# HeyPillow: Computationally Guided Sleep Behavior Study Through Sensing

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## ABSTRACT

Sleep is a large contributor to a person's health and well-being. Since sleep posture is a factor that may affect the quality of sleep, we investigate ways to encourage people to sleep in certain positions that may lead to better sleep quality. HeyPillow is a fabricated sensing pillow that processes the position and orientation of a person's head and recommends certain sleep positions, e.g. their left side, right side, back, or stomach, based on the user and their usage of the pillow. In addition to using HeyPillow as a means to investigate methods on whether this system can improve sleep quality, we also aim to explore whether a person's sleep positions can be influenced subconsciously through the recommendation system.

## BACKGROUND AND MOTIVATION

While sleep only takes about a third of our day, its quality affects us for the other two thirds. However, millions of people around the world suffer from sleep problems [1], some of which are related to their sleep position. Previous studies have found that sleep position affects sleep apnea and sleep paralysis. [2, 3]. De Koninck et al. found that sleep positions affect sleep quality as poor sleepers spent more time on their backs with their heads straight [5]. Gordon et al. found that people are good at self-reporting their "usual sleeping position," [6], which implies that people are aware of it.

Previous studies have focused on wrist-worn trackers, phone apps or even bed sheets, as devices to track sleep quality [7–9]. However, the research on trackers for sleep positions is limited. In this work, we set out to address this gap with creation of a sleep tracking system, HeyPillow, developed specifically to detect sleeping position (i.e. on the left side, on the right side, on stomach, on back, or head off the pillow). That way, we can encourage people to spend more time in the sleep position that leads to better sleep quality.

HeyPillow consists of a pillow with embedded sensors (a pressure grid, a gyroscope, and an accelerometer), and a server to collect and analyze the data. Users sleep on the pillow as they would normally, but it can also give them suggestions on which sleep position leads to the best sleep quality. Then, through a framework for self-experimentation, they can try that position for a few days and see if it leads to an actual improvement.

Beyond the creation of a tracker for sleep positions, our research also aims to understand how sleep positions are related to sleep quality. Our goal is to conduct user studies to explore (1) whether the user's sleep position can be controlled subconsciously, and (2) whether the self-experimentation framework can be applied to sleep positions to improve sleep quality.

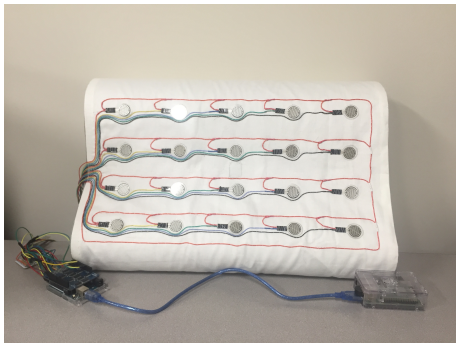

**Figure 1: HeyPillow is a fabricated sensing pillow that senses the position and orientation of the head through on-board inertia measuring unit sensors (IMU) and a resistant based pressure sensing grid.**

**Figure 2: HeyPillow can be used like any regular pillow. However, it uses voice-activation to collect and process data.**

## HEYPILLOW SYSTEM

Studies of behavior change for improve sleep offer recommendations during the day or before bed. HeyPillow is a fabricated sensing pillow, shown in Figures 1 and 2, that senses the position and orientation of the head. Through on-board inertia measuring unit sensors and resistant based pressure sensing grid, our device captures the orientation, position, and force of the head non-intrusively.

HeyPillow uses voice-activation to collect and process data through specific voice commands. To personalize the results of the pillow for a certain user, the user must indicate that they want to calibrate the pillow so that it can more accurately classify the data when it is being processed later.

Data collection begins when the user vocally indicates that they are going to sleep. During this step, HeyPillow retrieves data about the amount of pressure exerted on the pillow and the head's orientation via twenty force-sensitive resistors and an absolute orientation sensor (which acts a gyroscope and an accelerometer) embedded into the pillow. These embedded sensors are physically connected to an Arduino board that collects the data on command.

Overall, HeyPillow achieved an average of 98% accuracy in predicting head postures throughout the night. There are 5 potential classification outcomes for the system: whether the user slept on their left side, right side, stomach, back, or were off the pillow. We used a decision tree model with the absolute orientation and pressure sensor readings as training data, and users' head positions as labels. When used in the wild, our system guides users to move towards specific positions with computer generated voices (in calibration phrase).

Once the user vocally indicates to the HeyPillow system that they are done sleeping, the system sends the data to be cleaned and classified by the physically connected Raspberry Pi. After reading in this data through one of its ports, the Raspberry Pi acts as a local server in which the data is processed through local scripts. Next, the system uses this data to generate the personalized recommendations to be used for the self-experiments described in the next section.

## FUTURE SELF-EXPERIMENT STUDY DESIGN

When the data is processed and head positions are classified, the HeyPillow system follows SleepCoacher's model for self-experimentation to identify which head posture is most likely to lead to sleep improvement [4]. By conducting a user study based on this framework, we will be able to evaluate the system's ability to track and improve sleep. We will also be able to see if people are able to subconsciously control their position while sleeping.

In order to conduct the self-experiment, the HeyPillow system will first collect data for a few nights, and then it will calculate correlations between the sleep outcomes (time to fall asleep and awakenings per night) and the sleep postures.

Next, it identifies the highest correlation (e.g. laying on the right side is correlated with shorter time to fall asleep) and generates a recommendation for it. For example, "For the next 5 days, try going to bed on your right side to see if it helps you fall asleep faster." These recommendations are derived from a list that sleep clinicians have already pre-approved.

Finally, the system asks the user to follow the recommendation ("lay down on your right side") for some days and do its opposite ("lay down on any side but your right side") for a few more days. That way, HeyPillow is able to guide the user through a self-experiment and calculate whether "sleeping on the right side" actually helps the user fall asleep faster.

Overall, HeyPillow is a new self-monitoring system for sleep which uses voice iteraction to guide a user through a self-experiment.

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