Motion Coach

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Contents

Abstract

People find it difficult to do tasks which are related to maintaining correct posture. For activities related to performing a posture routine correctly by oneself, unfortunately there aren't many systems out there which help people to do so and provide feedback on what went wrong and how they could improve it. There are limited options for people who prefer to learn the activity by themselves, at their convenient location. YouTube [1] tutorials are a predominant option in this space.

Hence this Master's report presents Motion Coach, the first system which addresses these issues by guiding the user through a pose routine by breaking it into sequential stages, providing real-time feedback from the convenience of a user's laptop. Two assessments evaluated Motion Coach. In the user study 93.75% of the people felt that Motion Coach made the motion activity easier when compared to learning it from manual methods (*Figure 14(a)*). 100% of the users felt the voice instructions with corrective feedback, static pose images made learning the activity much easier (*Figure 14(a)*). 100% of the users agreed that they would like to use Motion Coach again, for learning other activities if possible (Figure 15). Users on average learned the activity 49% faster when compared to manual methods (Table 2). Motion Coach could effectively guide participants to do the motion activity (a pose routine) correctly and also save time. It needs no additional hardware, making it suitable to use for the majority of people. These promising results suggest that Motion Coach could serve as a starting point for future enhancements for applying it to physiotherapy [2], teaching golf swings, learning ballet or weight training.

1. Introduction

One of the most important factors in learning any new fitness related activity is structured feedback. Dr. Erin Nitschke, who is a health and human performance college professor, says "*Providing fitness clients balanced, constructive, and positive feedback about performance and progress is crucial to success. They rely on it in order to learn and grow. Without feedback, learning doesn't happen*" [3].

Hence on a related note, one day as I was performing squats [4] at the gym, I couldn't find a mirror to look into and check if my form was right. This was the problem I faced while performing many such other exercises where I didn't know what the correct form looked like and how I was doing. The coach isn't always around and looking into the mirror from all different angles isn't always possible. Hence I asked my friends how they addressed this problem, I got to know that yes, they too felt the same way at instances, and this was not only in the gym setting but also for other instances in sports/activities like Badminton, Tennis or Yoga [5].

The usual way to work around for me was to perform the exercise to my best knowledge but in some situations end up with pain or soreness. I wouldn't know how to correct this for next time. Hiring a personal trainer would be an alternative but wasn't always convenient with my school schedule. I asked my friends and their alternatives were to make an attempt but learning felt a bit random and measuring progress was hard. For those that did hire a trainer/joined a group coaching class felt the trainer didn't give enough attention or gave vague feedback.

Many people in the fitness community face this situation. Learning to perform a posture routine by oneself is difficult, takes time and suffers from a lack of corrective feedback. Users on average spend 2 mins on watching and re-watching a posture routine tutorial [6] of about 1 min to follow along. Every person associated with sports/ fitness goes through this process. And if that is the case, this should not be a tedious and time-consuming task. Motion Coach is aimed at solving this problem by allowing its users to make the process of learning a new activity easy and quick.

To give more context, for the case study of Peloton [7], a company which sells at home exercise equipment with virtual fitness programs has seen a sharp rise in user base in the past years [8], discounting 2020 for the global pandemic. There has been a growing trend towards people preferring at home fitness equipment, showing that there is a market for such apps. With improvement in quality of the equipment/ programs, apps providing accurate feedback people would find it more impactful and time saving when compared to manual methods.

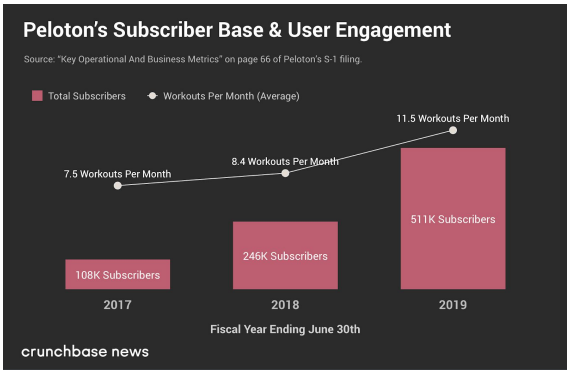

Figure 1: Sample virtual fitness app, Peloton's rise in user base in the past years [8]

2. Key Claims

The following key claims define why Motion Coach is innovative. The primary objective of this document is to explain how Motion Coach satisfies these key claims.

• **Key Claim #1:** *Motion Coach is efficient, it provides activity coaching and corrective guidance without needing additional hardware*

This claim is important because the objective of Motion Coach is to simplify the process of learning a motion activity by making use of commonly available resources. Motion Coach does this by using a laptop's camera feed, runs within brower to do pose inference [9] and provide guidance

• **Key Claim #2:** *Motion Coach shortens time to learn when compared to manual methods*

This claim is important because the objective of Motion Coach is to simplify the process of learning a motion activity. Learning by self or from a YouTube [1] tutorial takes multiple attempts, lacks corrective supervision. A time comparison was performed for all users for the time it took to perform the activity with manual methods vs Motion Coach

• **Key Claim #3:** *Motion Coach provides real time feedback to users on correcting their posture*

This claim is important because feedback is what lacks when users try to perform the motion activity on their own. Motion Coach fills this gap and provides a better learning experience though text and voice commands

• **Key Claim #4:** *Motion Coach is cost effective*

This claim is important because most systems which promise realtime guidance or live coaching are expensive to the order of costing $4000 - $7500 [10,11,12,13,14,15,16] for the equipment with high end cameras, depth, IR sensors and recorded programs. Motion Coach on the other hand costs nothing additional.

Motion Coach distinguishes itself from other current systems by providing real time guidance, conveniently within a browser using just the user's laptop camera. The guidance aspect is unique by breaking a motion activity into sequential stages and at each stage providing the user with voice and text instructions to meet the stage.

3. Related Work

This section presents various other systems aimed at solving a similar problem. These systems, while being innovative and useful to their specific problem scenarios, fall short of satisfying the key claims listed above.

3.1 YouTube Tutorial

This is the most common manual method. Manually trying to learn the motion activity by following a Youtube [1] tutorial [6] is the manual method which people mostly follow in the case of at home fitness. Motion Coach should definitely be an improvement to this baseline.

The process involves finding a tutorial online for the activity and going through it. Then the user proceeds to perform the activity to the best of his understanding and referencing the video.

Following a YouTube Tutorial has the following disadvantages:

- User must search online for an appropriate tutorial which takes time
- User then proceeds to follow through and perform by self, pauses and replays the video, which takes more time
- Learning happens without feedback, user is left with being unsure of correctness

Although this method of learning the correct way of motion is a common first step, it is inefficient and time consuming and, as mentioned in the introduction, can take upto 2-5mins for a 1 min motion activity.

