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Monitoring Respiratory Rehabilitation with YOLO Pose: Usability and Accuracy Assessment of a Mobile App for Spirometer Tracking

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Abstract. *Background:* Adherence to home-based respiratory rehabilitation is a significant challenge for cardiac surgery patients. Few studies have attempted to address this problem. *Methods:* This research introduces a digital solution to improve adherence to respiratory rehabilitation by offering virtual supervision. It leverages the YOLOv11 pose detection algorithm to track the Voldyne® 2500 incentive spirometer and monitor rehabilitation sessions. Usability and accuracy were evaluated with nine healthy volunteers, combining objective performance metrics with the System Usability Scale (SUS) survey. *Results:* The models demonstrated high accuracy in spirometer tracking and efficient inference times. The app achieved an average SUS score of 83%, indicating good usability, though refinements to the monitoring algorithms are recommended. *Conclusion:* This low-cost, non-invasive solution shows potential for clinical use. Future efforts will focus on enhancing usability and accuracy to prepare the app for clinical trials.

Keywords. YOLO Network, Cardiac Rehabilitation, Respiratory Therapies, Spirometry

1. Introduction

Prehabilitation and rehabilitation in the cardiac surgery field play a crucial role in accelerating the return to normal life and preventing adverse outcomes [1]. In recent years, traditional center-based rehabilitation was combined with home-based approaches, driven by scientific evidence of comparable effectiveness [2]. However, lack of compliance in home-based cardiac rehabilitation is a well-documented challenge [3, 4]. Insecurity in performing exercises alone after invasive surgery, lack of awareness of the importance of rehabilitation, and lack of short-term improvement are all factors that negatively impact compliance [5, 6]. Traditional cardiac rehabilitation programs rely on both physical and respiratory exercises. However, while several studies attempted to

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address the general adherence problem in physical rehabilitation [7, 8], few studies have explored possible solutions for respiratory rehabilitation using IT consumer technology.

This work presents a simple solution that could enhance adherence by providing virtual supervision to respiratory rehabilitation with incentive spirometers (IS). ISs are devices designed to improve respiratory function using a movable component that rises as the patient inhales through a pipe. This mechanism encourages patients to sustain their inhalation effort until they reach a target. Their low cost and ease of use make ISs widely used in clinical and home settings [9]. Some studies have attempted to implement innovative solutions to monitor IS execution, but they all rely on sensor-equipped and expensive devices [10, 11] or microphone-based applications [12], with significant limitations in reliability, usability, or cost. In a previous study [13], we developed an innovative mobile application for monitoring a three-ball IS (Figure 1a). The application integrates YOLOv8 Pose, a convolutional neural network (CNN) for keypoint detection, to track the movement of the spirometer balls in real-time using the device internal camera, providing execution feedback. The system was designed to offer an accessible and low-cost solution that preserves the traditional rehabilitation process.

The current study aims to enhance the previous work by evaluating the usability of this solution in a real-world context and applying the approach to a more complex IS, the Voldyne® 2500 (Figure 1b). This IS provides accurate feedback on both inhaled volume and inhaling flow rate, achieving higher tidal volumes and minute ventilation compared to the three-ball spirometer, beneficial for improving respiratory function [14]. In particular, the inhalation flow rate is an important factor to monitor, as inadequate inhalation can lead to negative effects on the lungs. The Voldyne® 2500 features a pipe where patients inhale to lift a green cylinder (Volume Cylinder) that measures the inhaled volume through written labels (spaced at 250 mL intervals), and a small circular component (Flow Rate Circle) that rises proportionally to the inhalation rate. To monitor these mechanisms, a mobile app was developed using the smartphone front camera and two YOLOv11 keypoint detection models [15], chosen over YOLOv8 for faster inference and higher precision in tracking the spirometer small components.
Finally, to evaluate the accuracy and usability of the proposed solution, nine healthy volunteers were tested, combining objective evaluations of the application performance with subjective feedback collected through the System Usability Scale (SUS) survey.

