Task Analysis on Yoga Poses Toward a Wearable Sensor-based Learning System for Users with Visual Impairment

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People with visual impairments may experience difficulties in learning new physical exercises due to a lack of visual feedback. Learning and practicing yoga is especially challenging for this population as yoga requires imitation-oriented learning. A typical yoga class requires students to observe and copy poses and movements as the instructor presents them, while maintaining postural balance during the practice. Without additional, nonvisual feedback, it can be difficult for students with visual impairments to understand whether they have accurately copied a pose – and if they have not, how to fix an inaccurate pose. Therefore, there is a need for an intelligent learning system that can capture a person’s physical posture and provide additional, nonvisual feedback to guide them into a correct pose. This study is a preliminary step toward the development of a wearable inertial sensor-based virtual learning system for people who are blind or have low vision. Using hierarchical task analysis, we developed a step-by-step conceptual model of yoga poses, which can be used in constructing an effective nonvisual feedback system. We also ranked sensor locations according to their importance by analyzing postural deviations in each pose compared to the reference starting pose.

INTRODUCTION

Learning and performing physical exercises can be challenging for the visually impaired population without additional guidance to compensate for their lack of vision. Imitation-oriented or observational learning is a common form of learning, which is achieved by observing and copying an instructor’s postures and movements (Ferrari, 1996). For blind and low-vision populations, it is difficult to understand the correct posture without access to visual feedback – observing an instructor’s posture, mirroring the posture, and visually inspecting one’s own posture for comparison and correction.

The challenges these populations face in exercising are a threat to their physical health (Capella-McDonnell, 2007; Stuart, Lieberman, & Hand, 2006; Weil et al., 2002). A previous study showed that the odds ratio of being obese in people who are blind or have low vision is 1.5 (95% CI, 1.3–1.6) (Weil et al., 2002). Among adults with visual impairment, 26.4% were obese (BMI > 30 kg/m\(^2\)) vs. 15.1% of those without disabilities (Weil et al., 2002). Barriers like inaccessibility or travel difficulties are other reasons impeding active involvement in exercise (Rector, Bennett, & Kientz, 2013).

Compared to other exercises, yoga may be more accessible to the visually impaired population: it is relatively stationary, requires minimal to no equipment, and can be done easily in one’s own space. However, yoga can be more challenging to learn than other types of exercises, as it involves maintaining postural balance beyond the level of balance control required for daily activities (e.g., standing, walking, or climbing stairs). A previous study showed that people with visual impairment have poorer static balance performance compared to sighted people, despite similar levels of knee and ankle muscle strength (Giagazoglou et al., 2009).

Researchers have previously attempted to develop virtual yoga learning systems. Eyes-Free Yoga is one such system, built with depth cameras (viz., Microsoft Kinect) for visually impaired people (Rector et al., 2013). However, the authors found that video-based motion tracking had limitations, as the quality of posture assessment can be affected by the occlusion and orientation of a subject’s body. An automatic yoga pose recognition system was also developed using 11 wearable inertial sensors for full-body tracking (Wu, Zhang, Chen, & Fu, 2019). This system was able to recognize 18 different yoga poses with 89.3% accuracy using a backpropagation artificial neural network and fuzzy C-means methods (Wu et al., 2019). In practice, a yoga garment with 11 inertial sensors may be challenging to maintain (e.g., charging, washing) and costly to manufacture. Thus, limiting the number of sensors is a critical aspect of wearability (Lim & D’Souza, 2020).

Our eventual goal is to develop an intelligent wearable sensor-based learning system that can help a visually impaired user learn yoga on their own. The system will have the following three components: (1) step-by-step verbal instruction, (2) posture tracking, and (3) nonvisual feedback for pose correction at each incorrect step. To implement these components, we aim to develop a system with inertial sensors embedded in yoga clothing.

As an initial step toward the development of a wearable sensor-based virtual learning system for people with visual impairments, we conducted a task analysis to understand the composition of yoga poses. Specifically, this work presents (1) a task analysis of yoga poses, which are decomposed as step-by-step movements; and (2) an assessment of wearable sensor attachment locations for the system. The analysis will be used in developing effective instructional guidance and feedback.
mechanisms for the aforementioned learning system. Implications and directions for future research are also discussed.