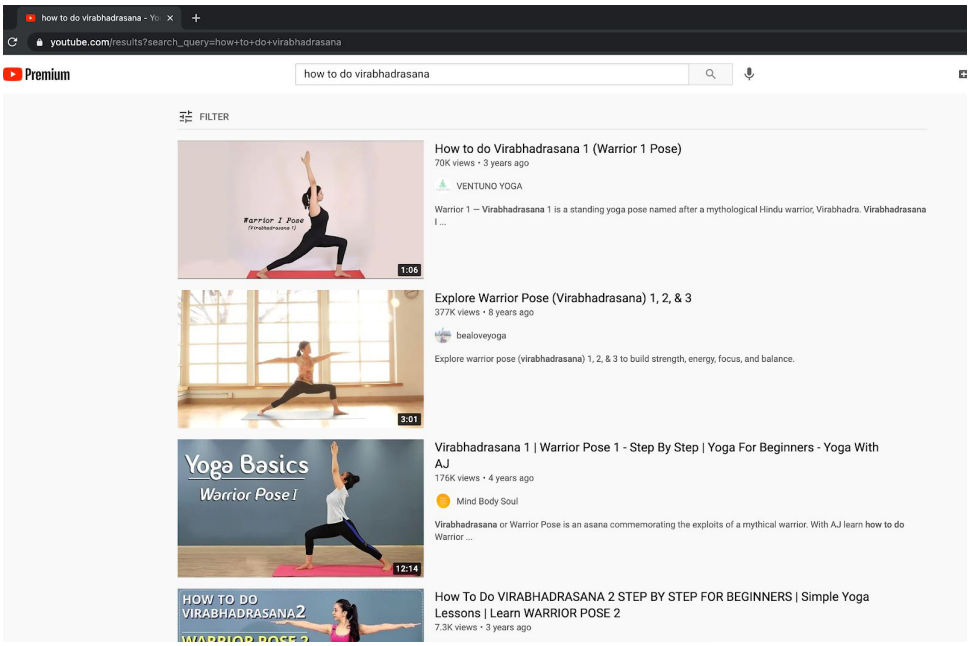

Figure 2: Looking up a sample YouTube Tutorial on performing a yoga pose routine [17]

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** Yes the system is efficient, doesn't need additional hardware
- **KC #2 (Shortens time when compared to manual methods?)** No. Method takes multiple attempts, including re-watching and pausing in between
- **KC #3 (Provides real time feedback?)** No. This method does not provide any real time feedback
- **KC #4 (Is cost effective?)** Yes. This method is free to access and publicly available

3.2 Tempo Studio

Tempo Studio [11] is one of the closest competitors to Motion Coach (Figure 3). Their product is powered with 3D & IR sensors, large 40” display screen to display correct form and provide instant feedback. The product comes with preloaded workouts, weights and barbell equipment, comes at a cost of $2000 [11].

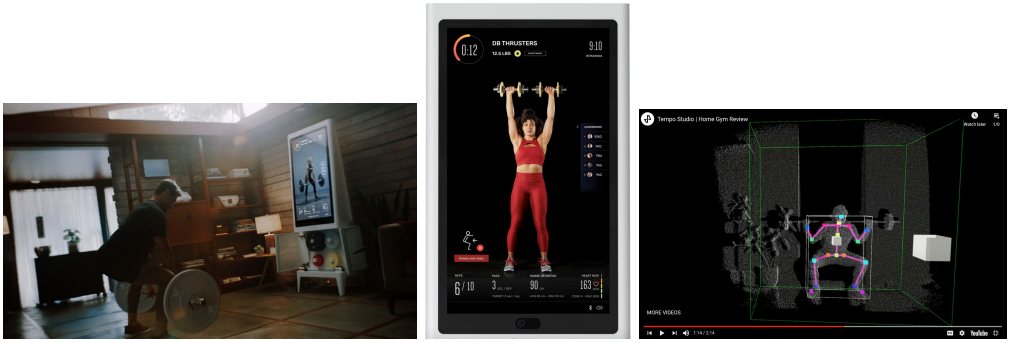

Figure 3: Tempo Studio [11] - Home Fitness product which helps users perfect their technique using AI guidance

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** The system uses depth and IR sensors to make a 3D model of the user
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** Yes. This product does provide instant feedback to user on their current posture
- **KC #4 (Is cost effective?)** Equipment costs around $2000 [11]

3.3 VAY.ai

VAY [12] is a human motion analysis company with products for motion analysis in the fitness and physiotherapy [2] space. They build a 3D human model from predicting 30 key body markers from the person's reference frame image and perform analysis and provide feedback with almost any camera setup, on mobile, laptop or custom hardware.

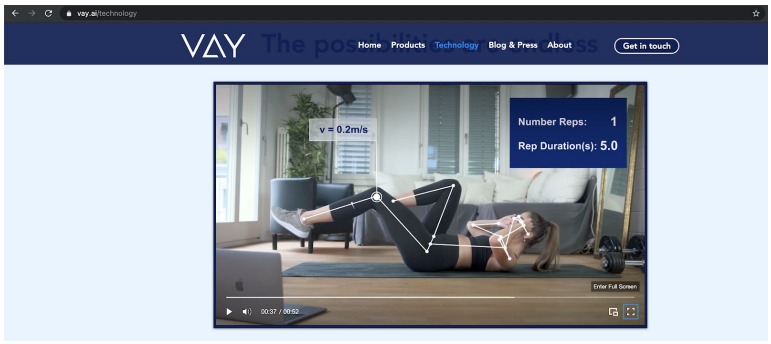

Figure 4: VAY.ai [12] - Provides users with real-time tracking, audio feedback from any camera setup, offering a complete, guided workout

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** Yes it is efficient. The product with its motion analysis, 3d human pose detection algorithm runs on any camera setup, laptop/mobile device without needing additional hardware
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** Yes. This product provide real time feedback
- **KC #4 (Is cost effective?)** Their product costs around $7500 [12]

3.4 OTARI Studio

OTARI Studio [13] is an Interactive workout mat with display. It's detachable arm contains a camera which tracks human pose and provides real time feedback via the display [18]. Product supports interactive workouts.

Figure 5: OTARI.ai [13] - An Interactive Workout Mat with Display

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** The product uses a detachable arm containing a camera which tracks human pose and provides real time feedback via the display
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** Yes. This product provide real time feedback
- **KC #4 (Is cost effective?)** The product is still in prototype stage and would be a monthly subscription based purchase ($1000 - $4000) [13]

3.5 MIRROR

MIRROR [14] is yet another home gym equipment which provides the functionality of guided workouts with a mirror like interface and a large display screen. The app provides functionalities like group fitness, recorded workouts which the user can select from and perform.

Figure 6: MIRROR [14] - Interactive workouts for a home fitness studio

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** The product uses depth sensors along with a HD camera to track human pose and provides real time feedback
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** No. This product mentions that it provides workout customizations but could not see realtime form corrections
- **KC #4 (Is cost effective?)** The product is a subscription based service with purchase cost around $1000 - $4000 [14]

3.6 Tonal

Tonal [15] is a smart home gym solution which provides the functionality of guided workouts, AI powered dynamic weights adjustment and movement analytics, and provides a large display screen.

Figure 7: Tonal [15] - Smart home gym equipment

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** The product uses HD cameras, weight sensors to provide real time guidance and dynamically adjust weights
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** Yes, it provides real time form feedback
- **KC #4 (Is cost effective?)** The product is a subscription based service, purchase costs around $1000 - $4000 [15]

3.7 Forme Life

Forme Life [16] is a home gym personal training studio which provides the functionality of guided workouts, progress tracking and comes with a large display screen which enables virtual workouts.