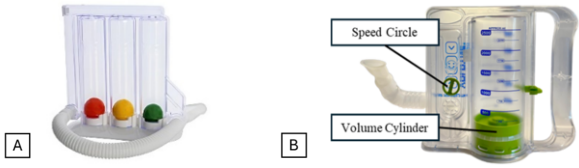

Figure 1. Three-ball incentive spirometer (a) and Voldyne incentive spirometer (b)

2. Methods

We developed a smartphone application for monitoring spirometer exercises performed with a Voldyne® 2500 spirometer. The application leverages the YOLOv11-pose keypoint detection algorithm, fine-tuned to track and monitor two key elements of the spirometer: (i) the Flow Rate Circle and (ii) the Volume Cylinder. To optimize the

performance in flow rate and volume monitoring, the application employs two fine-tuned YOLOv11-pose models:

- *Flow Rate Model*: Designed to track the Flow Rate Circle. It detects a limited number of keypoints and uses a smaller input image size to enhance inference speed, ensuring real-time feedback during the inhalation phase.
- *Volume Model*: Designed to monitor the inspired volume only at the end of each repetition. For this task, higher input image quality is used to capture the small written volume labels, resulting in a slower inference time.

2.1. Model training

To fine-tune the YOLOv11-pose models for the Voldyne® 2500 spirometer, two datasets were created: one for the Flow Rate Model (Figure 2a) and one for the Volume Model (Figure 2b). Each dataset consisted of 2210 labeled images, divided with an 8:2 ratio for training and validation, and augmented three times. For training, six models were tested for the Flow Rate Model (YOLOv11-pose Nano and Small with input sizes of 128, 192, and 256 pixels), and four for the Volume Model (Small and Medium with 256 and 288 pixels). All models were trained for 300 epochs using a grid search to optimize batch size and learning rate. For testing, 433 additional images were labeled to evaluate model precision and inference time in real-world conditions. Inference time was measured on a consumer smartphone, and model performance was assessed using precision, recall, and mAP50-95 (mean Average Precision), a standard metric for evaluating keypoints localization accuracy.

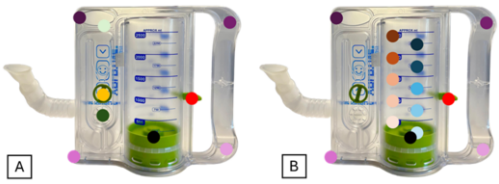

Figure 2. Keypoints labeling (colored circle) for Flow Rate (a) and Volume (b) models.

2.2. Mobile app development

The mobile application was developed using Flutter [16] for cross-platform compatibility. The user interface was designed to be simple and intuitive, even for individuals unfamiliar with smartphones. It includes: (i) a *Home Page* with general information about previous sessions, (ii) a *Training Overview Page* displaying rehabilitation session goals, (iii) a *Training Page* with a counter for repetitions and sets, and a text box for feedback (Figure 3a), and (iv) a *Recap Page* summarizing session results. In the Training page, the camera is activated, and YOLO models are used with monitoring algorithms to deliver real-time feedback and store data for performance monitoring. These algorithms rely on keypoints detected by the models, using fixed spirometer parts as a reference for tracking moving components. The main algorithms implemented are the following:

- *Repetition counting.* Uses the Flow Rate Model to detect when a repetition starts and ends, triggering the count.

- *Flow rate monitoring*. Uses the Flow Rate Model to monitor the Flow Rate Circle, emitting a sound when patients exceed the right inhalation rate.
- *Inspired volume monitoring*. Uses the Volume Model to calculate the inspired volume at the end of each repetition.
- *Spirometer positioning*. At startup, the app shows the camera view on the screen, allowing the patient to align the spirometer correctly (Figure 3b). During the session, if the spirometer is not fully visible, a prompt advises the patient.

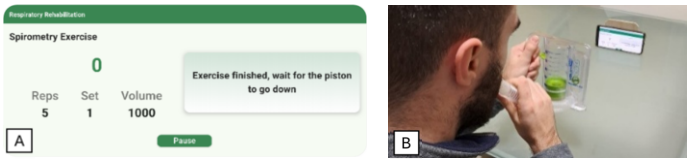

Figure 3. Training Page from the application (a) and session setup with smartphone and spirometer (b)

2.3. Usability Test

To evaluate the developed application usability and accuracy, a structured usability test was conducted with nine volunteers aged 50-60, all unfamiliar with the app and without cardiac or respiratory conditions. Participants were first instructed on how to use the Voldyne® 2500 spirometer and the app and then given a few minutes to familiarize themselves with them. During the test, they independently completed a respiratory exercise session consisting of four sets of 15 repetitions, with 20-second rest intervals. A test supervisor monitored the execution, tracking objective metrics such as repetition accuracy, volume measurements, and high inhalation rate alerts to identify discrepancies between app performance and user actions. Usability was assessed through the System Usability Scale (SUS), which was administered digitally to the tested volunteers, along with subjective feedback collected from the supervisor.