**METHOD**

Selection of Yoga Poses for Learning

A yoga practice session generally involves progressing through different sets of yoga poses. These sets of poses can be differentiated by their starting pose and difficulty level. Starting poses are the main category of yoga poses, where the student is either in a standing, seated, or supine posture. In each starting pose, variations on the poses decide the level of difficulty. A typical yoga session might involve 2–3 starting poses, each of which begins a set of 5–6 different poses that use the starting pose as a base. Within each set, easy to more advanced poses are practiced sequentially.

Commonly performed yoga poses were reviewed (Kaminoff, Matthews, & Ellis, 2007; Parkes & Culley, 2016) and selected for this study. We selected three of the most commonly used starting poses; namely, I: *Standing (Mountain)* pose, II: *Table* pose, and III: *Corpse (Supine)* pose as described in Figure 1. We chose various levels of yoga poses in each category to accommodate different levels of user experience, but excluded excessively complicated poses that requires high levels of experience and balance control (e.g., headstand). The difficulty level of each yoga pose was referenced from Parkes and Culley (2016). Additionally, we identified the symmetry of each pose to decide on sensor attachment locations (unilateral vs. bilateral attachment).

![Images depicting three starting yoga poses.](image)

Figure 1: Images depicting three starting yoga poses.

Task Analysis

Hierarchical task analyses (Annett, 2003) were performed to decompose each yoga pose into step-by-step movements. Instructional manuals and books (Devananda, 2011; Kaminoff et al., 2007; Parkes & Culley, 2016), as well as instructional videos (from https://yogawithadriene.com/), were reviewed for this purpose. Each yoga pose was broken down into micro-movement steps wherein the learner changes only one body segment or joint at a time. We pilot-tested these step-by-step instructions with people who had never practiced yoga before and revised the instructions using their feedback to avoid ambiguity. Movement steps between different yoga poses within the same starting pose category were highly overlapped, so separate task analyses were performed for each starting pose category (i.e., the standing, table, and corpse poses, as depicted in Figure 1).

Sensor Attachment Locations

As we plan to integrate inertial sensors in yoga clothing as part of future development, we conducted a systematic investigation of sensor attachment locations as a preliminary step. Ten body segment locations were initially selected for further investigation based on the most popular and preferred wearable sensor attachment locations in previous studies (Lim & D’Souza, 2020; Mokhlespour Esfahani & Nussbaum, 2018). These locations include the upper back (thoracic vertebra between T1 to T12), the lower back (lumbar vertebra between L1 to L5), the upper arms, the lower arms, the thighs, and the shin, as described in Table 2. Both the right (or dominant) and left (or nondominant) sides were considered in the analysis. For asymmetric poses that can be performed on either side of the body (e.g., Tree pose performed with either right- or left-foot lifted), we considered the pose with major postural deviations on the right side (e.g., Tree pose with the right-foot lifted).

We investigated the important sensor attachment locations by identifying the location of body segments showing critical movement in each yoga pose relative to the associated starting pose. Critical movement is defined here as any postural deviation that is the key movement in each step. This includes flexion-extension, abduction-adduction, and/or axial rotation in any body segment or joint. Body segments showing postural deviations in any of the steps within each yoga pose were coded as ‘1’ vs. ‘0’ for no changes. For example, *High Mountain* pose (1.1 in Table 1) is the standing upright posture with both arms above the head. Arm positions are the main deviation from the starting pose; thus, the upper and lower arms were coded as ‘1.’

**RESULTS**

A total of 17 yoga poses (3 starting poses + 14 variations) were chosen based on the selection criteria discussed. Table 1 groups the variation poses by their associated starting poses. The name, description, difficulty level, and symmetry of each pose are given. Among the selected yoga poses, 7 out of 17 poses (41.2%) were easy, 5 out of 17 poses (29.4%) were intermediate, and the rest of them (29.4%) were difficult. Eleven out of 17 poses (64.7%) were symmetric. Overall, the selection of poses was diverse in terms of the difficulty levels and symmetry types within each starting pose category.