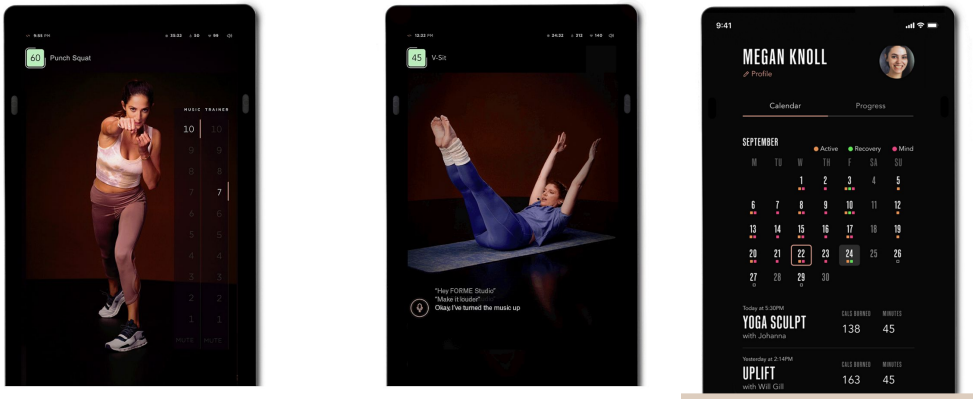

Figure 8: Forme Life [16] - Personal Training Studio for body and mind

Comparison with Motion Coach Key Claims:

- **KC #1 (Is system efficient or needs additional hardware?)** The product primarily makes use of the HD cameras to enable high quality live 1-1 virtual workouts with an actual person providing feedback
- **KC #2 (Shortens time when compared to manual methods?)** Yes. This method makes it convenient to learn the motion activity and shortens time compared to manual methods
- **KC #3 (Provides real time feedback?)** No. This product doesn't claim real time feedback/corrections on form
- **KC #4 (Is cost effective?)** The product is a subscription based service with purchase cost around $1000 - $4000 [10]

4. Solution

Motion Coach is the first system to *efficiently* provide real time guidance on a motion activity without using additional hardware. Key components of the system are as shown in Figure 9 below,

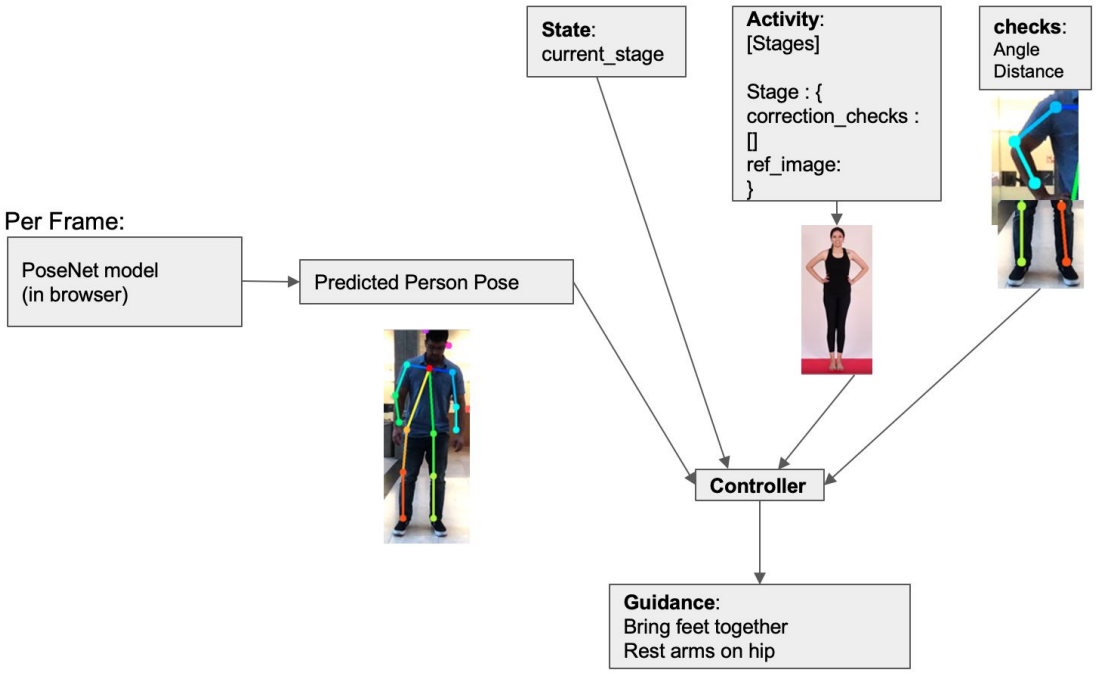

Figure 9: Motion Coach - Key Components

Motion Coach is a web-app which stores pre-processed information related to the motion activity like the key frames or stages within the activity and each stage stores the relevant checks to perform, corrective instruction is stored with each check to be given as voice and text instruction. User is guided till he reaches the last stage and activity is complete, the Controller keeps track of the current stage the user is in and provides step by step instructions. Motion Coach makes use of the PoseNet model [19] from Tensorflow.js [20] to infer user's 2D human pose [9] in real time.

4.1 PoseNet

PoseNet [19] is a lightweight deep convolutional neural network [21] based Human Pose Estimation [9] model. Where the model predicts 17 distinct key points like nose, leftEye, rightEye, leftEar, rightEar, leftShoulder, rightShoulder, leftElbow, rightElbow, leftWrist, rightWrist, leftHip, rightHip, leftKnee, rightKnee, leftAnkle, rightAnkle. The model is trained on a labelled MS-COCO [22] images dataset containing almost 200,000 images [23] and 250,000 person instances labeled with keypoints [23], which helps the model learn to predict human keypoints given an image. TensorFlow.js [20] has ported the model to be run within the browser. Briefly the model has a backbone network, MobileNet-V1 [24] /RestNet-50 [25] variants, followed by processing layers to predict joint heatmaps and joint part affinity fields [26]. Using these, the human pose is estimated.

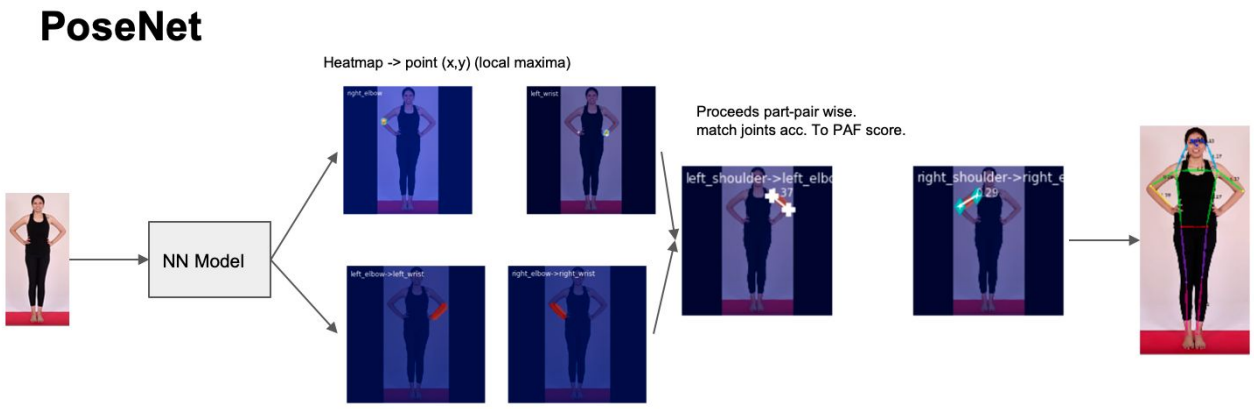

Figure 10: PoseNet [19] - detects human keypoints given an image frame

4.2 Controller

This was the logic which the browser would run, given the input frames from the laptops camera after being processed by the PoseNet [19] model would given the key points (joint positions) in the image frame, the controller would check against the current stage the user is in and provide relevant instructions.

The checks for each stage would be stored as in Figure 11 for the sample activity of raising both arms straight sideways.