3. Results

3.1. Model testing and selection

One model was selected for each task (Table 1). The YOLOv11-pose Small model with an input image size of 128 pixels was chosen for the Flow Rate Model. This model achieved a mAP50-95 of 86.09% with an inference time of 131±7ms, ensuring accurate and real-time performance. For the Volume Model, the YOLOv11-pose Small with input images of 256 pixels was selected, as it provides an excellent mAP50-95 of 93.37%, with an acceptable inference time (511±16ms). The medium-size Volume Model offered slightly higher mAP50-95 (~2%), but with nearly twice the inference time, making the Small model the preferred choice. Model selection was also accompanied by a visual evaluation of the predictions, which confirmed good results (Figure 4).

Table 1. Testing results for the chosen Flow Rate Model and Volume Model

Model			Keypoints metrics			Inference Time [ms]	
Model name	***Yolo Size***	***Pixels***	***Precision***	***Recall***	***mAP50-95***	***Average***	***Std. Dev.***
Flow Rate	Small	128	0.9606	0.9441	0.8609	131	7
Volume	Small	256	0.9931	0.9978	0.93369	511	16

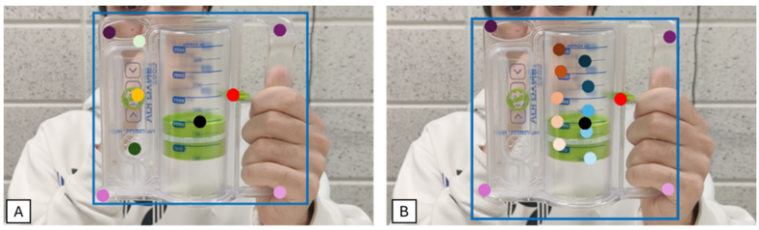

Figure 4. Inference results with Flow Rate Model (a) and Volume Model (b)

3.2. Usability results

The usability test results showed a general good accuracy. Of the total 540 repetitions counted by the app, 532 were real repetitions (98.52%) and 8 were counted without happening (1.48%). Only on two occasions, a repetition was executed but not counted. The app identified 131 out of 183 inhalation alerts observed (71.58%) and generated only 8 false alerts, resulting in an error rate of less than 1% per repetition. Regarding volume measurement, the app achieved precise volume detection in 65.41% of the analyzed repetitions, with an average error of 96mL.

The SUS survey results show a mean score of 83%, well above the usability threshold of 68, indicating a positive user experience. Only one user scored near this threshold (73%). Questions Q2 ("I found the system unnecessarily complex") and Q4 ("I think that I would need the support of a technical person to use this system") received the lowest scores, while remaining relatively high, suggesting minor usability concerns. Supervisor feedback aligned with these findings, noting that most users could complete sessions independently, though additional in-app guidance on positioning could be beneficial. They also observed significant performance variability due to differences in positioning and environmental conditions.

Table 2. Qualitative results relative to the SUS survey

	SUS general score for each user [%]									
	T1	***T2***	***T3***	***T4***	***T5***	***T6***	***T7***	***T8***	***T9***	***Average***
Score	*88*	*98*	*83*	*83*	*73*	*83*	*80*	*78*	*83*	*83*

4. Discussion

This study presents the application of the YOLOv11-pose model to track a Voldyne® 2500 IS, aiming to provide cardiac patients with digital support for respiratory rehabilitation. For this purpose, a mobile application was developed using two fine-tuned YOLOv11-pose models, one in charge of monitoring the inhalation flow rate and the other for evaluating the inhaled volume. Model testing showed high performance in tracking spirometer keypoints and achieving low inference times, critical for mobile use. The application was then tested with nine healthy individuals aged 50-60, to evaluate the accuracy and usability level. Although the developed application works generally well, it presents possible improvements in volume evaluation, inhalation alerts, and in general, with the management of some occasional edge cases (e.g. the app failing when the patient moved out of frame or counting repetitions that did not occur). SUS testing resulted in a mean score of 83%, above the benchmark of 68%, indicating good usability. Finally,

supervisor feedback highlighted the need for improved in-app positioning guidance and greater performance consistency across different environmental conditions.

Initial feedback on the application has been received from clinicians, who appreciate the ability to guide patients during the rehabilitation sessions. Future developments will focus on further increasing the usability and accuracy of the application to make it ready for clinical trials.

5. Acknowledgment

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