Figure 2 describes the overall step-by-step movements identified from the hierarchical task analysis for standing yoga poses (1.0 - 1.6 in Table 1). All of the poses under this category started in the upright standing pose, which is called *Standing (Mountain)* pose (1.0 in Figure 2). Some poses are performed as variations of others. For example, *Warrior II* (1.5 in Figure 2) and *Extended Side Angle* (1.6 in Figure 2) are both variations of *Warrior I* (1.4 in Figure 2).
Table 1: List and descriptions of 17 yoga poses (3 starting poses + 14 variations) grouped by starting pose (I: standing (mountain), II: table, III: corpse (supine)). Difficulty level was gauged based on the extent of balance control and strength required to hold the pose, referencing Parkes and Culley (2016). The symmetry of each pose was also identified: Sym = symmetric pose, Asym = asymmetric pose.

<table>
<thead>
<tr>
<th>No.</th>
<th>Pose Name</th>
<th>Description</th>
<th>Difficulty Level</th>
<th>Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Standing (Mountain)</td>
<td>Standing upright with feet slightly apart and arms at the sides of the body.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>1.1</td>
<td>High Mountain</td>
<td>Standing upright with feet slightly apart and arms slightly apart, above the head.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>1.2</td>
<td>Chair</td>
<td>Upright standing pose with a 45° bend in the knees, with arms slightly apart, raised above the head. Resembles sitting in a chair.</td>
<td>Intermediate</td>
<td>Sym</td>
</tr>
<tr>
<td>1.3</td>
<td>Tree</td>
<td>Single-leg standing pose with hands pressed together below the chin, the free foot resting on the ankle closest to the lower body.</td>
<td>Intermediate</td>
<td>Asym</td>
</tr>
<tr>
<td>1.4</td>
<td>Warrior I</td>
<td>Lunging forward pose with front knee bent at a 90° angle and back leg straight. Arms are above the head, shoulder width apart; back is straight.</td>
<td>Difficult</td>
<td>Asym</td>
</tr>
<tr>
<td>1.5</td>
<td>Warrior II</td>
<td>Adaptation of Warrior I with the back foot perpendicular to the front foot and the arms out to the side, parallel to the ground.</td>
<td>Difficult</td>
<td>Asym</td>
</tr>
<tr>
<td>1.6</td>
<td>Extended Side Angle</td>
<td>Adaptation of Warrior II with right forearm resting on the right knee and left arm raised.</td>
<td>Difficult</td>
<td>Asym</td>
</tr>
</tbody>
</table>

Starting Pose II: Table

<table>
<thead>
<tr>
<th>No.</th>
<th>Pose Name</th>
<th>Description</th>
<th>Difficulty Level</th>
<th>Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>Table</td>
<td>Starts on hands and knees. Knees are separated and legs are hip width apart.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>2.1</td>
<td>Downward-Facing Dog</td>
<td>Inverted pike pose with a 90° bend at the hips; hands on the ground, with feet and arms shoulder width apart. Head in line with the arms.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>2.2</td>
<td>Front Plank</td>
<td>Straight-body pose with elbows and feet on the ground, while torso and legs are raised in a straight line above the ground.</td>
<td>Intermediate</td>
<td>Sym</td>
</tr>
<tr>
<td>2.3</td>
<td>Sunbird</td>
<td>Table pose with opposite arm and leg raised parallel to the ground.</td>
<td>Difficult</td>
<td>Asym</td>
</tr>
</tbody>
</table>

Starting Pose III: Corpse (Supine)