Figure 11: Controller logic for a limb connection check within a keyframe

4.3 User Interface

Motion Coach is a webapp which first provides testing instructions on how to use it (Figure 12(a)) . It would then proceed to coach the user through a sample motion activity, a yoga asana [6] has been chosen for this lab study. The app would request video access to perform pose detections from the laptop camera feed. Motion Coach provides an overview of the activity (Figure 12(c)), then begins coaching the user through the routine by providing audio and text instructions, static images are also supplemented on the screen to help the user match the current pose (Figure 12(e)).

Figures 12(b) - 12(f) illustrates a few snapshots of Motion Coach in use, loaded within the web browser with the pre-selected activity of a yoga asana [6].

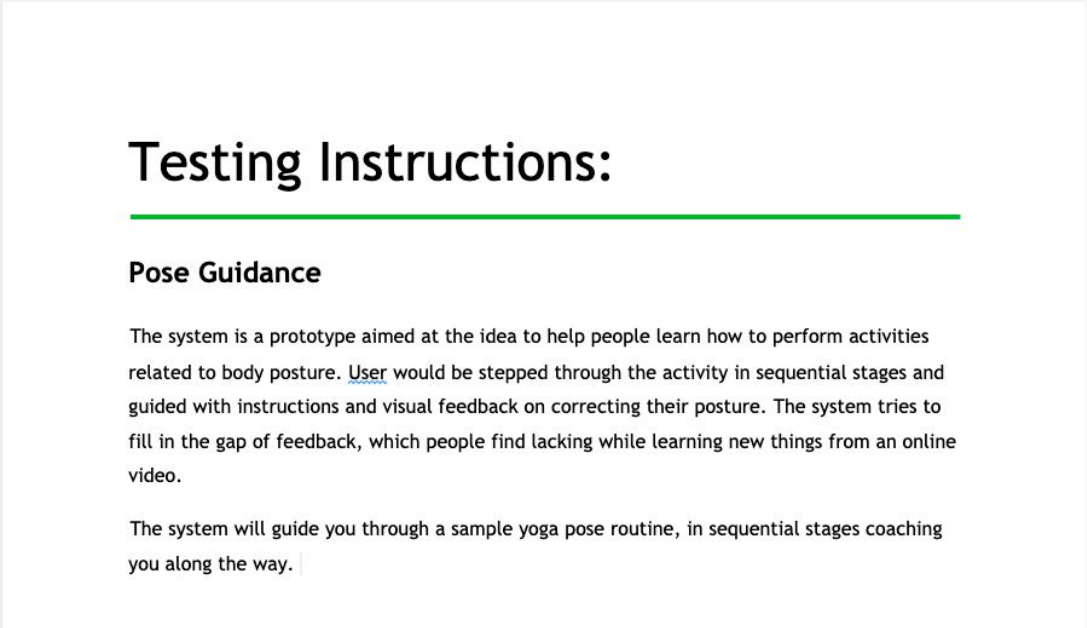

Figure 12(a): Motion Coach testing instructions

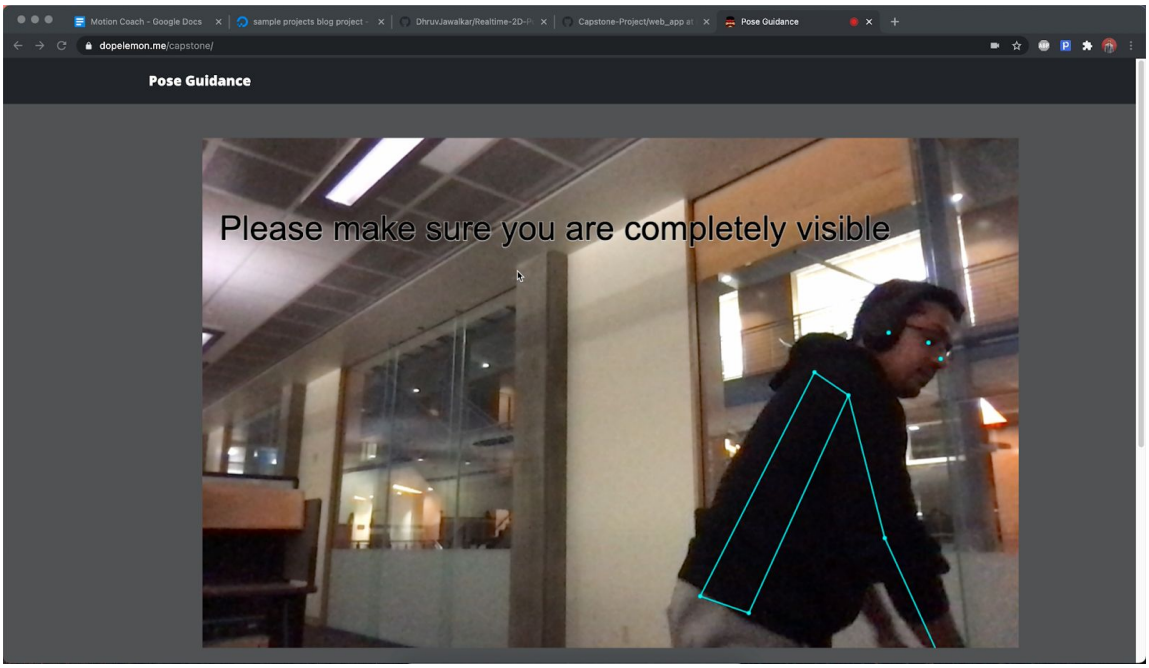

Figure 12(b): Landing page (loads camera feed)

