to support coaches and athletes.

## **3 Methodology**

This research adopts a mixed strategy including qualitative and quantitative methods in different stages of our research.

In the stage of framing the context and identifying the user requirements, eight semi-structured interviews targeting basic coaches and one unstructured interview with a former Italian national athlete were conducted. All the results generated in qualitative studies were transcribed and analyzed following the content analysis method (Himmelsbach et al., 2019). Besides, we adopted user observation, which involves observing participants in their natural environment, without interacting with them and with an uncontrolled or not structured approach. We also performed the literature review to identify relevant advanced technology and theory. Noteworthy, we also addressed online sources as basic coaches often actively search for relevant material.

Based on the insights generated, this research adopts classical methods in interaction design. The user journey (Marquez et al., 2015) visualizes their process, spotlighting stages and pain points. Scenario Map (Salazar, 2021) illustrates potential scenarios, focusing on the occupation of the gym, exercise type, and coach and gymnasts' disposition. User requirements analysis (Maguire & Bevan, 2002) was also embraced to clearly outline the user needs that shape the system design.

In the system evaluation stage, our objective is to validate the hypotheses, therefore we adopted the between-subject experiment with two conditions one of which involved training with the proposed assisted system, participants are invited to answer the questionnaires and join the interview sessions, both quantitative and qualitative data will be recorded. Besides, usability plays a central role to reflect systems' effectiveness, efficiency, and overall satisfaction, it refers to the quality of user experience during the interaction with an artifact. The System Usability Scale (SUS) is used in the research to assess the system's usability.

## 4 User Research

The procedure of the user research could be divided into two main spaces, according to the objectives and the phase of the research:

1. *Getting* to know the users and framing the context, specifically, this includes empathizing with the users, investigating how coaches learn, and exploring methods they adopted to fill the gap perceived in their official education ;
2. *Getting* to know users' thinking after the concept has been developed. So, to acquire more specific knowledge for the designing part by, for example, framing their requirements.

### 4.1 Interview for framing the context

#### 4.1.1 Objective and procedure

The first set of semi-structured interviews aimed at two basic coaches had as objectives: 1)

*Understanding* the “level” of the team of athletes the coach trains, consequently the type of training more or less difficult or specific; 2) Understanding how RG societies are organized, who are the figures that work (athletic trainer, postural gymnastics instructor, sports psychologist etc.) With the athletes how is their level of preparation; 3) Exploring how a coach prepares her/himself to the training session, why to choose some exercises rather than others, how to explain them to the athletes; 4) Understanding how the evaluation of the correctness of the exercise occurs; 5) Exploring their approach to technology; 6) Identifying some other pain points. Each session lasted between fifteen and twenty minutes.

#### 4.1.2 Results and insights

**Basic coaches' objectives.** From this first set of interviews, the main objectives identified are listed below:

- The gymnasts understand the exercise they propose;
- The gymnasts are ready to perform the exercise;
- The gymnasts perform the exercise intelligently, not necessarily perfectly;
- Everyone should be on the same level;
- *Understanding* if the exercise is right for their gymnasts;
- *Understanding* if the performance of the exercise is right.

***It is challenging to perform the correction efficiently and confidently.*** The assessment part of a training exercise can be something complicated, some movements, especially for the more dynamic exercises can be lost, or the focus on one part of the body can lead to not seeing other errors. In many cases, however, especially for unfamiliar exercises, the coach may also feel unable to perform the correction efficiently and confidently. For example, P1 mentioned that “*On specific exercises, like abdominals, I’m not sure they’re being done correctly using the right muscles*”; and P2 said: “*I don’t feel like I have enough of formation, it also depends a lot on the exercises, but I haven’t actually studied this, so it’s possible that I could have people do exercises that could lead to pain; often with the training you try to deal with that.*”

***It is promising regarding the role of technology.*** Regarding the use of technology in their work, both coaches acknowledged its potential, for example, to find new exercises and inspiration, or as a tool to help explain mistakes in front of the gymnasts, moreover, to analyze exercises and focus on mistakes, as well as a bridge to reduce distances, as was the case during the lockout period in Italy. After having explained to them examples from other sports of computer vision applications, both seemed to be interested in the evolution of those systems into RG.