<table>
<thead>
<tr>
<th>No.</th>
<th>Pose Name</th>
<th>Description</th>
<th>Difficulty Level</th>
<th>Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>Corpse</td>
<td>Lying down on the back with feet hip width apart. Arms on the ground to either side of lower body.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>3.1</td>
<td>High Corpse</td>
<td>Supine pose with the arms raised above the head.</td>
<td>Easy</td>
<td>Sym</td>
</tr>
<tr>
<td>3.2</td>
<td>Knee to Chest</td>
<td>Supine pose with one leg straight, in line with the body; the other is leg pulled up by the chest, with both hands holding up the knee.</td>
<td>Easy</td>
<td>Asym</td>
</tr>
<tr>
<td>3.3</td>
<td>Reverse Plank</td>
<td>Straight-body pose with palms and heels on the ground, while the hips and torso are raised up flat towards the ceiling.</td>
<td>Intermediate</td>
<td>Sym</td>
</tr>
<tr>
<td>3.4</td>
<td>Bridge</td>
<td>Supine pose with the hips raised, knees bent above the ankles at a 90° angle and feet hip width apart. Arms are besides the hips, with shoulders and neck on the ground.</td>
<td>Intermediate</td>
<td>Sym</td>
</tr>
<tr>
<td>3.5</td>
<td>Seal</td>
<td>Imitates the posture of a seal, arching the back with the torso up off the floor.</td>
<td>Difficult</td>
<td>Sym</td>
</tr>
</tbody>
</table>

Table 2: List of 17 yoga poses and their corresponding postural deviations from the starting pose for each body segment (left). The level of postural deviation was coded as ‘1’ if any postural deviations are observed for that particular body segment in any of the movement steps within each yoga pose. ‘0’ was used to indicate no changes. For the table and corpse starting poses, standing (mountain) pose was used as a reference pose in calculating postural deviations. Circles over body parts (right) show the count of postural deviations across different yoga poses from the table to the left. Left side body segment is indicated by * if the left side posture is symmetric to the right side.

<table>
<thead>
<tr>
<th>No.</th>
<th>Pose name</th>
<th>Upper back</th>
<th>Lower back</th>
<th>Upper arm</th>
<th>Lower arm</th>
<th>Thigh</th>
<th>Shin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
</tr>
</tbody>
</table>

Count: 10 8 14 (12*,1) 15 14 (13*,1) 11 10 (7*,3) 9 10 (8*,2)
A-1: Begin in the mountain pose standing upright with your feet slightly apart and your arms at the sides of your body.

A-2: Inhale and raise your arms straight above your head so that they are shoulder width apart. The arms should be straight and parallel to each other.

A-3: Turn your palms to face each other, while keeping your arms inline with your shoulders and hands apart.

B-1: Relax your shoulders down while keeping your arms, legs, and back straight.

C-1: Bring your feet together and press your legs together.

C-2: Exhale while bending at the knees so that the legs are in a squat position.

C-3: Keep your neck, back, and arms straight.

D-1: Transfer your weight to the left side of your body, as you are about to lift your right leg up.

D-2: Lift your right leg up and place your right foot at the your left ankle bone. The right knee should be bent and pointing directly down and to the right.

D-3: Press and hold your hands together in a clapped position at chest level. Your palms should be together and elbows should be pointing diagonally down to the ground.

D-4: Your shoulders should be relaxed and your back should be straight.

E-1: Exhale and take a big step backward with your left leg. Slightly turn your left foot out away from your body and press your foot firmly into the ground.

E-2: Bend your front right knee forward to make a rectangular shape while keeping your back leg straight.

E-3: Face your body forward.

E-4: Tilt your head back, while keeping your hips facing forward.

F-1: Turn your hips to the left to now be facing the side in the same direction as your back left foot.

F-2: Lower your arms out to the side, parallel to the ground. Your palms should be facing down.

F-3: Keep your hips parallel to your back left foot.

F-4: Relax your shoulders down and turn your head towards the right arm.

G-1: Lean your body towards your right leg and rest your right forearm on your right leg.

G-2: The arm should be bent in a rectangular shape with your right palm facing the ceiling.

G-3: Raise your left arm above your head reaching up towards the ceiling.

G-4: Rotate your face to angle up towards the ceiling.

Figure 2: Task analysis of standing yoga poses (1.0 - 1.6 in Table 1) with the sequence of movements. Each rounded shape represents a final yoga pose after following the indicated step-by-step movements (shown as blocks). The rounded shapes’ colors indicate the difficulty of the poses, with green, yellow, and red representing easy, intermediate, and difficult levels, respectively.