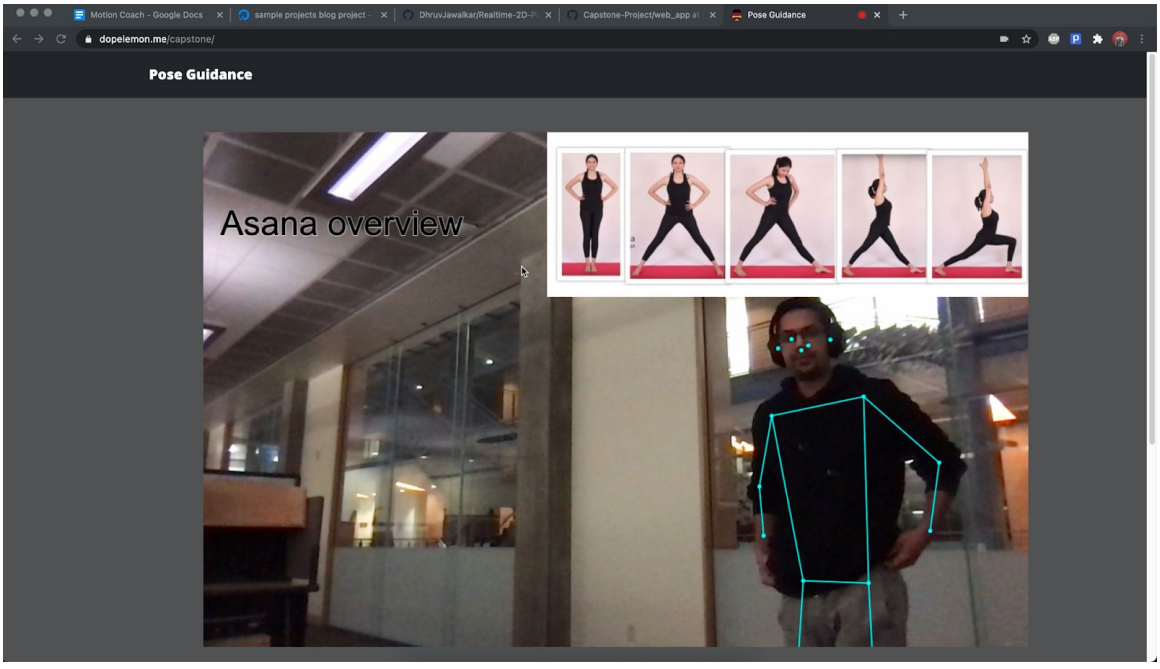

Figure 12(c): User is shown activity overview

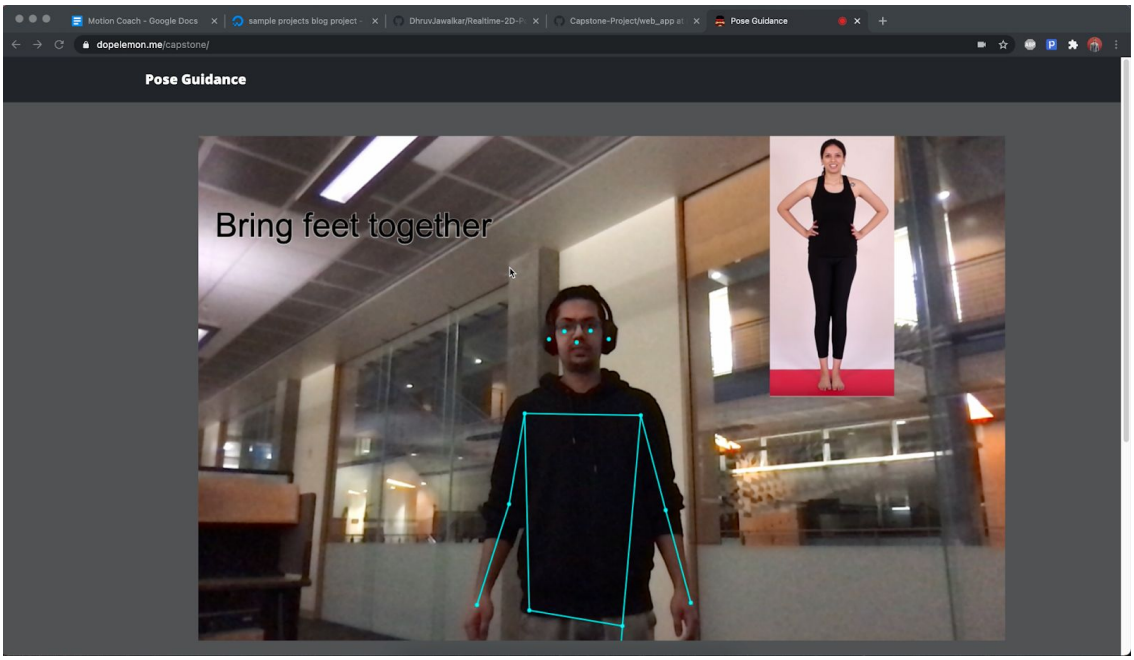

Figure 12(d): User guided within a stage with sequential instructions

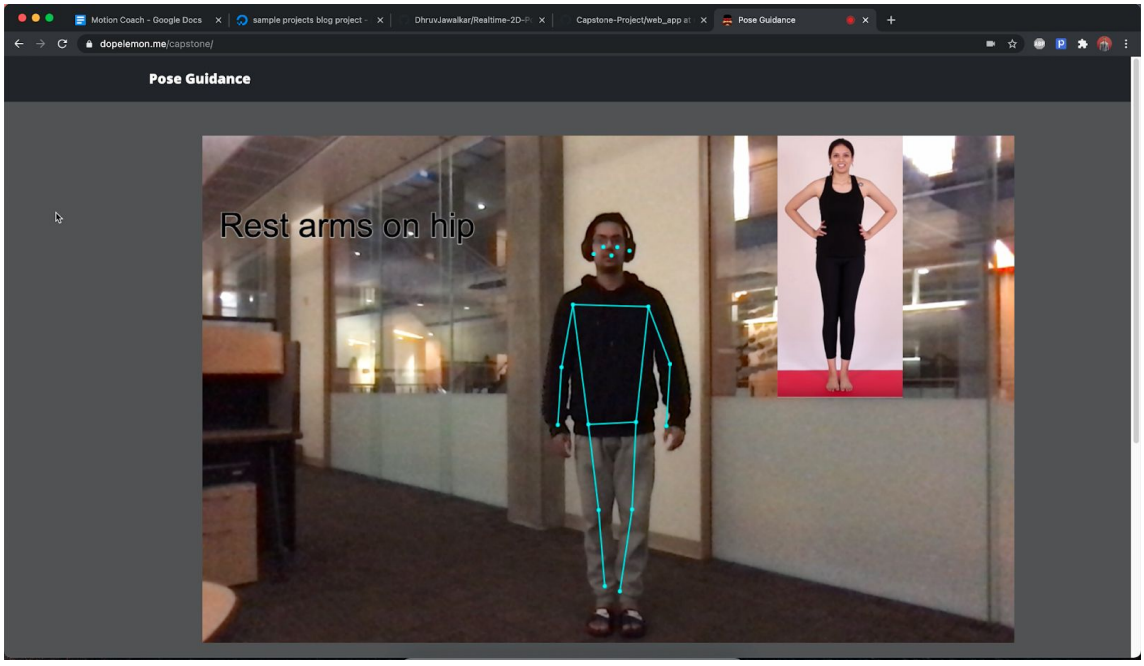

Figure 12(e): User guided within a stage with sequential instructions

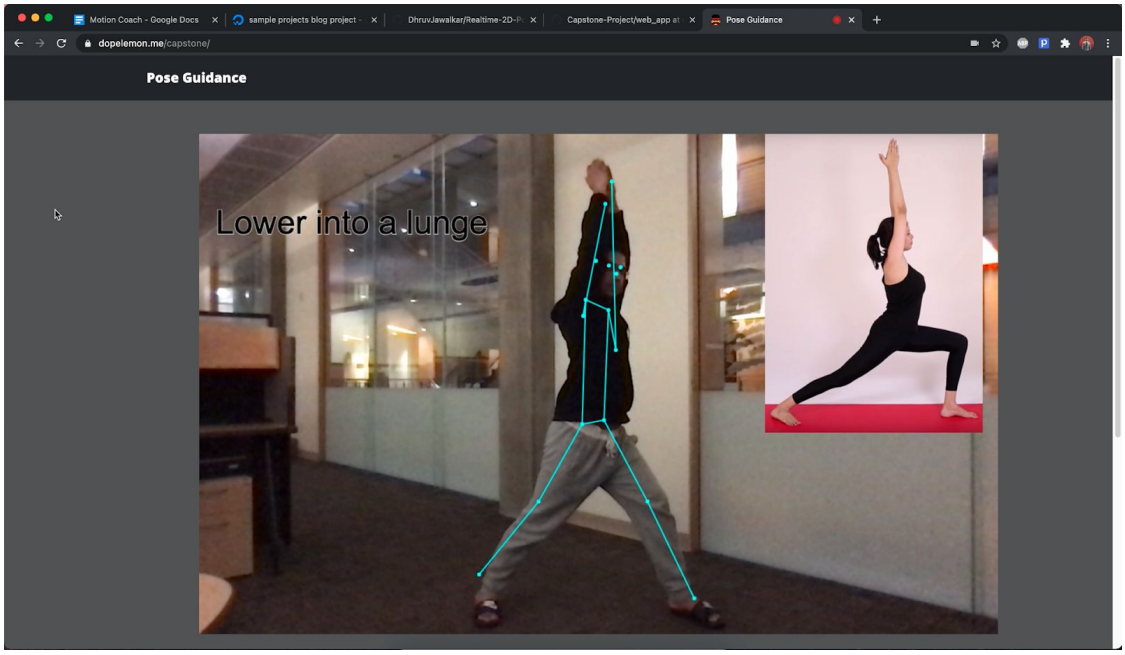

Figure 12(f): Once a stage is met, Motion Coach steps the user through next stage

4.4 Video Access, Dark Lighting and Visibility

In the case where the user is not comfortable sharing their laptop feed or is concerned about their image privacy, Motion Coach cannot proceed and the user simply cannot use Motion Coach. For the case of bad indoor lighting conditions there is a chance for the performance of the PoseNet [19] model to suffer thereby reducing keypoint predictions and then the guidance aspect would consequently suffer by waiting for the specified joint to be predicted. In the case of all key points not being completely visible in the frame, a prompt is shown to the user which indicates the user to take a few steps back/adjust the laptop screen such that the entire frame of the user is visible within the camera frame (Figure 12(b)).