## **4.2 The user observation and second interview for analyzing the scenarios**

### **4.2.1 Objective and procedure**

Based on the results from the first interview, we proposed the concept of adopting computer vision technology in an interactive system to assist the coach in enhancing their learning path. To further examine the specific user requirements, we conducted the second structured interview to identify and analyze the scenarios around the moment of the training. Through user observation and the second set of interviews, it has been possible to study the context of use, by analyzing the relationship between the users (coaches and athletes) and the space and how it affects their interactions during the training. The user observation was conducted in an indirect way, one basic coach was asked to record the training during the warming up two different times. In the second review, the coach was required to select just three exercises and record from the explanation to the correction. The user observation clarified how it is important to consider three different moments regarding an exercise: 1) Before the exercise; 2) During the exercise; 3) After the exercise.

### **4.2.2 Results and insights**

***User journey.*** The user journey in the image represented in Figure 1. describes the detailed actions and findings after the user observation. It shows how the stages were then analyzed according to the specific objectives and methods used. Technology is presented to help in the demonstration with

some videos, but also during and sometimes after the execution to review the performance. The pain points also contribute to summarizing the user requirements, shown in Figure 1.









BEFORE THE EXERCISE		
Explanation		
	The coach explains the exercise to be performed while the gymnast listen. If the exercise is a "new one" then the explanation will be quite longer and more detailed.	<b>Pain Points</b> Difficulty in selecting the most appropriate exercise
Demonstration		
	The coach demonstrates the exercise by herself in front of the gymnasts while explains the most important tips. If the exercise requires some tools then the coach uses them.	<b>Pain Points</b> Use a gymnast to demonstrate who is not able
	The coach uses one gymnast to demonstrate the exercise explaining the most important corrections, while the other gymnasts watch and listen	The gymnasts have a different perception of what they see
DURING THE EXERCISE		
Counting		
	The coach counts the repetitions to keep the rhythm, the gymnasts should respect that time and be synchronised.	<b>Pain Points</b> Not all the gymnasts are able to keep the same time
Correction		
	During the performance of the exercise the coach gives verbal suggestions to correct the movement while she keeps counting, or she stops.	<b>Pain Points</b> Missing some errors The coach does not know how to correct the errors
	During the performance of the exercise the coach gives verbal suggestions to correct the movement, while she keeps counting, or she stops. The gymnasts listen	The coach does not recognize the errors The gymnasts does not understand the correction
AFTER THE EXERCISE		
Give feedback		
	After the execution the coach verbally or physically gives some corrections	<b>Pain Points</b> Lack of confidence
Ask feedback		
	The coach asks where they feel bad, so as to understand if they have worked in the right way	<b>Pain Points</b> The gymnasts have worked with different muscles; coach does not know the muscles engaged

Figure 1. User journey that demonstrates the actions and pain points in different stages.

**Scenarios Map.** To better identify how computer vision may contribute to the training sessions of RG, 24 possible scenarios (as shown in Figure 2.) were identified according to the criteria of supervision of the coach, coach's movement, gymnasts' movement, group or individual session, space and tools. Considering how the system using computer vision technology from a simple device such as a smartphone or a tablet might work, the scenarios in which it could be more efficient are those where the coach does not move around but stands in front of the group of gymnasts, also taking into consideration the limitations deriving from the technology, the static exercises have more possibilities to be efficient. So, the best scenarios are the numbers: 1, 7, 16, and 22. This does not mean that the other scenarios must necessarily be excluded from further exploration in this sector, but that due to the conditions in which this research has been placed, the indicated scenarios will be considered for the experiments and tests.