Figure 3: Step-by-step movements from an example yoga pose, Warrior I (1.4 in Table 1), were depicted to illustrate the postural deviations from the prior step (denoted by red lines and a circle). Each step is associated with task numbers (Task #) in Figure 2.

The importance of sensor attachment locations was quantified for each yoga pose and body segment. Figure 3 shows step-by-step movements and postural deviations from one of the example yoga poses, Warrior I. From the starting standing pose, the second step (Tasks A-2 and A-3) showed postural changes in upper arms and lower arms (denoted by red lines in Figure 3). In the following steps (Tasks E-1 through E-4), postural deviations were observed in the left thigh and left shin, right thigh and right shin, upper and lower back, and head, sequentially. Table 2 summarizes the results of the analyses performed for each yoga pose to investigate the importance of sensor attachment locations. Overall, the lower arms (R/L) showed the most deviations from each starting pose across all yoga poses. The upper arms (R/L) and right thigh followed,
with more postural deviations from each starting pose compared to the shins (R/L) or back. Upper back and lower back postures did not change much within each group, relative to the group’s starting pose. This suggests that the poses within each group involved variations in the upper or lower extremities, rather than in the core.

**DISCUSSION AND FUTURE DIRECTIONS**

This study was performed as an initial step toward developing a wearable sensor-based yoga learning system for visually impaired users. People with vision impairments may experience difficulties in picturing and following along with yoga poses without visual guidance. Thus, this study aimed to identify step-by-step sequential movements, using hierarchical task analysis, to facilitate the creation of a modular learning scenario. In future prototype development, progress within each step will be assessed by wearable sensor-based postural information, and the user will be given appropriate feedback to guide them towards completion of the full yoga poses.

The analysis of postural deviations in each body segment for each yoga pose provides a systematic approach to deciding the critical sensor attachment locations for the learning system. The lower arms were identified as the most critical locations for sensor attachment, followed by the upper arms. Although the right and left sides were identified as almost equally important, the detailed analysis on symmetry of each pose revealed that most of the left-side (nondominant) arm motion is symmetric to the right-side motion even though the pose itself may not be symmetric.

Limiting the number of sensors is a critical aspect of wearability in terms of user comfort and maintenance (Lim & D’Souza, 2020). Unless the sensors are fully embedded in a garment that can be maintained without detaching the individual sensors, increasing the number of sensors will decrease usability. The optimal number of sensors required for the system remains to be determined in future work with more involved analysis including feature extraction and selection process with the observed motion data. The findings from this study suggest a particular progression through which we can increase the number of wearable sensors; for instance, the upper and lower extremities, such as the lower arms, upper arms, and thighs are the most important tracking locations. The back was only important in ensuring accurate starting poses, and it may be possible to interpolate this information from the combination of two or more sensors attached to the extremities. Additionally, since the left side mostly mirrors the right side, additional feedback or instructions such as “Your right and left arms should mirror each other in this pose” may be enough to guide the user without directly measuring both sides using sensors.

In the future, we plan to evaluate the potential of sensor locations for providing vibro-tactile feedback as well. In previous works, only verbal feedback was given to a user for posture correction (Rector et al., 2013; Wu et al., 2019). In one example yoga pose, Reverse warrior, Eyes-Free Yoga gave 20.7 verbal feedback instructions (e.g., “Lower your arms”, “Bring your arms closer to your head”) on average per participant for posture correction (Rector et al., 2013). This can be strenuous for users. Thus, combining different feedback modalities (e.g., verbal and vibro-tactile) can be effectively used to enhance the learning experience without stressing the user. Visual and localized haptic feedback combined improved motor training of the lower extremities in a virtual learning scenario compared to visual feedback alone or haptic feedback alone (Koritnik, Koenig, Bajd, Riener, & Munih, 2010). Further investigation of the specified locations remains for combining multimodal feedback, which can potentially be more effective than verbal feedback alone.

**REFERENCES**