5. Evaluation

The Motion Coach evaluation consisted of measuring activity learning time for the users when using Motion Coach vs using manual methods (Table 2). Usability tests in the form of questionnaires (Table 1, Figure 14(a)) and finally getting system feedback (Figure 14(b)) is also performed.

5.1 Laboratory Study

The laboratory study investigated how learning a motion activity with the manual method (watching a YouTube tutorial) compares to using Motion Coach. The goal behind Motion Coach is to enable an approach of learning a motion activity, with real-time corrective feedback and without use of additional hardware. The goal was also to compare the average time user had to spend to learn the activity with the manual method vs Motion Coach.

In particular, the study focused on three questions:

(1) Could users learn the motion activity approximately as well with the Motion Coach as with the manual method?

(2) Could the users using Motion Coach do so approximately as quickly as the users doing it from the manual method?

(3) Would users judge the Motion Coach to be approximately as usable as the manual method?

Participants: Users (N=16) were chosen as participants for the study, part who had been performing the activity since 3-5 yrs, part for 1-2 yrs and part who had never tried it before but were interested to learn.

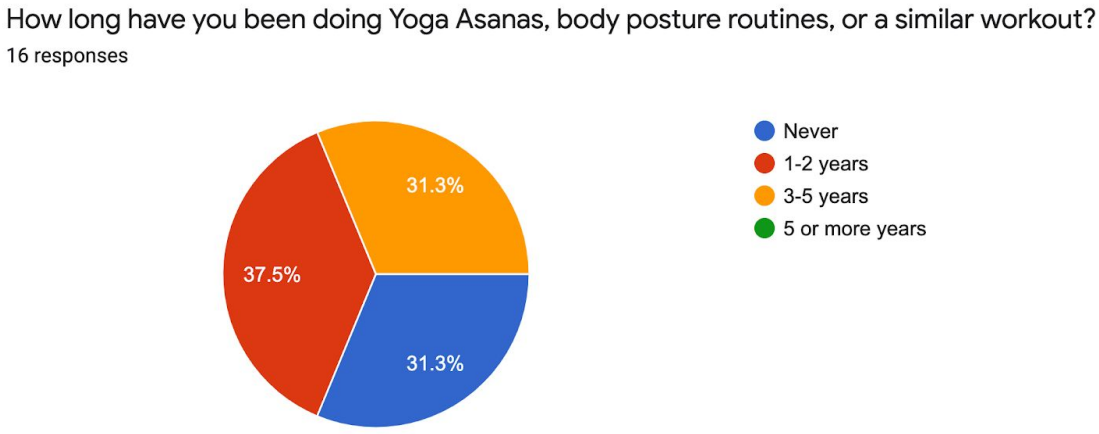

Figure 13(a): Pre-Study survey, participant split

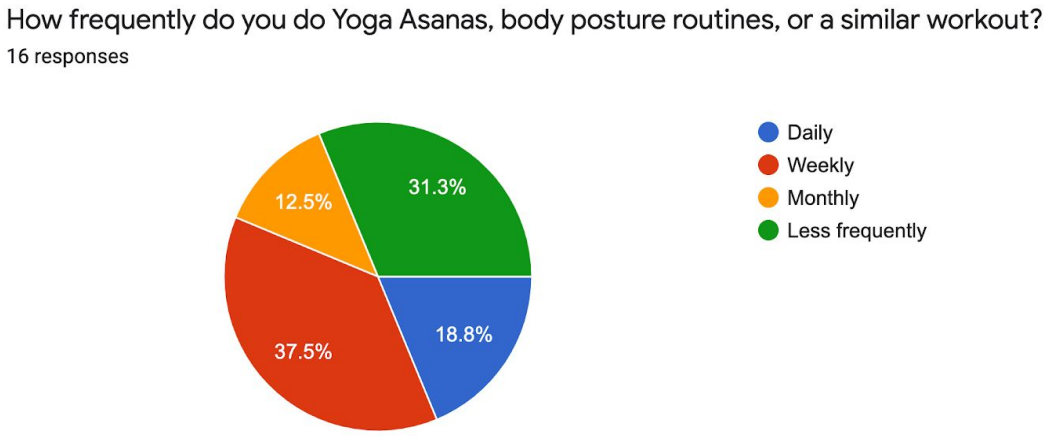

Figure 13(b): Pre-Study survey, prior familiarity with activity

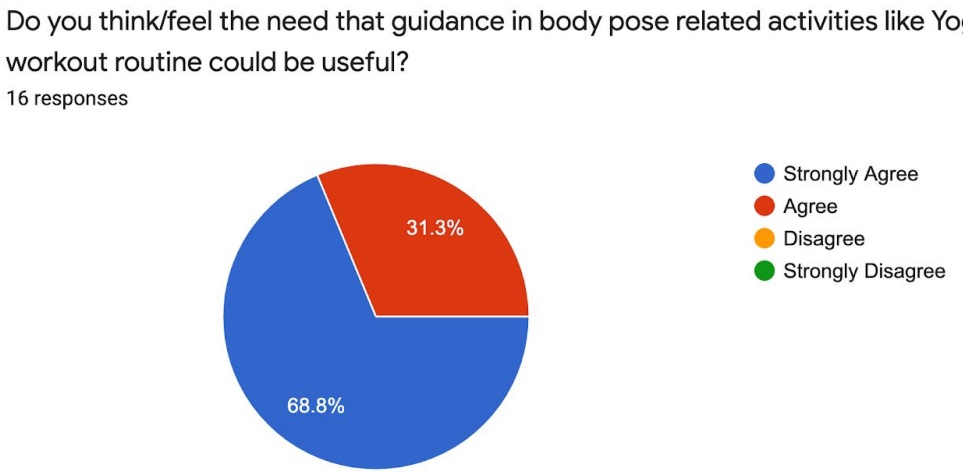

Figure 13(c): Pre-Study survey, enquiry about motion guidance

Procedure: A yoga asana [6] was chosen as the motion activity to be performed by the user's in the study. The first set of 8 participants tried Motion Coach first then the YouTube tutorial, remaining 8 trying the other way following a counterbalanced design, to remove the bias of users becoming familiar with the activity. Each user performed the motion activity twice once using Motion Coach, once by the manual method. Each participant was shown a 1 minute video tutorial about the activity being performed when trying it with the manual method and was told to mimic or perform it on their own. When using Motion Coach a testing instructions document was shown before using and the user was then told to follow the audio and on-screen instructions till activity was done. Finally, the users completed a questionnaire (Figure 14(a) - (c)).

Data acquisition: The total time taken to perform the activity was logged for each user, using the manual method and Motion Coach. The total time required was measured with a stopwatch. Usability ratings were obtained from a questionnaire, which asked participants to rate the key features of Motion Coach and users to rate the system as a whole (Table 1).