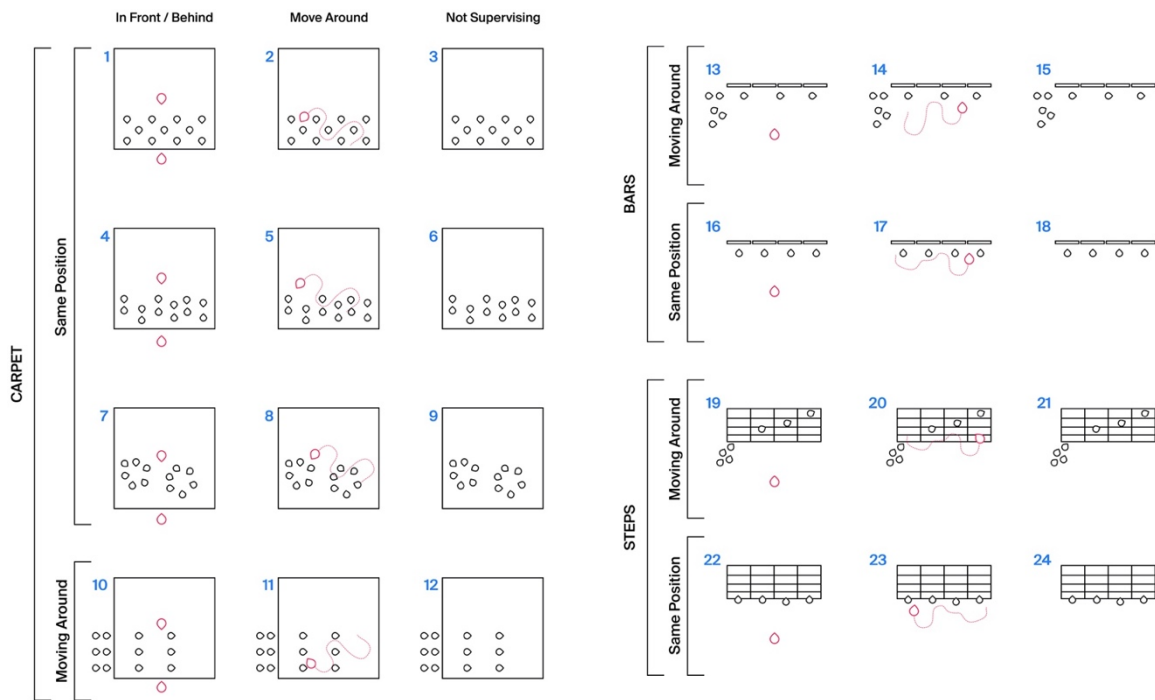


Figure 2. Scenarios Map.

**User requirements.** While one of the most useful findings from the user research was the definition of users' requirements in various categories. As Figure 3. shows, the users referred to are both basic coaches (blue rectangles) and athletes (pink). Those marked with the blue circle deal with the topic of basic coach learning. The purple square, on the other hand, indicates those belonging to how to support the coach in demonstrating and evaluating the exercise. Finally, the yellow triangle wants to refer to user requirements related to performance improvement.



## User Requirements



Figure 3. User requirements

## 5 System Descriptions

To further investigate the research questions, the digital prototype of a system built on the basis of the requirements that emerged during the user research phase was developed.

### 5.1 System functions

The system has been translated into a digital platform designed primarily for mobile devices such as phones or tablets, which are already widely used in the gymnasium, that takes advantage of pose-estimation technology. The application has simple features and easy navigation; the menu has four pages: home, athletes, results, and settings. The language of this software is Italian.

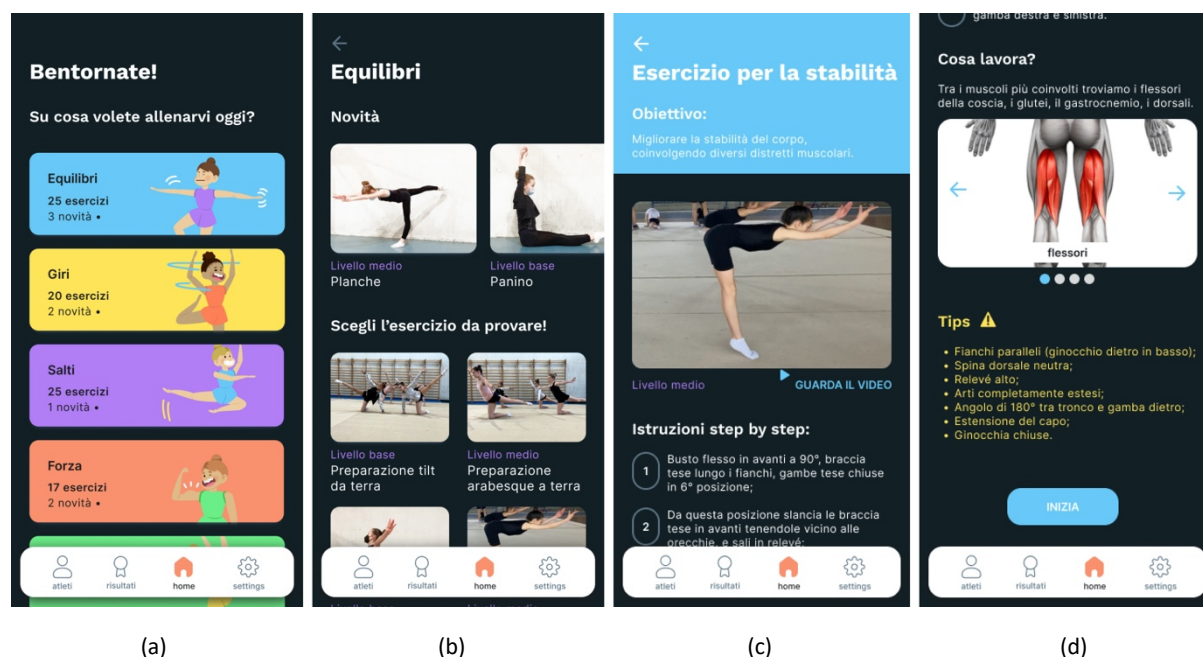


Figure 4. Demonstration phase: a). Homepage; b). exercises per category; c). detail page; and d). anatomical deepening.

#### 5.1.1 Demonstration phase

- Firstly, user will encounter the onboarding where the main functions and user journey of the system are explained.
- Subsequently, users are directed to the homepage (Figure 4a) where exercises are categorized into distinct categories, including balances, pivots, jumps, strength, flexibility, endurance, and coordination. This categorization facilitates effective differentiation of training requirements, aligning with the users' expectations for exercise diversity and specificity in the system.
- In each category, exercises are organized on a dedicated page (Figure 4b). The new exercises are presented in a horizontal scroll, followed by older exercises in a vertical scroll. To assist users in selecting exercises appropriate for the level of their gymnasts, each exercise is accompanied by a photo of a gymnast performing it, a brief title describing it, and an indication of its difficulty level.
- On the "Detail" page (Figure 4c), users can access a detailed exercise explanation, along with a demonstration video and anatomical information. Muscle groups involved in the exercise are highlighted visually, and bullet-point tips are provided for coaches to guide gymnasts effectively.

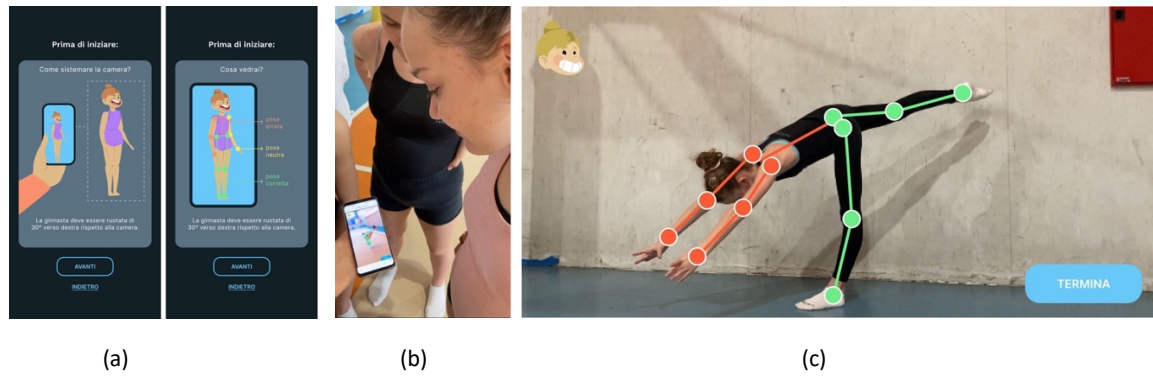


Figure 5. Assessment phase: a). positioning; b). introducing; c). pose-estimation with AR feedback.

### 5.1.2 Assessment phase

In the assessment phase (Figure 5), a skeleton with key points and segments is drawn over the body of the gymnast in augmented reality. Correct poses are colored green, incorrect poses are red, and neutral poses that are not part of the exercise are yellow. The purpose is for the coach to identify areas where pose corrections may be needed and assist the gymnast in adjusting their movements, acting as a moderator rather than solving the problem directly. Therefore, the augmented feedback is not given directly to the gymnast, but is mediated by the coach, who remains in control of the situation. Finally, the gymnast's total score and her awards earned will be displayed in the result page.

## 5.2 Preliminary experimentation of pose estimation

In this research, the experimentation has been done with Google Teachable Machine (Carney et al., 2020) and OpenPose (Cao et al., 2017), and it turns out the latter is able to detect gymnastics poses more efficiently in our study, Figure 6 shows the training process.