Analysis: The average time taken by participants to learn the activity was compared. The average response was calculated for each item in the questionnaires. Statistical tests were not used to compare between the methods, in part due to the small number of participants in each group, but even more so (as noted earlier) because the goal was to ascertain if users could perform *approximately* as well with the Motion Coach as the manual method.

Table 1: Post-Study questionnaire asked about overall system usability, and questions about the system's key features.

Questionnaire
Please rate on a scale of Strongly Disagree/ Somewhat Disagree/Somewhat Agree/Strongly agree:
The instruction on the screen was useful
The Static Image in the pose routine was useful
The system made learning the activity easier, compared to its YouTube tutorial
It was easy to understand how to use the system
The system, overall, was useful
I would use the system again
I would like to use the system for learning other activities if possible
I would recommend the system to friends interested in these activities
Any suggestions for improvements?
What activities, besides the yoga pose demonstrated, would you like to see the system used to teach?
What body posture related activities do you struggle with/ would find helpful if given correct posture and instructions?

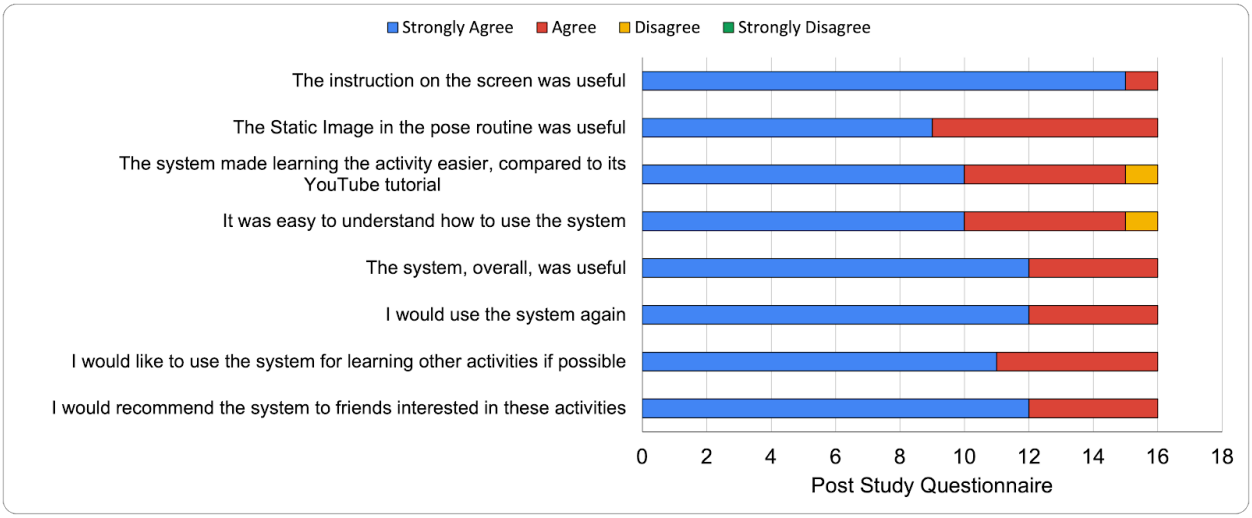

Figure 14(a): Post-Study questionnaire

Any suggestions for improvements?

15 responses

The system right now is good. It would be better if it could detect dynamic pose demonstrations.

A count down to when the activity would start would be useful since I was not sure when the tutorial had started.

Based on the detected pose, correction instructions while doing the activity would be useful as continuous feedback.

Maybe incorporate common errors people do while doing some asana.

Indicate progress and better feedback would improve it a lot

Along with the audio feedback, if some visual animated feedback is also given, it would make it easier to follow. Some small animations involving each step would be a helpful feedback. If the animations are themselves are generated by taking the body shape of the user and projecting into the image space, then that would be super amazing.

Nothing. Everything is perfect.

Figure 14(b): Post-Study survey, suggestions for improvement feedback

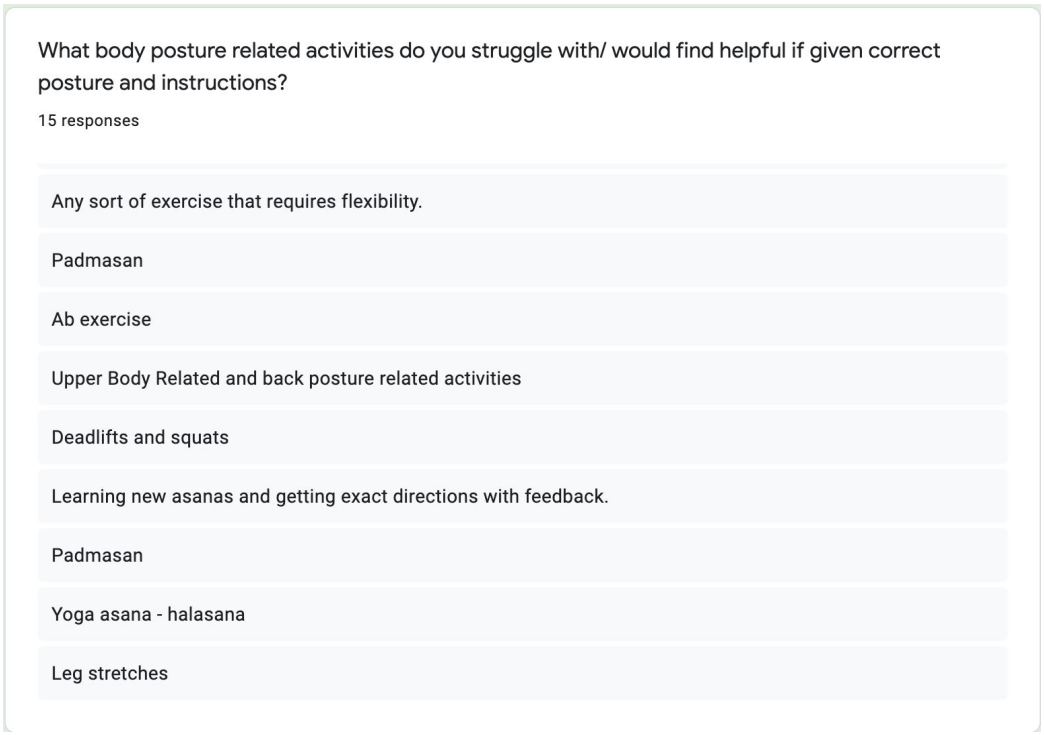

Figure 14(c): Post-Study survey, posture related activities participants struggled with

5.2 Results

Average completion time: All 16 participants succeeded in completing the activity, with an average of 0:01:42 min with the manual method and 0:00:55 secs with Motion Coach. Of the 16 participants, for 2 participants the body part detections were not accurate at instances when some parts of the body were occluded or if there was bad lighting in the room, for these cases Motion Coach was noted to have been stuck till it could detect the body part. The other 14 participants experienced correct detections and guidance stopping at each stage. Thus the participants were able to perform the activity as well as with the manual method as Motion Coach (Table 2).

Learning rate: Cumulatively the 16 participants could complete the activity in 0:14:44 minutes with Motion Coach compared to 00:27:16 minutes with the manual method. The reduction in time comes with the fact that Motion Coach has already broken down the activity into stages, displays static keyframes to the user and provides structured guidance instructions. The tutorial on the other hand has lots more content and users might fail to identify stages within the activity while following through continuous instructions. Manual method lacks corrective pause. Fastest participants compare 00:00:14 seconds vs 0:01:09 minute.