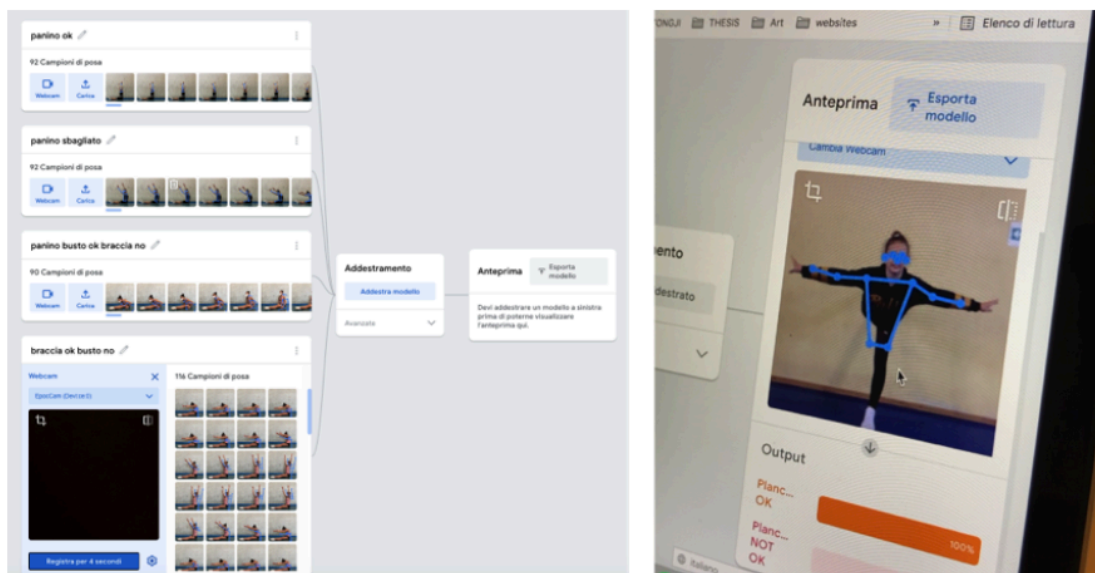


Figure 6. Algorithm Training.

A very important point, considering the requirements of the RG, is accuracy in recognizing the feet, not just as a single point, but through three different key points: the ankle, toe, and heel. This makes it possible to assess whether the foot is extended or not. Another specificity of rhythmic gymnastics that would require the creation of an ad hoc pose recognition system concerns the back; both GTM and Open Pose reduce the back to a straight line joining the pelvis and the shoulder line. This

representation can be considered reductive, as it does not take into account flexibility movements. Having a model that can also describe this condition would be essential to integrate into such a system. In the latest version of the prototype, the pose estimation part was integrated into the system, the algorithm was trained on a selected training exercise. The dataset used in the study consisted of five classes as a demonstration of our concept.

## 6 Evaluation

The evaluation part wanted to verify the usability of the system and validate the following three hypothesis:

1. With the system the coach is able to provide a better explanation of the exercise; and improve his/her learning.
2. With the system the coach is more confident in the correction phase of the exercise.
3. With the system, the coach is more confident in evaluating the exercise. The gymnast understands the exercise better and is more motivated.

### 6.1 Protocol and procedure

The evaluation employs a between-subjects design, dividing users into two groups: one with the system (3 coaches and 4 gymnasts), the other without (2 coaches and 4 gymnasts), with subsequent result comparison. Following task completion, both groups answered an identical questionnaire (specific questions are listed in Figure 7) and follow-up interviews. Four coaches completed the SUS to assess system usability, with usability test data analyzed in the discussion.

### 6.2 Results

The results from the SUS, shows that the four respondents find the system usable ( $M = 85$ ,  $SD = 8.16$ ). The average of the results is 85 and represents the average satisfaction level of the sample analyzed on a scale that goes from 1 to 100. And Figure 7 demonstrates the results from the questionnaire.