Table 2: Activity learning time for participants using the Motion Coach matched or was much shorter than that of participants following the manual method.

	Motion Coach	Manual Method
Average time (seconds)	0:00:52	0:01:42
Slowest participant (seconds)	0:02:07	0:02:23
Fastest participant (seconds)	0:00:14	0:01:09

Perceived usability: On average, participants either somewhat agreed or strongly agreed with all statements about the overall usability of Motion Coach. The exception was for a participant who somewhat disagreed with the ease of use due to lack of setup time to position the laptop for the participant to be entirely visible in the frame before Motion Coach loads the camera feed. In addition, one of the participants had privacy concerns with sharing their video.

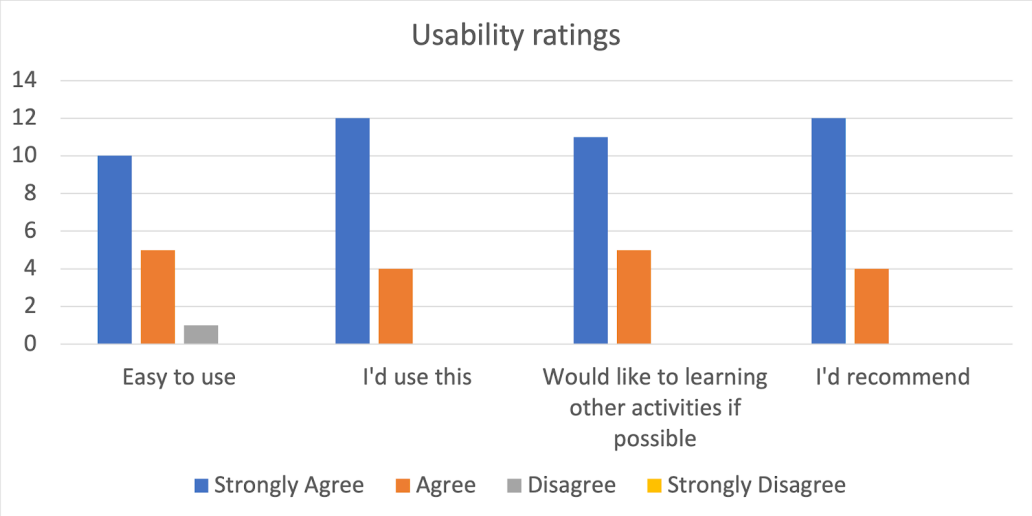

Figure 15: Usability ratings for Motion Coach

Participants in their answer to the final question in the questionnaire, about opportunities to improve the system, suggested that the system be used to teach other activities, answers have been displayed as in Figure 16.

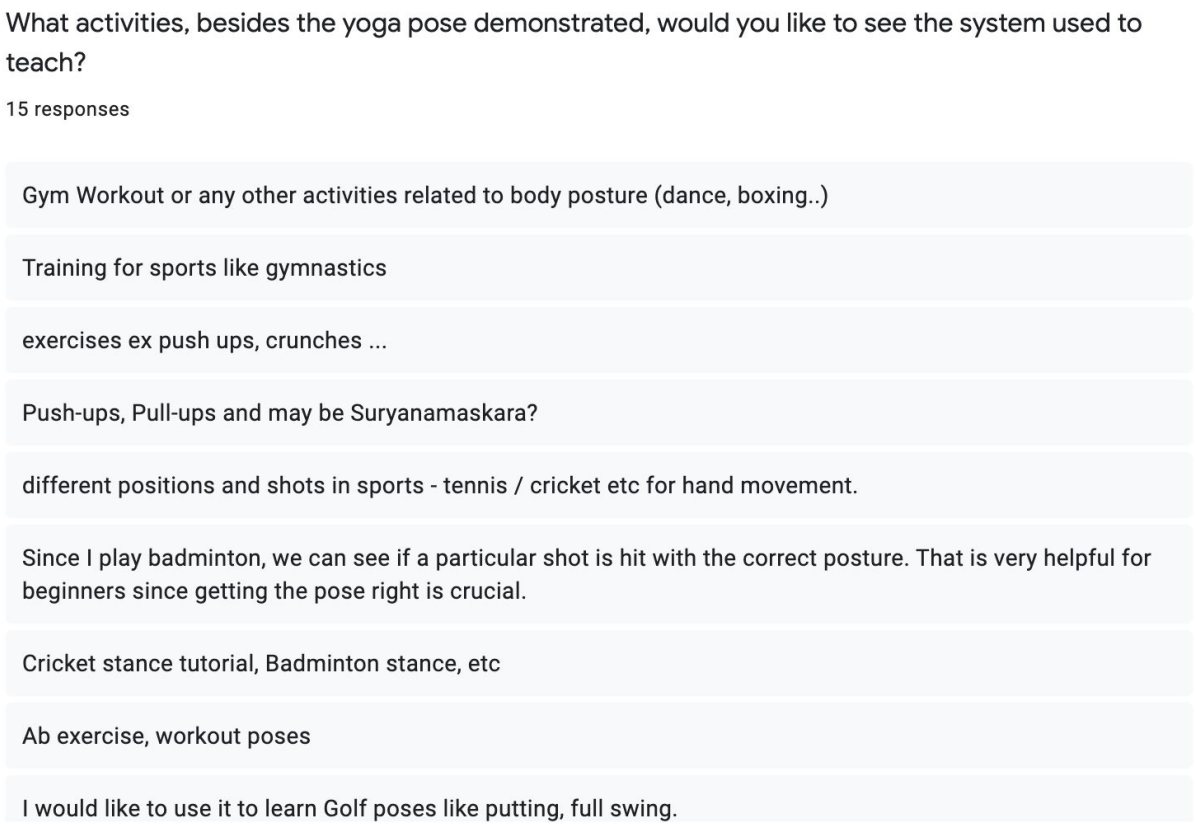

Figure 16: Potential activities for future support

6. Conclusion

Motion Coach is the first system to efficiently provide real time guidance on a motion activity like yoga asana without using additional hardware. In particular, it is the first to do it at the convenience of a user's laptop within the browser.

The system performed successfully on the task of coaching the user through an activity. In the laboratory study, participants completed a motion activity of 1 minute in 00:01:42 min with manual method vs in 00:00:55 secs using Motion Coach, saving time by half. Motion Coach did not require additional hardware, making it suitable for indoor/outdoor, personal/professional settings, and participants generally agreed with statements about its usability.

Overall, these results point toward the suitability of Motion Coach as a means of improving personal fitness/posture correction as part of physiotherapy or sports movements. The promising results suggest that Motion Coach could serve as a starting point for future enhancements.

First, although Motion Coach worked for the case of a slow moving motion activity, it would not work as well for fast performing motion in multiple instances of sports due to the limitation of the inference speed of PoseNet [19], improper camera position and lighting would also be bad conditions. At present, these activities are mostly human assessed and feedback is from trained professionals. However, developing a low-cost-method of providing assessment and feedback in these categories could invite experimentation with such software and in turn increase demand if good results are achieved. Thus, it could be desirable in the future to enhance Motion Coach to accommodate more sports analysis and feedback related features. One way to

accomplish this might be to modify Motion Coach to support a custom Offline Motion Analysis Model. This would make it possible, for example, to provide metrics on key moves in sports during training.

In conclusion, Motion Coach is an important innovation that opens up new directions for addressing the need for posture detection, analysis and correction. It performed admirably in terms of effectiveness, efficiency, and usability. Equipping it with new features could enhance its uses in sports and fitness.

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