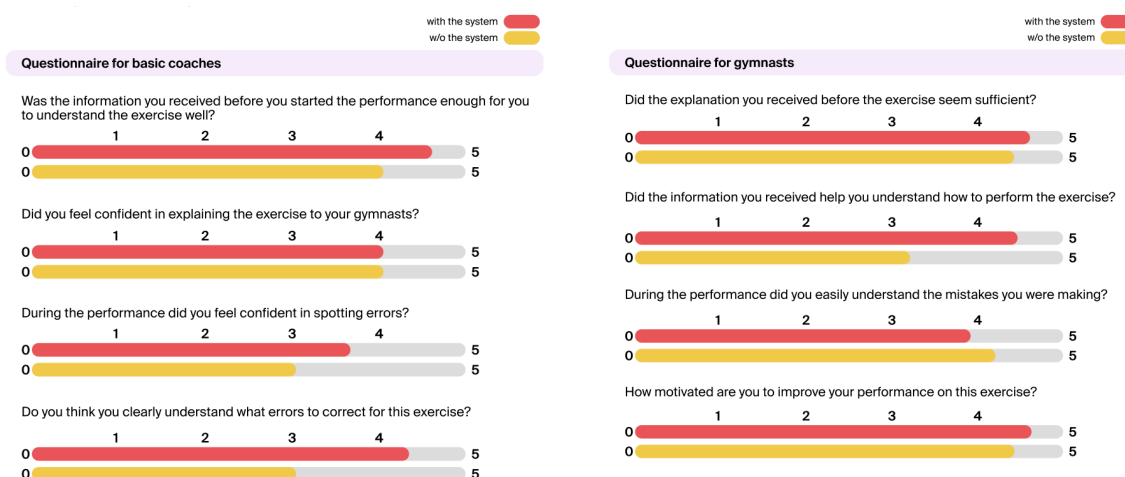


Figure 7. Questionnaire results: left) questionnaire for basic coaches; right) questionnaire for gymnasts.

## 7 Discussion

### 7.1 System Implications and User Insights

Analyzing each question from the questionnaire it seems that: most respondents would frequently utilize the system in their workflow, with only one indicating infrequent use. Respondents generally concur that the system is easy to use and all of them think that the functions are well integrated without inconsistency.

Coaches of the first group think they received enough information to understand the exercise, more than the second group. While both groups exhibit an equivalent level of confidence in explaining exercises to gymnasts. Qualitative analysis suggests that coaches using the system provide more precise explanations with professional terminology compared to non-system users. Furthermore, system-using basic coaches exhibit a slightly elevated level of exercise comprehension. System users perceive its value in comprehending pose accuracy and identifying errors, consequently fostering their willingness to use it.

It is found that none of them are completely confident in using the system. This could be linked to the fact that they think they need to learn some processes before being able to use the system. Part of this reluctance may come from the fact that none of the users were used to using such a system with pose estimation. An improved approach might be to work even more on the initial information phase, to propose a bit more hands-on onboarding, for example by allowing the user the first time he/she accesses the application to test what the pose-estimation part will be like.



*Figure 7. One of the user test scenarios.*

The hypothesis regarding coach confidence during exercise correction holds merit. The level of confidence in spotting errors was higher for coaches with the system, linked to a more comprehensive error comprehension and correction approach. The body parts involved were recognized correctly by both groups. Those who used the system believe it was helpful in understanding the correctness of the pose and as a support in identifying the errors.

Lastly, the system effectively motivates gymnasts to improve through its gamified approach. From the questionnaires, it seems like the level of understanding by the gymnasts is about the same, but those who participated in the test with the system were more involved in the process and made their understanding explicit, intervening with some comments.

This endeavour stresses the importance of incorporating various learning methods into formal education frameworks. The research's practical concept takes the form of a mobile application, encouraging coaches to embrace innovative tools that facilitate learning and athlete advancement.

## 7.2 Future Implementations

Technology serves as a potent tool to enhance basic coaches' training, augmenting gym-based efforts and, notably, enriching coach-athlete communication. Our preliminary method allows users to receive augmented feedback related to the movement of the gymnast during the exercise and the poses she takes. In the future, it would be sufficient to improve and guarantee the system's accuracy. A team of experts could train the pose-estimation algorithm on a specific exercise to recognize correct and incorrect poses to create a valid model. The same technology then used in the gym by the basic coach would be able to support her/him in identifying and correcting errors. Besides, the accuracy of open source pose estimation is enough for this research given its exploratory nature, but for more in-depth research or where greater accuracy is required of the system, it will be necessary to work with algorithms trained to predict poses closer to rhythmic gymnastics.

## 8 Conclusion

This study holds significance for those engaged in advancing technology applications within sports, particularly in disciplines akin to Rhythmic Gymnastics. Following the approach in interaction design, this research explores the potential of a digital interactive system in coaching, bridging the gap between formal education and practical learning for coaches. The hypotheses have been validated, about the ability of the system to support the coach with a better explanation of the exercise and to increase the explanations, in increasing the confidence in giving the correction and in the final evaluation as well as in raising athletes' motivation to improve their performance. While the aim was not to investigate a replacement path to the current formal education but to investigate how technology, such as pose-estimation, can create new learning situations that could be accompanied by the path to obtaining qualifications. The ongoing integration of technology within coaching work is evident, with the potential to revolutionize coach learning, necessitating innovative, flexible methodologies.

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